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Adapting to the Future:

How Digitalization Shapes Sustainable Logistics and Resilient Supply Chain Management

Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle
Prof. Dr. Thorsten Blecker
(Editors)

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Edition	1st edition, September 2021
Publisher	epubli GmbH, Berlin, www.epubli.de
Editors	Wolfgang Kersten, Christian M. Ringle and Thorsten Blecker
Cover design	Beverly Grafe
Cover photo	Photo by Moritz Kindler on Unsplash
Layout	Theresa Schludi, Beverly Grafe and Martin Brylowski
ISBN	978-3-754927-70-0
ISSN (print)	2635-4430
ISSN (online)	2365-5070

Preface

Digitalization continues to positively impact logistics and supply chain management. Data science can be seen as a key driver of digitalization that has the potential to introduce new sources of growth. The recent advances in machine learning and automation have created a whole new business ecosystem.

This year's edition of the HICL proceedings complements the last year's volume – Data science and innovation in supply chain management: how data transforms the value chain. All entities along the supply chain are challenged to adapt new business models, techniques and processes to enable a smooth transition into an innovative supply chain.

This book focuses on core topics of adapting to the future in logistics. It contains manuscripts by international authors providing comprehensive insights into topics such as Supply Chain Risk Management, Artificial Intelligence, Blockchain, Technology Management or Advanced Manufacturing and offers future research opportunities in the field of supply chain management.

We would like to thank the authors for their excellent contributions, which advance the logistics research process. Without their support and hard work, the creation of this volume would not have been possible.

Hamburg, September 2021

Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle
Prof. Dr. Thorsten Blecker

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I.
Advanced Manufacturing and Industry 4.0

Parametric Selection of Hybrid Parts for Additive Manufacturing

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Purpose: *The combination of additive and conventional manufacturing techniques allows the combination of the strengths of both approaches. Additive manufacturing can be concentrated on functional and complex geometries while the basic body of a part is produced conventionally leading to cost advantages and thus enables new application fields of additive manufacturing.*

Methodology: *To identify parts suitable for a hybrid production, the application of a software evaluating part properties based on CAD data were examined. Different criteria for the selection of components are presented and tested. The methodology was qualitatively validated by an exemplary application to a library of 3D models of components using the 3D Partfinder software.*

Findings: *By applying the presented criteria for the part selection, the software can automatically perform the necessary part comparison. It can be concluded that the complexity index allows a typologization of parts while respecting economic parameters. In particular products with a high number of variants but only small geometric deviations in volume and surface area show a high potential for hybrid production.*

Originality: *So far, little research on hybrid additive manufacturing has been done. The paper shows the applicability of software solutions and offers typologization criteria as a general search strategy for suitable parts.*

First received: 12. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Additive manufacturing processes were initially used mainly in prototype production (Gibson, Rosen and Stucker, 2015). Today, the implementation of additive technologies into series production is still hindered by a low level of industrialization and a lacking cost competitiveness in many applications (Baumers, et al., 2016; Caviezel, et al., 2017). Despite the frequently mentioned advantages of additive manufacturing, such as production without tools, without corresponding lead times for the creation of tools or the lower dependence of production costs on component complexity compared to conventional manufacturing processes, additive manufacturing is still mainly used to produce components in small quantities (Klahn, Leutenecker and Meboldt, 2014; Lutter-Günther, et al., 2015; Gebhardt, 2016; Thomas, 2016; Klahn, et al., 2018). However, the existing and forecasted market development combined with an increase in the economic efficiency of additive manufacturing processes promise additional use of the technology in the coming years (Strategy&, 2018; Wohlers, 2018; Grand View Research, 2021). When looking for suitable components to be built by one of the various 3D printing technologies, the focus in the metallic area has so far been on highly complex or energy transferring components. Improved performance parameters in existing processes and new technologies such as two-stage metallic binder jetting are leading to significant cost reductions increasing the attractiveness of additive manufacturing (Wildemann, 2019). Components with less complex geometries can also be manufactured cost efficiently in larger quantities using additive manufacturing. As a result, an increasing number of components comes into focus which are used in large quantities in existing products and are to be manufactured additively in the future.

While component selection in additive manufacturing processes is often focused on the identification and evaluation of isolated components or products, hybrid manufacturing concepts would broaden the scope of consideration. To combine conventional and additive manufacturing, there are three basic approaches (Ley, et al., 2018):

1. In Directed Energy Deposition processes (with powder or wire), geometry elements determining the variant or integrating functionality are added to an existing component.

2. Individual geometry elements of a component can be manufactured additively and then joined to a basic body. For components that are only differentiated by individual interfaces or geometry elements, the basic body can be standardized and the number of pieces of the basic body to be produced can be increased.
3. In additive manufacturing processes in which a component is manufactured from the powder bed, as in selective laser beam melting, building platforms made of different base body materials can also be used or base bodies can be attached to the building platform. These then present the starting point for the further building up of layers with the selected material of the 3D printer.

While a direct comparison of different manufacturing alternatives can be made for isolated components, the consideration of hybrid manufacturing requires an additional division and interface definition between the conventionally and additively built component structures and thus changes the approach of identifying suitable components compared to building full parts additively. As a proposal to reduce the effort of the component selection, the possibility of using software to create a preselection and to automate the part selection is qualitatively investigated.

2 State of the Art in Science and Technology

In additive manufacturing, a component is manufactured starting from a 3D digital component model. Additive processes are characterized by the fact that material is built up layer by layer and joined together to form a component. The material, which is built up is usually shapeless material that is provided in powder, paste, liquid or wire form. VDI Guideline 3405 defines additive manufacturing processes as processes in which "the workpiece is built up element by element or layer by layer" (Verein Deutscher Ingenieure, 2014). Here, no component specific tools are required for the additive manufacturing of a component. The layer by layer application results in the possibility to add material only where it is needed. In contrast to subtractive manufacturing processes such as CNC machining, additive manufacturing can thus reduce the amount of material required. A differentiation of additive manufacturing processes with regard to the possibility of manufacturing hybrid parts is offered by the design of the build area in the additive manufacturing machine (Gibson, Rosen and Stucker, 2015; Gebhardt, 2016). For

processes such as selective laser beam melting, selective laser sintering or stereolithography, the build space is filled layer by layer with unfused material, which is then selectively fused into a component. In a fused filament fabrication, direct energy deposition or the MELD™ process, the required material is provided by a conveyor mechanism without the necessity of surrounding material. The working area of the process and the structure of the component is thus geometrically less restricted than in powder bed based processes.

Existing work and practical applications demonstrate the feasibility of manufacturing hybrid parts. For example, the processes grouped under the term Directed Energy Deposition are already being used to repair worn components (Gibson, Rosen and Stucker, 2015; Kumke, 2018; Leuteritz, et al., 2018). This process corresponds to a hybrid construction method in which geometrically determined elements are applied to an existing base body. Components created using selective laser beam melting can also be used as casting molds (Bauer and Nolis, 2014; Leuteritz, et al., 2018). If powder bed based processes are combined with conventional processes, a semi-finished product must be introduced into the powder bed. The prefabricated, semi-finished product must be prepared in such a way that alignment in the installation space of the additive manufacturing system is possible to avoid any collision with the material feed mechanism and to ensure a sufficiently high-quality connection between the semi-finished product and the additively built geometries. For this purpose, the separation direction of the component, the design of the support structures, fixation possibilities of the semi-finished product in the build space, and the possibility of necessary preparations of the semi-finished product for the process must be taken into account (Roj, 2019). The term hybrid part also incorporates parts that are manufactured from a combination of different materials. In this case, structures made of a material that is not the same as the base body are added during additive manufacturing (Scheithauer, et al., 2017; Uhlmann and Kashevko, 2017). The material transition can be discrete or continuous (Yao, et al., 2018). For gradient components, the material transition is built up continuously (vgl. z.B. Zhiyuan Xu, et al., 2019). Here, the gradual material transition serves to reduce residual stresses and the tendency for layer separation between the layers (Bharti, Gupta and Gupta, 2013).

Different approaches exist to evaluate the suitability of a component for additive manufacturing, based on a qualitative or also parameter component analysis. Expert knowledge is often assumed for a heuristic component selection to evaluate the feasibility and usefulness of additive manufacturing (Achillas, et al., 2015; Knofius, van der Heijden and Zijm, 2016; Burkhart and Aurich, 2017; Illgner, Lutter-Günther and Seidel, 2018; Kumke, 2018; Fontana, Klahn and Meboldt, 2019). Many approaches are focused on benefits of additive manufacturing e.g. in terms of improved heat and mass transfer, possibilities for component integration and weight optimization to reason the advantage of the technology (Knofius, van der Heijden and Zijm, 2016; Burkhart and Aurich, 2017; Feldmann and Pumpe, 2017; Fiedler, 2018). While the mentioned criteria have essential relevance for the evaluation of the economic viability of additive manufacturing, the parameterization and evaluation of these criteria by software poses a challenge in the authors' experience. A detailed economic evaluation for additive and conventional manufacturing is only possible if detailed product and usage information is available (Schmidt, 2016).

3 Qualitative Assessment of identification possibilities of economically advantageous hybrid part manufacturing

The presented evaluation aimed at a qualitative assessment of the possibilities to implement a software supported process to partly automate the identification of parts with a high likelihood to be economically beneficial for a hybrid manufacturing process as a combination of conventional and additive manufacturing. The qualitative assessment is based on the following three steps:

1. Qualitative assessment of advantages of hybrid manufacturing to deduce a typology of parts which could be suitable for the manufacturing approach.
2. Identification of parameters which can be used to create filter criteria according to literature and deduction of parameters according to the presented typology.
3. Assessment of filter criteria through the exemplary software implementation in a case study and evaluation of the results.

The proposed steps are described in the following section. A discussion of the results is presented in Section 5.

4 Selection of Hybrid Parts for Additive Manufacturing

Additive manufacturing enables the economic production of complex products and the integration of functionalities into a component that can often only be realized at comparatively higher costs using established manufacturing methods (Klahn, Leutenecker and Meboldt, 2014; Wildemann, 2021). However, the economic advantage of additive manufacturing processes generally diminishes with increasing quantities of a component (Eschner et al. 2017). One way to expand the economic application possibilities of additive manufacturing processes is to combine conventional and additive manufacturing, which is referred to in the following texts as the production of a hybrid part (Eschner, et al., 2017; Silva, et al., 2017). It is assumed that in this manufacturing setup, additive manufacturing is only used to produce functional carriers and complex geometry elements on a base body produced by means of established manufacturing processes.

Because the strength of additive manufacturing lies in the production of complex parts, the basic body is assumed to be a geometrically less complex component than the additively manufactured geometry elements to make use of the advantages of both conventional and additive manufacturing. For hybrid manufacturing, there are the options of additively building up a geometry feature on a conventionally manufactured base body or joining a conventionally manufactured base body to an additively manufactured component via a suitable joining process (Ley, et al., 2018; Oettel, et al., 2019). The basic body could then be manufactured independent of the variant, due to the combination of several component variants, to achieve economic advantages through scale effects.

To create a part by hybrid additive manufacturing showing a profitable business case in comparison to conventional manufacturing, the strengths presented by both manufacturing technologies should be respected. Because hybrid manufacturing

essentially describes a combined manufacturing process, both conventional and additive manufacturing can contribute to the overall profitability of the part.

4.1 Economic Evaluation

The combination of established and additive manufacturing processes enables using the cost wise effective production of components in high volumes by conventional processes while simultaneously applying the extended design possibilities of additive processes. This makes it possible to increase the cost effectiveness of components produced in high quantities using additive processes and thus expanding the range of applications for additive manufacturing. In principle, the economic advantages of additive manufacturing can be transferred to hybrid manufacturing with some limitations (Hague, 2006; Gibson, Rosen and Stucker, 2015; Mavri, 2015; Scott and Harrison, 2015; Lakomiec, 2016; Möhrle, 2018):

- reduction of fixed costs and lead times for tools and fixtures for specific components,
- higher manufacturing flexibility due to machine equipment for the additive manufacturing processes which is not specific for manufactured components,
- possibility of decentralized manufacturing of additively manufactured components,
- reduction of manufacturing process steps,
- reduction of the lead time, and
- possibilities for component individualization and economic implementation of complex component designs with advantages in the component utilization phase.

It is assumed by various authors that a high part complexity indicates a high possible advantage of additive manufacturing because manufacturing costs are observed to increase stronger for an increasing part complexity if conventional technologies are used than when additive manufacturing is implemented (Hague, 2006; Conner, et al., 2014; Wildemann, 2019). The focus on part complexity enables linking the part geometry to its suitability for additive manufacturing. In line with this, KUSHNARENKO (2009) and LAKOMIEC (2016) present the part complexity as a possible parameter to be used to identify components suitable for additive manufacturing.

However, due to the hybrid manufacturing approach, the advantages of additive manufacturing cannot be considered isolated from the conventional manufacturing process. The economic justification of hybrid manufacturing may result not only from a cost advantage due to additive manufacturing, but also from conventional manufacturing of the basic body, and could thus even partially compensate for possible, additional costs for additive manufacturing. In addition, the size limitation for additively manufactured components due to the installation space of the manufacturing equipment is relativized by the hybrid approach. To produce the basic body, economic advantages may result from the increase in the production quantity in case a technology with scale effects is used. The higher quantity in which a basic body is produced can lead to economies of scale or a change in the manufacturing process with which the respective basic body can be produced at lower, variable costs and possibly with higher quality.

The conversion and combination of several components or assemblies into hybrid parts with a common basic body also results in a modularization, which leads to advantages in the generation of variants, a reduction in error susceptibility and interface complexity (Wildemann, 2016). The variant creation point is shifted, which increases the company's supply flexibility and reduces the planning effort (Waltl and Wildemann, 2014). In addition to the planning effort, the reduction in complexity can also lower the amount of safety stock required and thus reduce a company's working capital (Große-Heitmeyer and Wiendahl, 2004; Wildemann, 2014). A simplified geometry of the basic body can result in advantages regarding tooling, manufacturing process and quality costs. The simplification of the component geometry during casting can for example lead to a reduced use of cores and a reduction in wall thickness differences can lead to a lower probability of shrinkage cavity formation (Klocke, 2015).

The production of hybrid parts could consequently enable improved coordination of cycle times from the perspective of the entire process chain. Additive manufacturing processes have lower material deposition rates compared to established manufacturing processes such as casting. By combining several manufacturing processes, the process time of additive manufacturing can be shortened and thus an increase in productivity can be achieved from an overall process perspective (Eschner, et al., 2017). By combining

different materials for the manufacturing steps according to the requirements due to strength, corrosion, wear requirements and thermal stress between the base body and the additively manufactured geometry elements, cost reductions can be implemented if this means that the basic body can be realized with a favorable material, while only the geometry element is printed with high-quality materials with a higher load capacity.

In the profitability analysis, costs for possible component adaptations in the sense of design for additive manufacturing and design changes to previous manufacturing concepts must also be considered, as significant changes to the cost composition can be associated with the design adaptation. There are high interdependencies between the selected design, the definition of the interface between the basic body and the additively manufactured geometry element, and the resulting total costs for the manufacturing of a component. However, the definition of an interface offers a new possibility for implementing a platform strategy at component level and can thus be a form of modularization with the corresponding advantages (Waltl and Wildemann, 2015).

In accordance with the possible economic advantages presented for hybrid parts, a typologization can be carried out based on the criteria of the geometric conformity of the basic body between different products, the complexity of the differentiating geometric component elements and the marginal scale effects resulting from the increase in the number of units of the basic body (cf. Figure 1). A high degree of conformity of the geometry of the basic body forms the prerequisite for the presented approach to the selection of hybrid parts. If the differentiating geometry elements show a low complexity, normally, a low suitability of additive manufacturing would be assumed. However, in the production of hybrid parts, this decision can be compensated by a high marginal scale effect of increasing the quantity of the basic body. A high marginal scale effect can result in a cost advantages when a component that was previously produced in a low quantity, e.g., in small series, can be merged with a component that is produced in high quantities. From the combination as a carry-over part, cost advantages can be achieved through the transfer of economies of scale. If both components are already manufactured in high quantities, the marginal scale effect decreases, since only a small cost advantage can be achieved from increasing the quantities of one component. If the differentiating geometry elements are highly complex and therefore highly suitable for additive

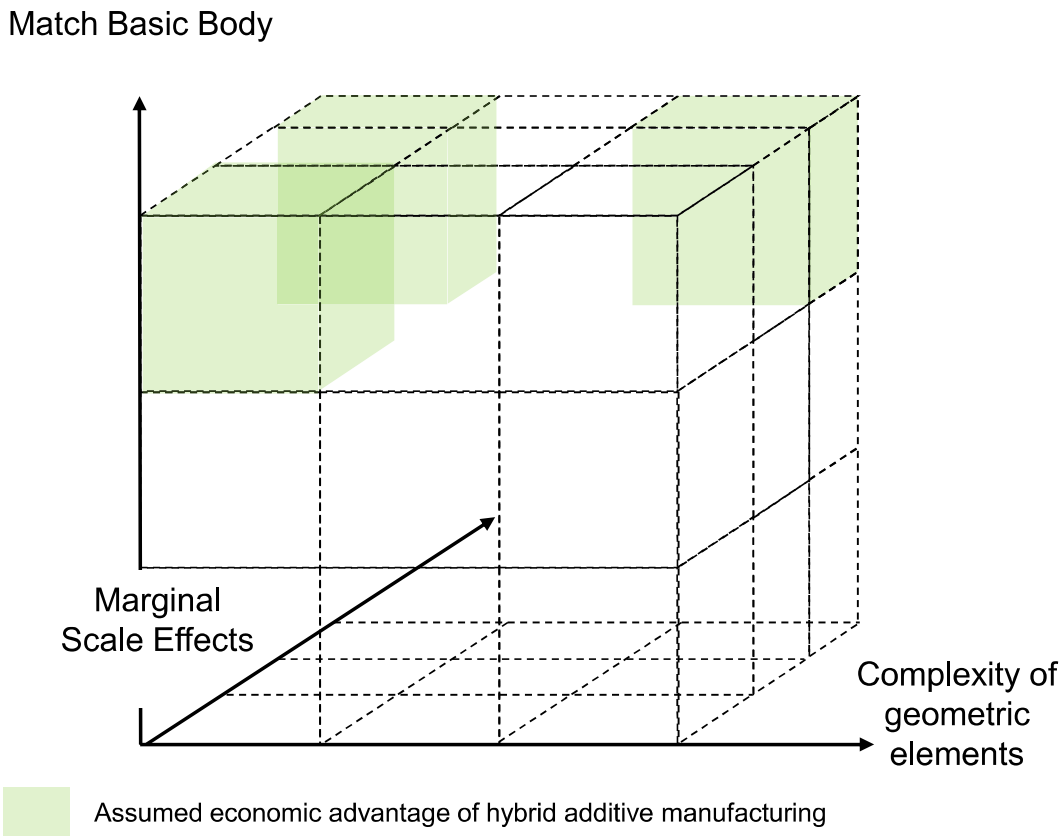


Figure 1: Typologization of economic application fields of hybrid parts

manufacturing, economic advantages can result from additive manufacturing even without taking the marginal scale effect into account.

4.2 Parametric Part Selection

From the preceding deduction of possible economic advantages of a hybrid part, there are two main objectives for component identification:

1. The basic bodies of the original, identified components to be manufactured hybrid should have as high a congruence as possible to be defined as a common part, and
2. the geometry elements that differentiate individual components should have a high suitability for additive manufacturing.

Based on the assumption that the basic body will be produced by a conventional manufacturing method which is advantageous especially when used for high part volumes, the basic body should be usable for many different products to create a high demand. To evaluate the congruence, a different orientation of the 3D model in terms of rotation or translation are not relevant for the use of the basic body as a invariable part. Scaling of the component will preclude its use as a common part, unless it is in such a small range that a common design would be possible considering higher production volumes of the common part.

By using automated and similarity evaluation based on contents of 3D data sets, both, the effort and the possible subjectivity of manual evaluation of data objects can be avoided (Bustos, et al., 2005). In the literature, approaches can be found to reduce the effort of the part comparison and the resulting computation time by extracting essential information regarding the parts resulting in a reduced information complexity still sufficient for a comparison (Roj, 2016). Furthermore, statistical 3D descriptors, extension based methods, volume based methods, descriptions of the surface geometry, image analysis or a feature based vector comparison can be used (Bustos, et al., 2005). In addition to an evaluation of the component geometry, the geometry elements and the hierarchical structure of a data model can also be used for a comparison if the data is available (e.g. Ding, 2014). If the simplification approach is chosen, smaller geometry elements are neglected in the automated part comparison, which can be considered advantageous for the identification of parts with a high similarity in the context of the definition of an identical basic body (Roj, 2016).

Component evaluation and selection can be carried out based on the geometric properties of a component and the characteristic values derived from them such surface area or volume as will be shown in the case study. A parameterization of the geometry evaluation enables a comparison of several components based on the resulting characteristic values. If the parameterization is possible based on the digital models, the entire component selection can be automated across a larger component portfolio. However, when evaluating geometric elements to identify components for hybrid manufacturing, the geometry element must be suitable for additive manufacturing or assembly on a base body, in contrary to conventional approaches for the component

analysis and selection in which a part is fully manufactured by one technology. Accordingly, geometry elements that are produced purely subtractive, such as holes or eroded free forms, are omitted in the part comparison since it is not possible to add them on an existing part.

For the evaluation of the geometric component complexity KUSHNARENKO (2009) presents a parameter which results from a weighted evaluation of the individual geometry features of a CAD model as well as their arrangement. LAKOMIEC (2016) presents a parameter for the evaluation of the component complexity from the quotient of the component surface and volume, which can be derived with values usually available in the 3D modeling software (Lakomiec, 2016). Another way to evaluate complexity is to compare it with alternative manufacturing processes. The software Materialise allows component complexity to be assessed by a direct comparison of additive manufacturing with a casting process on a scale from "no undercuts" to "impossible to cast in one piece" (Materialise, 2019). It should be noted here that such a qualitative evaluation may strongly depend on the evaluation competence of the user. Furthermore, the approach neglects other manufacturing processes besides casting, such as CNC machining. RUDOLPH ET AL. (2017) present an automated approach to component evaluation for additive manufacturing. Using an online interface, component data is read, and a topology optimization of the component is performed. The manufacturing cost comparison is performed based on the costs of additive manufacturing of the component which has been optimized regarding its topology and the costs of manufacturing the original component using CNC machining or investment casting.

4.3 Software Based Selection of Hybrid Parts for Additive Manufacturing

From the definition of a hybrid part, it follows that the selection parameters to be derived should enable the detection of components which,

- on the one hand, exhibit a high degree of conformity and,
- on the other hand, differ in detail like geometric elements.

The latter should be complex and have a high suitability for additive manufacturing. In the presented approach, a high complexity of the geometry element to be manufactured additively is used as an indicator for a high economic efficiency of additive manufacturing. In this case study a two-stage approach was used for the component analysis, in which a geometric similarity analysis of all components is first performed in a CAD database, followed by a complexity analysis. Accordingly, the components identified have a high rate of similarity of the basic bodies and complex, differentiating geometric elements. Consequently, it is deduced that such components have a high suitability as hybrid parts. Based on the exemplary case study, the applicability of the procedure is generalized in the following by means of inductive proof. From an exemplary analysis of a CAD database with components from various industries and different areas of application, individual components suitable for hybrid manufacturing are in a first step extracted by filter criteria generally applicable.

The approach of reducing the component information or rewriting the data to substitute values while reducing the information content can be regarded obsolete due to powerful software for component identification. The entire information content of a CAD file can be used for part identification. Such a solution is offered by the 3D Partfinder of the company CoreTechnologie, which completely reads the data contained in a CAD file and enables intelligent, evaluations based on filters by storing all parameters in a database (enter2net, 2021). In addition to parametric data, the software also considers features, PMI (Product Management Information), and values calculated from geometric data, such as area, volume, or wall thickness. Advantageous in this context is the trend to integrate information that was previously noted in 2D drawing derivations, such as surface roughness or data regarding fittings, into the parametric data model thus making this information available for automated analysis. Furthermore, the geometric values can be supplemented by economic values from the ERP systems (Enterprise Resource Planning systems) to consider further decision criteria. In addition to cost data, parameters from the supply chain, such as production lot sizes and replenishment times, also can be considered.

4.3.1 Software supported analysis of geometric data to identify components whose basic bodies have a high degree of conformance

The comparison criteria proposed are the similarity of the volume of the investigated components and the projected area of the component based on normalized coordinate systems. Both criteria are weighted equally in the evaluation. The relative index calculated from this then provides a statement on components with the same or similar basic bodies in terms of percentages. Figure 2 and Figure 3 show the results of such an automated evaluation, which was carried out with the help of the 3D Partfinder. A degree of agreement of at least 99% was selected here, with the application of which many components with matches can already be identified.

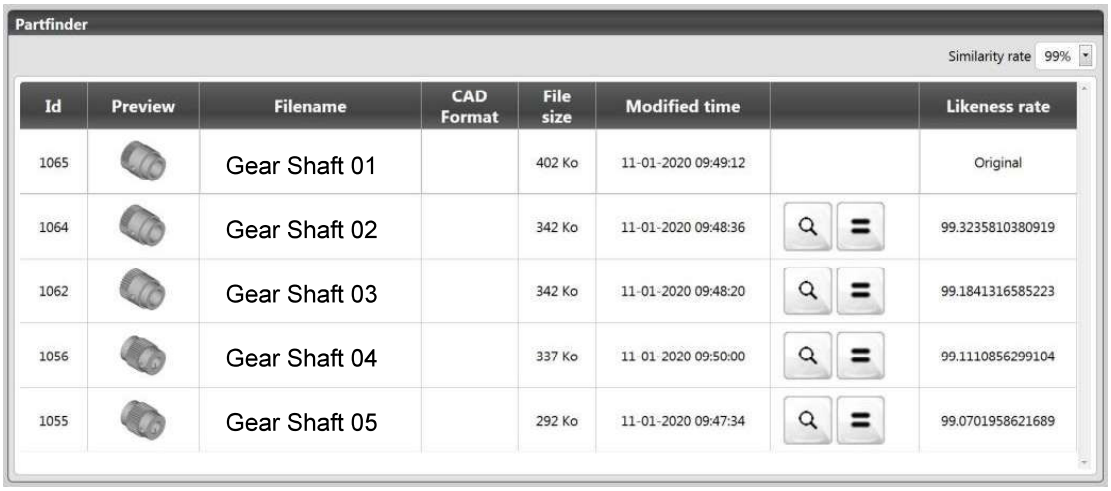


Figure 2: Results of the similarity search (excerpt 1)

Figure 3 shows an excerpt of the analysis showing parts made of bended sheet metal which are in the experience of the authors not producible with a good business case in additive manufacturing because the sheet metal and the manufacturing processes are very cost effective. It quickly becomes apparent that hybrid manufacturing does not promise advantages for all identified components. A differentiation of the identified components with a similarity rate of at least 99% is required regarding the suitability for hybrid manufacturing based on the complexity of the geometry elements.

4.3.2 Software based identification of geometry elements that have a high suitability for additive manufacturing.

To select suitable components, the detected components from the previous analysis were filtered according to geometric complexity indicators. The parametric evaluation of the component complexity is regarded as an indicator for determining whether a geometry element is suitable for additive manufacturing. In combination with the initial analysis, the user is supported in deriving a statement as to whether hybrid manufacturing is advantageous for the part. In the 3D Partfinder, a parametric evaluation of complexity metrics can be mapped for this purpose, as illustrated in Figure 4. The following key figures are suggested by the authors for a complexity evaluation:

- Value of the first quartile of wall thickness data values ordered by size: The lower the value, the more thin-walled areas the component has. This is an indicator of parts with many thin-walled elements. This is beneficial for a variety of 3D printing processes.
- Minimum wall thickness: This serves to exclude components with wall thicknesses that cannot be produced by the respective 3D printing processes available.
- The standard deviation in the wall thickness distribution of a component: The higher the standard deviation, the more different the wall thicknesses are in the component.



Figure 3: Results of the similarity search (excerpt 2)

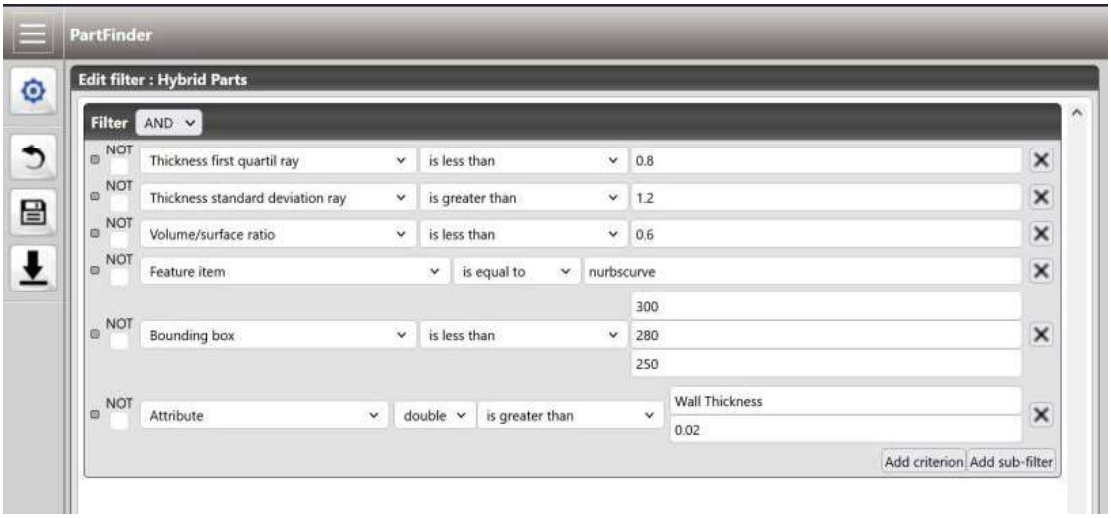


Figure 4: Definition of complexity filter criteria

- The ratio of volume to surface area of the component: A low value is an indicator for filigree or large surface components with low mass (lightweight construction). It should be noted that thin-walled components with a corresponding surface area also have a low value. These are often components with predominantly constant wall thickness, such as sheets, washers, or screws. In combination with a high standard deviation in the wall thickness distribution, such components can easily be excluded.
- Freeform surfaces: The identification of geometrically complex surfaces can be identified by means of design features such as nurbscurves or nurbssurfaces.

The filtering in the example is practically supplemented by the criterion of the bounding box to take into account the maximum installation space of the printer. In this way, components that would not fit into the installation space of the selected systems can be excluded in the search.

Figure 5 exemplary shows the result of the similarity analysis based on geometric complexity indices. Various components were found which, based on a shaft, have different variants of gears regarding their geometry. As a function of a reference component, components were selected from the previous analysis with a similarity rate of at least 99%.

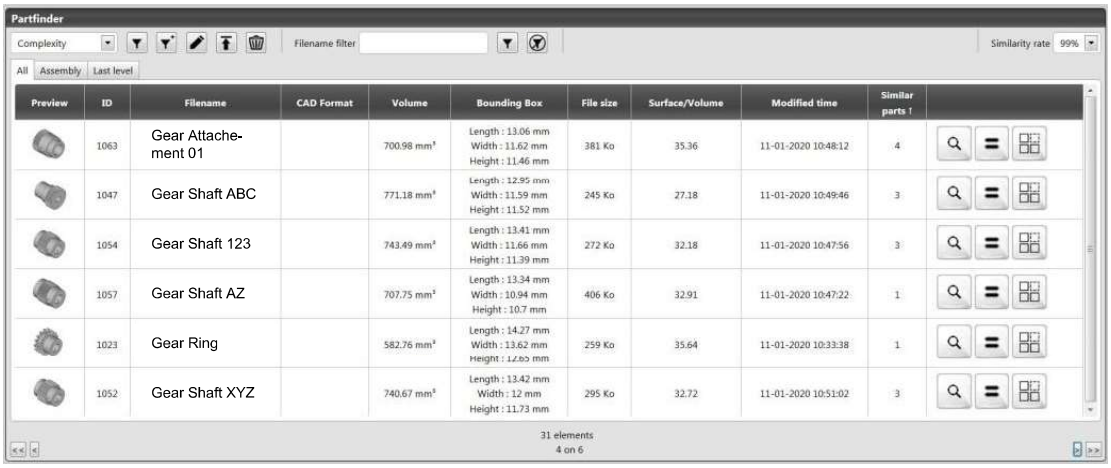


Figure 5: Result of the combined search with the prioritized components

5 Evaluation and Discussion

By qualitatively assessing possible advantages of hybrid manufacturing by combining conventional and additive manufacturing technologies, a typology of parts which might show advantages for hybrid manufacturing was deduced. This typology assumes that a basic body of a part is created by conventional manufacturing methods showing advantages through scale effects and thus the production of a high volume of identical parts. Advantages for additive manufacturing are assumed for the production of complex geometric elements which can be added on the basic body either by directly manufacturing these elements on the body or by separate additive manufacturing and a subsequent assembly of both parts.

Based on the identified advantages of the technologies, parameters were deduced to be used in an automated software based approach to identify parts fulfilling the criteria constituted in the typology. These parameters were subsequently successfully translated in filtering criteria to be used in the software 3DPartFinder in a two-stage approach combining filtering strategies to identify parts with a high congruence and complex differentiating geometric elements. The filter criteria were then used on a sample to create a case study.

Combining both filtering strategies, several groups of components were found, each having an almost identical basic body differentiated by complex geometry elements in the form of gears that differ in positioning and interlocking. It is striking that the identified components are compact in design. The criterion of the ratio of volume to surface area of the component is of limited value for identifying components for hybrid manufacturing in this example. Nevertheless, generic values can be derived from the analysis results that can be used for future evaluations. However, these must always be validated and adapted according to the component spectrum to be analyzed.

The use of the software enables users to reduce the effort of the portfolio analysis by automating the part selection process. However, it will still be necessary to subsequently analyze the identified parts regarding suitability for hybrid manufacturing and its business case.

6 Summary and Conclusion

A method was presented with which component selection for additive manufacturing can be carried out through a software application. An exemplary case study was used to demonstrate the feasibility of the approach. The identification of possible hybrid parts is based on criteria for the selection of suitable components. It should be noted that the identified components usually have to be modified in terms of design for the optimal implementation of a hybrid design. The 3D Partfinder enables the analysis of components with a high degree of similarity and thus a high potential for a possible overlap and unification of the component defined as the basic body. However, it is important to note that the interface between the basic body and the geometry element to be manufactured additively must be defined by the user, who has to break down the originally analyzed component into diverse assemblies.

The developed typology for evaluating the economic suitability of hybrid parts adds to the scientific discussion by systemizing and pointing out possible levers to economically justify hybrid additive manufacturing. The typology thus offers a new field of possible application areas for additive manufacturing. Additionally, it could be shown that selection criteria for additive manufacturing and in this case especially for hybrid

additive manufacturing can be translated for software use and thus for automatically analyzing a part portfolio. The successful application of the software according to the defined goal was demonstrated by a case study.

Limitations of the presented research result from the case study presented being a generic example using CAD data from a pool of standardized components. The applicability of the presented approach and the presented software should be used for further validation in industry using the respective own database of the company. The concrete economic evaluation shows a high dependency on the circumstances in the company and the quantity structure. In addition to testing the approach on a practical example, possibilities should be sought for implementing an automated interface definition between the conventionally manufactured basic body and the additively manufactured geometry element. This would reduce the necessary know-how of the user and the component selection could be further accelerated.

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Designing the Data Supply Chain of a Smart Construction Factory

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Purpose: *The purpose of this paper is to design a concept of the data supply chain of a smart construction factory by analyzing the information flow and Building Information Modeling (BIM) object data that are available through innovative identification technologies and communication systems. Furthermore, an appropriate system for controlling logistics processes is defined.*

Methodology: *The approach is developed using the Digital Twin Concept Model. In the first step, the examined use case is evaluated and compared with the digital twin fulfillment requirements. Subsequently, the data supply chain is designed considering the three attributes conceptualization, comparison, and collaboration.*

Findings: *The paper shows how the idea of a data supply chain of a smart factory can be transferred into the building industry. The digital core in terms of a data warehouse monitors material flows according to quantity, location and time and can help to pilot logistics processes.*

Originality: *Smart factory research has predominantly focused on production processes of the biggest industries, without taking the building sector and externally required logistics into closer consideration. However, significant changes are expected as a result of the European Green Deal, which will change the entire industry as well as related logistics.*

First received: 30. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Industry 4.0 still inspires the manufacturing industries and leads to the introduction of new technologies every day. Driven by the fourth industrial revolution, companies are investing in the development of smart factories with the aim of integrating digitalization into fabrication structures (Ruile, 2019). By creating an autonomous production and logistics environment in which machines, systems and vehicles communicate independently with each other, companies hope to remove humans from manufacturing processes in order to operate more efficiently (Scheer, 2017).

Undoubtedly, the building industry seems trivial with their rather stereotypical processes and analog techniques, when compared to the pioneering power of the automotive or mechanical engineering industry. In addition, the industry is not really getting off the ground when it comes to digitization (Agarwal et al., 2016). Nevertheless, there has to be a major restructuring in the near future. This is mainly due to the existing building stock which is in high need of renovation and causing 79 Mton CO_2 emissions annually. This leads to a contribution of 40% of the total energy use and 36% of the CO_2 emissions in the European Union. To deal with the climate change, European climate and energy objectives were defined. By 2050, CO_2 emissions should be cut to 80-90% compared to 1990 and all buildings should be energy-neutral (European Commission, 2019, European Environment Agency, 2015).

Although there is enormous potential for optimization if digital technologies were used, the renovation industry applies mainly manual on-site renovation techniques, resulting in a low renovation pace, high labor costs and a long duration (Decorte et al., 2020, Lange and Krämer, 2019). This is especially questionable since the building industry is one of the key industries for the national economy, which employed around 2 million people and produced a construction volume of approximately €400 billion in Germany in 2018 (Federal Ministry of the Interior, Building and Community, 2020). This enabled a contribution of 5.3% to the overall economic gross value, which puts the building industry even ahead of most of the individual industrial sectors (Federal Ministry of Labour and Social Affairs, 2019).

Initial studies show that the integration of smart factories is also possible in the manufacturing process of renovation panels for old buildings (Decorte et al., 2020). The dovetailing of industry and construction would create new, more efficient manufacturing structures that can both comply with the required housing demand and reduce CO_2 emissions to a uniform standard to achieve the climate targets on time.

However, the introduction of novel technologies in new application areas may be challenging. The increasing demand in customized products is resulting in a higher complexity in production processes. Every day, several hundred houses have to be renovated, measured beforehand, and their renovation elements have to be produced with centimeter precision. In addition, unlike in the automotive industry, there are no fully identical buildings in the construction industry.

This paper explores how data from the buildings being renovated can be used to manage logistics processes, such as ordering, transportation, or storage, along the supply chain and aims to address this intention by designing the data supply chain of a smart factory to be developed in the construction industry. Accordingly, the research question of this study can be summarized as follows: How can building data be obtained, processed, and used to control logistics processes of a smart factory?

The outline of this paper is as follows. Section 2 presents the background of data supply chains, BIM, and smart construction factories by reviewing relevant literature. Section 3 describes the methodology which is applied in the development of the data supply chain of a smart construction factory in section 4. Lastly, section 5 summarizes the results, illustrates the recommendations for future research, and concludes the paper.

2 Background

In the following sections the theoretical background for this paper is discussed and relevant definitions are presented to reach a common understanding. This review of existing literature is organized as follows. First, we present the relevance of this paper by evaluating the systematic research. Second, we outline the function and structure of data

supply chains. Third, we explain the purpose of BIM. Fourth, we emphasize the production and logistics processes of smart construction factories.

2.1 Literature Review

A systematic literature analysis according to Baker (2000) was performed to identify the development of smart factories and data supply chains in the building industry. The literature review was conducted using Scopus, Elsevier and EBSCO-host in May 2021 focusing on English and German literature from 2015 onwards. The following variety of keywords was used:

- (<Smart Factory> OR <Intelligente Fabrik>) AND
- (<Data Supply Chain> OR <Digital* Supply Chain> OR <Digital* Logistik*>) AND
- (<Building Industry> OR <Construction Industry > OR <Civil Engineering> OR <Bauwesen>)

Keyword category one focuses on the development of smart factories, category two on data supply chains and digital transformation of logistics, and category three on the building industry. The joint consideration of category one and two shows that there has been scant inclusion of logistics in the development of smart factories to date, as production is still the top priority. Categories one and three show that it will be possible in the future to manufacture entire house units in a decentralized manner in smart construction factories. However, a large number of the publications in these categories relate primarily to the structure of smart factories and not to the production of house units. The mention of digital supply chains together with construction has also been insufficiently explored.

The final combination of the categories shows that there has marginally been any cross-thematic work that represents the interdigitation of smart factories, the building sector/BIM, and data supply chains (see figure 1). The scientific relevance of this paper derives from this research gap, which is to be closed by the design of the data supply chain, in addition to the challenge of reducing CO_2 emissions and housing shortage.

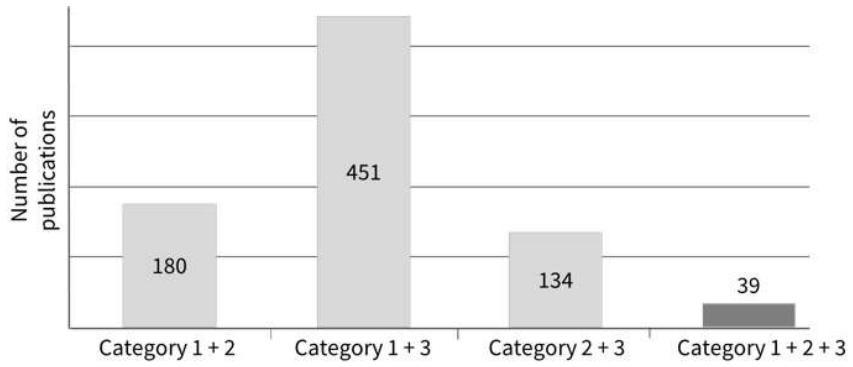


Figure 1: Number of relevant publications

2.2 Data Supply Chains

In Industry 4.0 digitization reaches a new level through a variety of innovative technologies, intelligent software tools and cloud-based communication. One of the most important trends is called "Digital Twin" which is a virtual representation of an engineered object or system that is updated from real-time data and thus spans its lifecycle by using simulation, machine learning and reasoning (Herlyn and Zadek, 2020, Wright and Davidson, 2020). The generated data has become the fifth new production factor after land, labor, capital and technology and created a digital economy (Wang and Huang, 2021).

In logistics, suppliers, manufacturers, customers and service providers use, generate and share digital information with each other that lead to a multitude of challenges and opportunities (Büyüközkan and Göçer, 2018). Current supply chains are in constant evolution which is driven by changes in the markets and emerging needs of the fourth industrial revolution era. For this reason, new terms for digitalized supply chains (DSC) have been flourishing combining the digital twin concept and logistics (Garay-Rondero et al., 2019). Kinnett (2015) describes a DSC as an intelligent, value driven network that leverages new approaches with technology and analytics to create innovative forms of business value, through a centric platform that captures the utilization of real-time information emerging from a variety of sources. Otherwise, Büyüközkan and Göçer (2018) define DSC as a system that is based on the capability of data disposal and

communication for digital hardware, software, and networks to support and synchronize interaction between organizations.

In a DSC, the data supply chain describes a specific area of expertise that focuses on the reuse of existing data and that represents a lifecycle for data (Singh et al., 2021). The data supply chain begins when data is created, imported, or combined and then flows freely through the supply chain (Li et al., 2018). Unlike the traditional supply chain, in which products do not return to the original producer, the data supply chain is close-looped (see figure 2). It consists of three parts. On the supply side, data is created, captured, and collected. In the management phase, data is enriched, analyzed, and improved. On the demand side, data is used and exploited (Li et al., 2018).

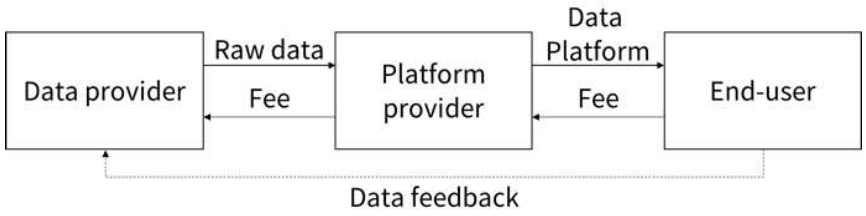


Figure 2: Closed-loop data supply chain model

In principle, a data supply chain works like a real-world supply chain, in which raw materials are transformed into finished goods. In the data supply chain, the unprocessed data represents the raw material that needs to be improved to create a product. It is about controlling the amount of data available along the information flow by putting it into standardized formats that can be read by the appropriate systems (Abandaa et al., 2017). The data is also stored in a warehouse, then processed and analyzed before being made available as a tangible product in the desired format. The companies that generate the raw data are often not yet in a position to analyze the data themselves or have the intention of selling the data. In both cases, the raw data is bought by platforms that measure and process the value of the data and then resell it to the users of the data (Li et al., 2018, Groth, 2013).

2.3 Building Information Models

In construction industry, data containing information about buildings has been largely generated and represented by BIM. BIM is a method that enables the networked planning, execution and management of buildings based on the continuous use of digital representation (Borrmann et al., 2018). The result represents a virtual three-dimensional model of a building, that contains the combination of graphical data, non-graphical data and documents related to a building or construction project all stored and managed together in a common software environment (see figure 3) (Erdélyi et al., 2021). It delineates a reliable basis for decision-making during the entire life cycle of the building, from conception to deconstruction (Ibrahim et al., 2019).

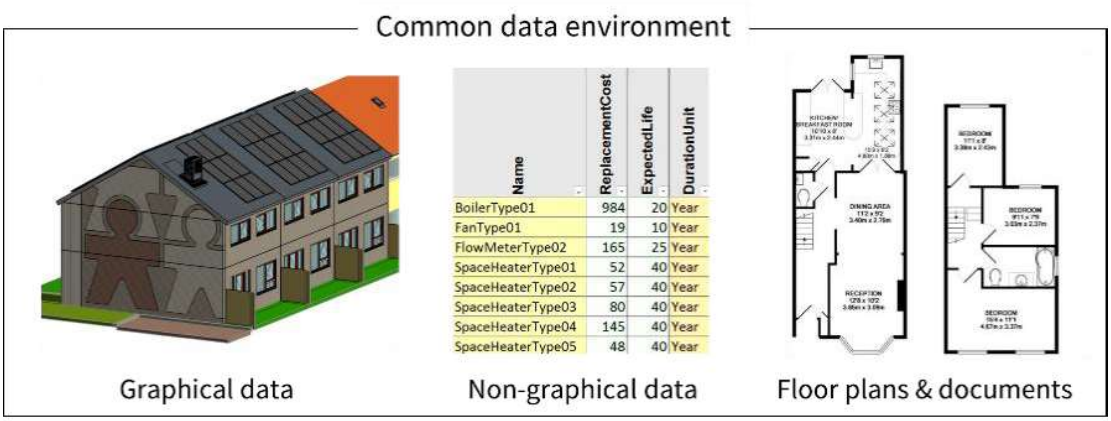


Figure 3: BIM model components

Each building component is to be described by a multitude of attributes. The model provides the historical development of all information through the construction stages (Pocobelli et al., 2018). In today's construction planning, an architect creates in the beginning a sketch with the help of Computer Aided Design (CAD) systems. The building then passes through various lifecycle phases, starting with requirements planning, followed by design, negotiation and tendering, construction, use, renovation, and demolition. In each phase, a large number of documents describing the building status are generated (Mehta et al., 2018). In addition, quantity takeoff is generated to determine costs. This requires linking the geometries with qualitatively and monetarily defined

service components so that the individual quantity details can be summed up in service items (Monteiro and Martins, 2013).

BIM models improve the information flow between stakeholders involved at all stages of the supply chain, since data is collected centrally in one place. This is resulting in an increase in efficiency by reducing the laborious manual re-entering of information (Borrmann et al., 2018). However, a BIM model still does not represent a digital twin, as it is not designed for real-time operational response (Pan and Zhang, 2021).

In the future, BIM models will be applied even more to existing building needs, so that not only new buildings are digitally mapped. One of the essential technologies that can make this possible is scan-to-BIM. In a scan-to-BIM-process, a laser scanner is used to capture an accurate 3D scan of the real-world conditions (Rausch et al., 2021, Bosché et al., 2015). The output from scanning is similar to the data obtained from photogrammetric surveys and includes high resolution images, point clouds with triangulated and textured surface models. The main advantages of the laser scanning technologies are characterized by high geometric accuracy and fast measurements (one million points per second) in comparison to traditional optical and satellite geodetic methods (Badenko et al., 2019).

Since the technology is mainly used to measure existing buildings, it can consequently be used for the preliminary work of a detailed energetic renovation. Thus, the houses with high CO_2 emissions can now be scanned in order to produce customized renovation packages, consisting of facade and roof panels, on the basis of the resulting scan-to-BIM models. With the assignment to the data supply chains of intelligent factories, the data can be directly integrated into the procurement, production, and distribution processes. This opens up new possibilities for driving forward the digitization of the construction industry and reducing CO_2 emissions to meet climate targets on-time. This is the main focus of this paper. Since the panels to be produced are manufactured offsite in so-called smart construction factories, it is important to introduce these for a fluent integration into the data supply chain to be developed.

2.4 Smart Construction Factories

The expectations for Industry 4.0 are clear: manufacturing companies want transparency, traceability and process optimizations to reduce repair as well as maintenance costs while increasing machine availability and efficiency (Bosch, 2021). In the future it will be possible to produce entire house units in a decentralized manner in smart construction factories that aim for a standardized, cost-effective and faster production of residential properties compared to conventional construction on-site processes (Tetik et al., 2019, Vestin et al., 2018).

By manufacturing according to an industrial scale, the housing shortage can be counteracted. Furthermore, these factories can target the market for old buildings and renovation projects as the production of customized renovation packages is also possible. These consist of prefabricated wall and roof panels, which can be additionally supplemented with solar panels or heating and ventilation systems (Zander et al., 2020). In this context, production planning has to consider how the processes of incoming goods, warehousing, production and outgoing goods can be controlled by cyber-physical systems (Yao et al., 2017).

Smart construction factories have diverse data sources. In particular, they obtain their production data from BIM models of houses being renovated. Based on the derived number of windows and doors and the square meterage of the facade, they can manufacture panels to the millimeter. Furthermore, the factory, as the center of the supply chain, continues to have all necessary data of procurement and distribution. Based on part lists it knows at what time which materials arrive at the factory, to which panels they belong and when production has to take place in order to transport the panels to the construction sites on-time (Rausch et al, 2021). A challenge in developing the data supply chain is to convert any existing data into a uniform format for production and logistics control.

3 Research Methodology

The data supply chain is an essential part of the digital supply chain. Thus, it can be developed using the "Digital Twin Concept" (DTC) by Grieves and Vickers, which is based on the idea that a digital informational construct about a physical system could be designed as an own entity. By using the concept, a twin of the information is created that is embedded within the physical system itself and which is now linked with the system through the entire lifecycle (Grieves and Vickers, 2017). The DTC contains three main parts:

- Physical products in real space,
- Virtual products in virtual space, and
- Connections of data and information that ties the virtual and real products together.

On the one hand, the DTC identifies, how the digital twin can move from a concept to a critical component of an enterprise-wide closed-loop product lifecycle. On the other hand, it shows how the connection between the data about the physical product and the information contained on the virtual product has to be synchronized to use this information for a digital factory simulation. The DTC is based on three principals to solve innovative problems at any time with the same scheme (Grieves, 2014):

- Conceptualize visually the manufacturing processes.
- Compare the formation of the physical product to the virtual product in order to make sure that the product produced is as imagined.
- Collaborate with others throughout the supply chain to have up-to-the-minute knowledge of the products.

In the beginning of the development of the digital twin, a fully annotated 3D model of the product is designed. In the second step, to be able to simulate the production processes digitally, the needed manufacturing processes including the Bill of Processes (BOP) and the Manufacturing Bill of Materials (MBOM) are engineered. This simultaneous view and comparison of the physical and virtual product can acquire major benefits, especially in the real-world manufacturing phase of the product. Lastly, a Unified Repository (UR) tool is needed that is delivering the substantial benefits from the linkage between virtual and physical products (Grieves, 2014).

4 Development of the Data Supply Chain of a Smart Construction Factory

The conceptual development of the data supply chain is structured as follows. In the analysis, the linear supply chain in which the data is transferred is discussed to gain a basic understanding of the building industry. Based on this, the physical products in real space and virtual products in virtual space are identified. Further, the smart manufacturing system requirements are analyzed to check which properties the digital twins have to possess. In the development phase, the data supply chain for a smart construction factory is designed. Finally, a system is presented that acts as an UR tool and can control the data of both the virtual and physical products.

4.1 Analysis

The main supply chain processes in which the necessary data is produced, used and transferred is presented in figure 4. At the beginning, the operating company of the smart factory receives the order for the renovation of a building, which is then measured with 3D scan systems. As a result of the scan-to-BIM process, a virtual image of the building is created. Based on this, an architect designs the renovation packages. The data of these packages are converted into the machine language of the simulation systems and production machines.

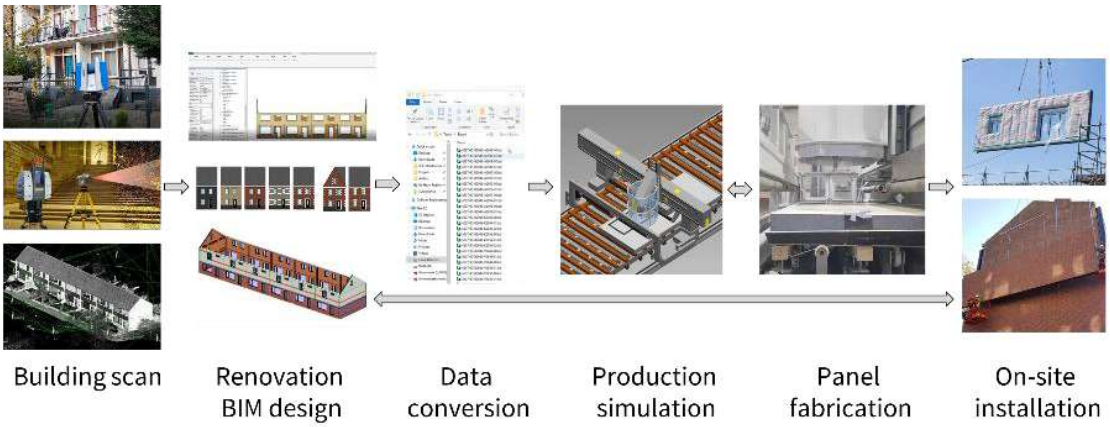


Figure 4: Process Overview

The virtual simulation of the automated production process is done on basis of this data. Afterwards, the panels are physically produced and then again compared with the virtual images to make sure that the product produced is as imagined. In a next step, the panels are transported to the construction sites and installed. Finally, the refurbishment packages are connected to the house monitoring system in order to obtain a daily status of the life cycle. This can in turn be linked to the BIM model, which would also create a kind of closed-loop process here.

Following the process illustration in figure 4, it is necessary to define the system requirements of the digital twins to ensure smooth integration. In the data supply chain to be developed, the digital twins can basically be divided into “product” and “production”, which need to be put into relation. The relationships between both twins can be represented in form of a Venn diagram to graphically organize the association between the requirements and components (see figure 5). It can be used to highlight where the digital twin product and the digital twin production differ and where they have commonalities, or which data is identical and how it is related.

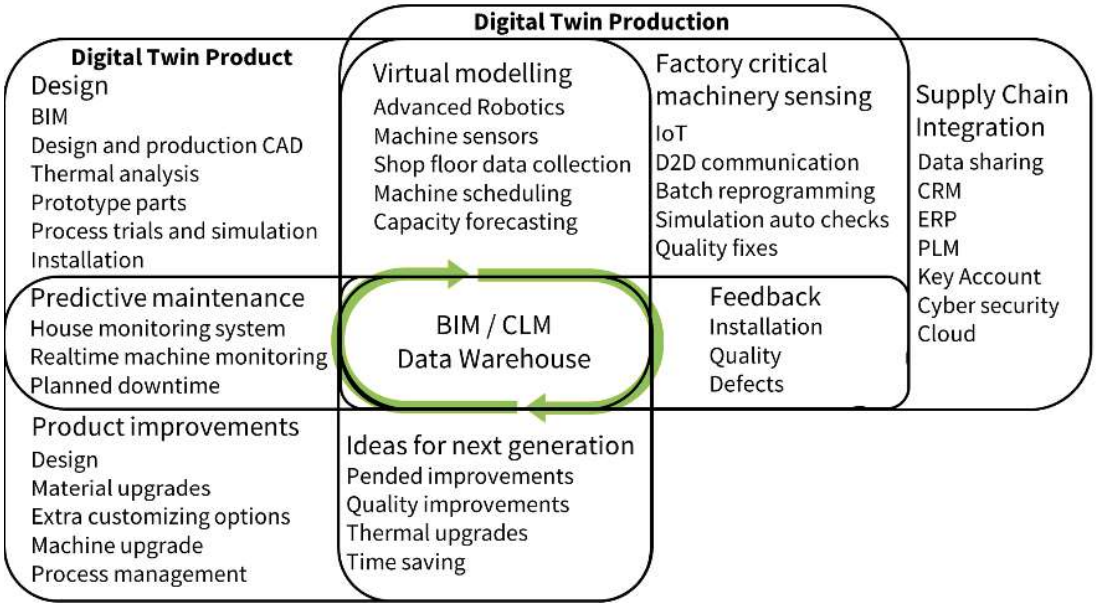


Figure 5: Smart Manufacturing System Requirements

For the product, a good basis is already available at the beginning. With the BIM model of the house to be renovated, the digital product is available virtually immediately after the scan-to-BIM process. However, in order to create a digital twin from the BIM model, further measures must be carried out.

After the prototypical BIM model of the product has been created, the relationships between the components are defined in the design intent as part of the product development, and a thermal analysis is carried out in order to check whether the CO_2 emissions of the houses can be reduced. Next, the life cycle of the products is analyzed and the first factory blueprint is designed. During the launch of the product, the production and logistics processes are developed, and the CAD relationships of the machines are checked. Subsequently, the processes can be presented in a trial. Finally, the products are manufactured for the first time in a test environment. As soon as error-free production is possible, customized products are designed, produced and later installed on the construction sites.

In the digital twin of production, which represents the smart factory, the components are virtually modelled. Corresponding data of the processes have to be collected in order to generate a twin of the production, which represents a real-time representation of the physical processes. This is supported by factory critical machinery sensing, which integrates Industry 4.0 technologies into production. The feedback from other processes in the supply chain is important in order to be able to adapt the processes accordingly and to collect ideas for the next generations.

In order to obtain a real-time operational response for both twins, predictive maintenance has to be considered to detect errors at an early stage (Çınar et al., 2020). For the products, this is mainly possible through the house monitoring systems.

Furthermore, supply chain integration plays an overriding role, as it involves all stakeholders (Ivanov and Dolgui, 2021). In particular, uniform communication channels for data exchange, respective customer relationship management (CRM) and enterprise resource planning (ERP) systems as well as key account management must be considered here. In the future, these processes could be controlled by configuration lifecycle management (CLM) systems, which are explained in the following chapter.

4.2 Development

The development phase refers to how the available data in the supply chain can be transferred into uniform formats in order to control the respective processes and tie the virtual and real products together. The developed concept of a data supply chain of a smart construction factory is presented in figure 6.

After the 3D measurement of the buildings, the data of the point cloud models are converted to BIM models using Revit, a BIM software that brings all architecture, engineering, and construction disciplines into a unified modeling environment (Autodesk, 2021). The BIM models are usually in Industry Foundation Classes (IFC) format. In addition, an OBJ file is exported for later simulation and production. Both files are sent to the warehouse of the data supply chain, where they are processed. The warehouse consists of the Autodesk BIM software, the manufacturing CAD server and the CLM system. Autodesk BIM is responsible for all actions related to the design of the building. The CLM system organizes the procurement, logistics and transports and takes care of customer management. The manufacturing CAD server controls the production. SQL servers as data migration tools coordinate the transfer between the individual areas.

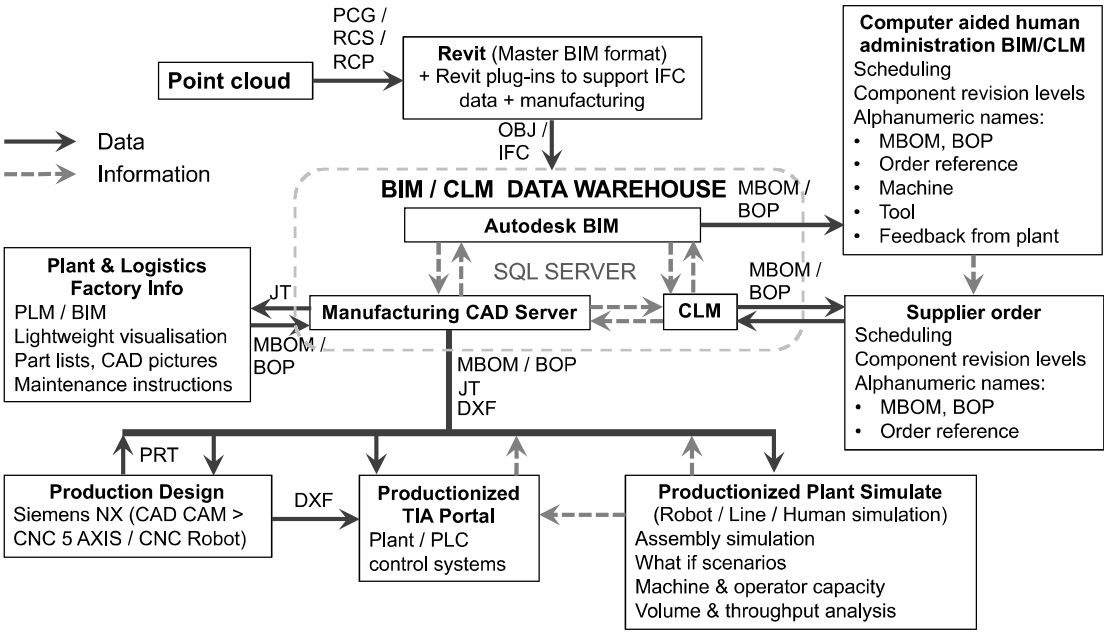


Figure 6: Data Supply Chain of a Smart Construction Factory

The first part of the warehouse is the Autodesk BIM software, that, in addition to design and building management, can be used to define the required MBOM, in which all details such as item numbers, quantities, part descriptions, and lifecycle state are listed that are needed for production. Through exchange with the manufacturing CAD server, the BOP can be created. Both files are then used within the computer aided human administration portal to create the corresponding orders for the factory, to forward them to the accounting department and to create production sequences.

The CLM system as second component of the warehouse is responsible for the contract management from initiation through execution, performance and renewal/expiry and covers all functions of ERP, PLM and CRM along the product life cycle. Thus, all procurement, warehousing and transport processes are coordinated and contracts are agreed with the relevant companies and service providers.

The third part is represented by the manufacturing CAD server, which converts the BIM models and their MBOM and BOP into the corresponding JT and CAD files, sends it to the production, and thus assigns the materials to the specific panels. Before this, the corresponding simulations is carried out. In this case, Siemens Tecnomatix Plant Simulation was selected visualizing the physical twin in real-time. Since this allows the integration of a physical system with the virtual environment, it is able to retrieve data of events from the physical twin via the cloud-based database (Siemens, 2020) Here, the various parts of the physical twin that function and move together are grouped (Redelinghuys et al., 2020). After the processes have passed the plant simulation, they are forwarded to the Totally Integrated Automation (TIA) portal, which provides complete access to the entire digitized automation from digital planning to integrated engineering to transparent operation and establishes the direct link to operations. If even more accurate product models are needed, they could be created beforehand in Siemens' NX interactive CAD system.

A closer look reveals that the data supply chain is not a linear chain, but rather an adaptive network, which enables connectivity, transparency, resource optimization, and faster response times (Singh et al., 2021). Thus, the normative planning area as well as the operational machine area are now decoupled from the physical material flow and decisions are made decentrally on basis of the available real-time information (Tao et al.,

2019). The resulting supply chain network is thus an integrated set of digital logistics functions driven by a connected information flow (Sinha et al., 2021).

The greatest insight gained through the conceptual development of the data supply chain is that a link between the players in the building industry and in particular between old buildings and smart factories can be created. Within a few days after being measured, buildings can be renovated in a climate-neutral way. Decentralized production is many times faster than traditional manual renovation on site. Communication with suppliers, service providers and customers is largely digital and based on previously defined contracts. Furthermore, production is resiliently linked to the construction sites, which means that there are no nonconforming products in the event of short-term errors, as the system can react quickly. In the end, the data supply chain shows how the DTC from Grieves and Vickers works in practice and how it can be used and how digital twins can move from a concept to a critical component of an enterprise-wide closed-loop lifecycle. On the other hand, it shows how the connection between the data about the physical product and the information contained on the virtual product has to be synchronized to use this information for a digital factory simulation.

5 Conclusion

The paper shows how production processes in the building industry are changing through the integration of smart construction factories. In this context, a conceptual data supply chain was developed following the approach of Grieves and Vickers. The data supply chain is based on two digital twins, product and production, and is controlled by a digital core, the data warehouse, which consists of Autodesk BIM, a manufacturing CAD and a CLM system. As a result, an adaptive logistics and production network is created. Consequently, any processes in the supply chain are likely to be transparently coordinated with each other. Finally, this can make a significant contribution to climate protection and housing shortage, as manual on-site construction processes can be replaced by efficient decentralized mass production.

The most valuable constituents in the data supply chain from a logistical and manufacturing viewpoint are algorithmic and parametric designs for describing the

geometry of all individual parts making up the full renovation package MBOM to be used by suitable software able to automate the planning of key process operations.

However, it is to be mentioned that this investigation was predominantly based on the combination of Autodesk Revit as well as Siemens Tecnomatix Plant Simulation and thus only one possible solution was tested. The software used is a studied example of how the conversion of data with subsequent production of products can work. Of course, other systems from different manufacturers can also be used.

The restriction of the investigation represents the few researches about the interaction of smart factories and the building industry. Furthermore, there are no fully developed CLM systems that ensure safe application and integration into the chosen simulation software. For future research, we propose that the transfer of BIM models into real CLM systems of existing enterprises is to be investigated. Nevertheless, the construction companies and housing cooperation are now being forced to push themselves ahead with digitization in their industry in order to meet the specified guidelines on-time.

Acknowledgements

The described object of research was carried out as part of the Interreg project "INDU-ZERO: Industrialization of house renovations towards energy-neutral". The realization is co-financed by the European Regional Development Fund.

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How to apply Artificial Intelligence in the Additive Value Chain: A Systematic Literature Review

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Purpose: *Additive manufacturing (AM) enables the manufacturing of metal parts and is therefore increasingly important for industry. Unfortunately, the manufactured parts exhibit many imperfections, such as faults or other quality defects. The use of artificial intelligence (AI) allows for the steady optimization of processes, making its potential implementation in AM interesting as it could help to improve processes for industrialization and serial production.*

Methodology: *A systematic review was conducted of the literature on applications of AI in AM. A total of 741 articles published between 2008 and 2020 were scanned to determine whether they described an explicit application of AI in a metalworking process. A detailed analysis yielded 87 relevant sources.*

Findings: *The articles were scanned for existing application areas of AI in AM, including application in the associated value chain phases of AM planning and AM execution. In AM planning, AI is frequently used to support the design process, while in AM execution, AI is mostly used for process monitoring and defect detection.*

Originality: *The applications of AI in AM were investigated by means of a systematic literature review. The resultant findings should provide insights into existing and potential application areas for AI in AM.*

First received: 21. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Additive manufacturing (AM) is characterized by the layer-by-layer building of a component based on a CAD model. This enables the production of many complex geometrical structures (e.g., topology-optimized structures), and reduces costs and waste. The value chain of AM consists mainly of design, material selection, manufacturing and quality assessment (Qi, et al., 2019). There are various reasons for the industrial use of AM, including design flexibility, the enabling of a high degree of product customization at relatively low cost, and shorter lead times (Stoyanov and Bailey, 2017).

Unfortunately performance, quality and reliability are all major challenges for AM (Stoyanov and Bailey, 2017). One problem is that defects – such as pores – occur frequently (Qi, et al., 2019). Moreover, residual stresses that influence stability and mechanical performance as well as shape accuracy also present critical problems. Particularly common processes include fused deposition modelling, selective laser sintering, inkjet printing and stereolithography (Stoyanov and Bailey, 2017).

Recently it has been recognized that the use of artificial intelligence (AI) techniques, and particularly the use of neural networks, accelerates the development of AM technologies and also allows for many new possible applications (Qi, et al., 2019). With AI, no analytical equations are necessary, since the algorithm used can learn relationships between input parameters and output performance and recognize patterns autonomously based on existing data (Hassanin, et al., 2020). Input parameters include design, material and process parameters, while “output performance” means microstructural and mechanical properties (Qi, et al., 2019). The training of neural networks is time-consuming, requiring significant computing power as well as a substantial number of training samples, but their subsequent use allows for the acceleration of processes (Aggarwal, 2018).

The aim of this work is to identify the possible application areas of AI in AM by examining previous works. Consequently, the research question has been formulated as follows: Where has artificial intelligence been applied in additive manufacturing?

The remaining paper is structured as follows. It proceeds with an explanation of the methodological approach of the literature review in Section 2. Section 3 then continues with the descriptive and qualitative content analysis of the use cases. This is followed by an explanation of the results of the research in Section 4. Finally, Section 5 summarizes the findings and provides an outlook on further possible research areas.

2 Methodology

The systematic literature review was carried out according to the methodology laid down by Tranfield, Denyer and Smart (2003). The research was thus first planned, and from the planned steps a review protocol was written to ensure objectivity. The research question was then formulated and, as a result, the two thematic contexts of AI and AM were identified. Based on these generic terms, suitable search terms could be determined by means of synonyms. Consequently, a search string could be formulated by means of Boolean operators, which can be seen in Figure 1.

The second step was to conduct the research. In the two selected meta-databases, Scopus and Web of Science, the search string was used to search within the abstract, title, and keywords of sources in order to identify suitable papers. This resulted in the identification of 758 potentially relevant papers on Scopus, and 293 on Web of Science (September 11th, 2020). After the removal of duplicate works, the result was 741 published works. Finally, a title and abstract screening was carried out to exclude works dealing with use cases in the context of medicine or the plastics processing industry. This resulted in a reduction to 190 potentially relevant literature sources. By means of a full-text screening, a final determination of thematic relevance followed, resulting in the selection of 87 relevant literature works, which are considered below. This procedure is outlined in Figure 1.

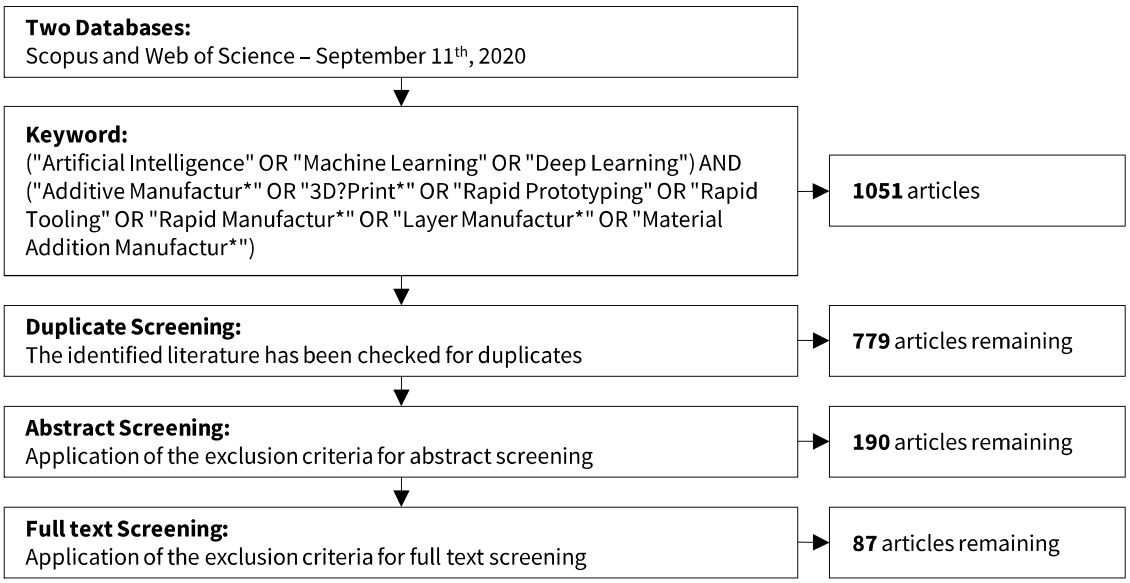


Figure 1: Methodological Approach of Exclusion to Determine Relevant Articles

3 Artificial Intelligence in Additive Manufacturing

In this section the descriptive analysis of the identified literature works is carried out first. This is followed by the results of the qualitative content analysis, wherein different application areas of AI in AM – divided between AM planning and AM execution – are presented.

3.1 Descriptive Analysis

One way is to examine the literature is to look at papers in terms of their frequency distributions by year and document type. Strikingly, over 95% of the selected sources were from the last six years (2016 to 2021; see Figure 2). This reflects recent advances in AI, including increased computing power and storage capacity, and highlights the novelty of AI in AM. Furthermore, the increasing number of use cases shows the growing relevance of AI in AM. The flattening number of use cases in 2020 can be explained by the

fact that the databases were accessed on the 11th of September, meaning that the use cases ranging from mid-September to the end of December were not recorded.

Of the selected literary works, 31% were conference papers and 69% were journal articles. The high number of journal articles, which are often of higher quality than conference papers, illustrates the scientific importance of the topic. The increasing number of conference papers also indicates that research interest in this topic is continuing to grow.

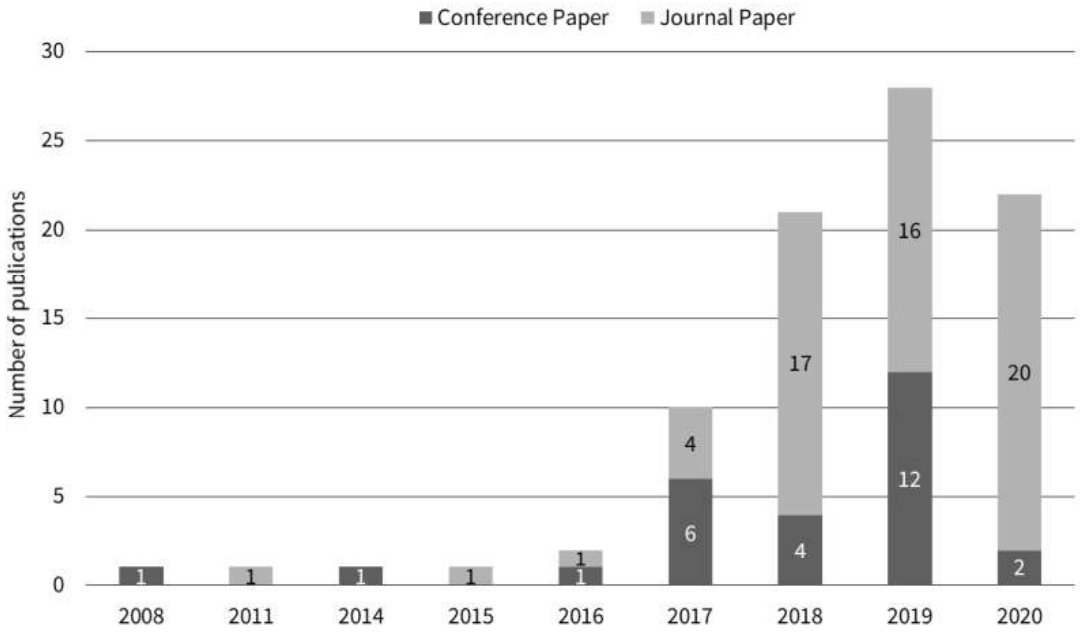


Figure 2: Frequency Distribution of the Relevant Articles

In the distribution of used algorithms, which can be seen in Figure 3 an accumulation can also be observed in the use of deep and supervised learning algorithms.

The use of supervised learning algorithms can be explained by the fact that many internal data sources were used, such as machine and sensor data from researchers' own experiments. It was to this data that AI was applied, rather than, for example, text data from the internet. In addition, the sensor technology and structured storage must have been defined before the data was recorded so that the data was available in a structured form. Among the supervised learning algorithms, slightly more classification algorithms

than regression algorithms were used; this would result in the making of more categorical decisions as opposed to predicting continuous evolution. Regression algorithms do, in fact, also try to take into account the development of the data and to approximate future developments on this basis. In some use cases, a combination of both types of algorithms was used, so that future developments were predicted alongside the making of categorical decisions. In some use cases, researchers went a step further, with a combination of clustering, unsupervised learning algorithms and classification algorithms. This was done, for instance, when external data was evaluated in addition to the internally collected data, or when criteria for structuring the data were not yet known.

The frequent use of deep learning algorithms suggests how current this topic of AI in AM is in research. These are very new and innovative algorithms that are themselves capable of recognizing patterns, although it is not entirely clear how they actually work. However, this loss of control is accepted due to their established use in the industry and hopes surrounding their ability to add value.

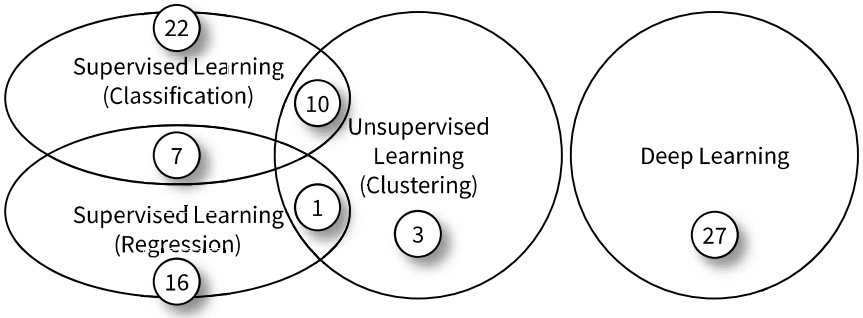


Figure 3: Distribution of Used Algorithms in the Relevant Articles

3.2 Qualitative Analysis

In the qualitative analysis of the identified use cases, different application areas of AI in AM could be identified on the basis of the areas defined by Razvi, et al. (2019), which were extended with some additional application areas. These areas of application can be divided roughly into the use of AI in AM planning, and its use in AM execution. Most of the use cases – 62 of 87 – took place in AM execution. Particularly high numbers of use cases

were observed in process monitoring and in the monitoring of defects. Further information can be seen in Figure 4.

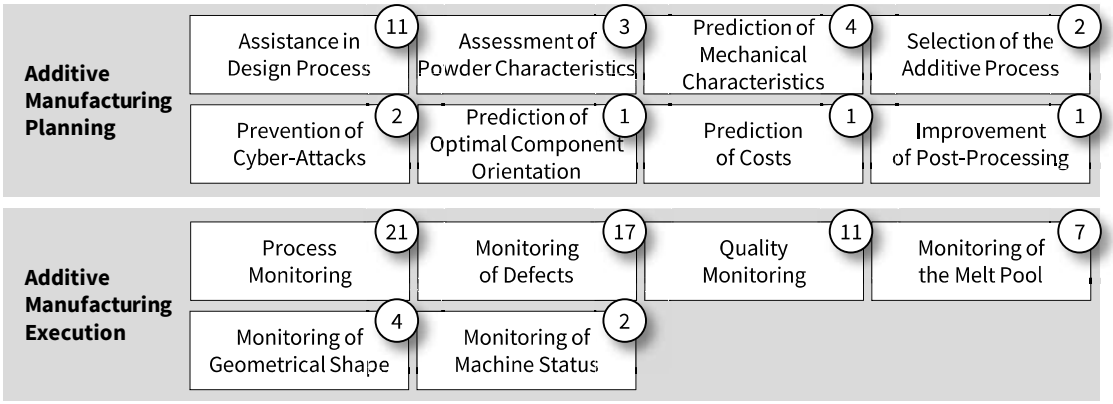


Figure 4. Observed Application Areas in AM Planning and AM Execution

3.2.1 Artificial Intelligence in Additive Manufacturing Planning

Assistance in Design Process

One major problem is often lack of experience on the part of engineers with additive processes, which can lead to errors. This was highlighted by eleven of the identified literature items. In such cases, AI can support the engineer in the design of additive products, which should lead to an increase in efficiency (Murphy, et al., 2018).

The identified use cases are very diverse, ranging from the development of design rules to the optimization and manufacturability testing of design ideas. For instance, design rules for thin-walled features were developed by Gaikwad, et al. (2019). A paper by Mycroft, et al. (2020), on the other hand, is concerned with exploring the limits of manufacturability in additive processes by identifying problematic regions, while in the work of Yang, et al. (2020) a decision system was developed for the identification of part candidates for AM applications.

AI can also be used to predict AM attributes, such as mass, required support structures and build times, as was done in the work of Murphy, et al.(2018). The work of Yao, Moon and Bi (2017), on the other hand, deals directly with a system that can suggest design solutions based on certain construction features.

Prediction of Mechanical Characteristics

The prediction of mechanical characteristics with AI is very relevant due to the high location dependency caused by many heating and cooling cycles. Since the layer-by-layer build-up process is often subject to strong process fluctuations, a prediction is much more difficult than it would be in conventional processes. Here, AI can help to predict mechanical properties on the basis of various data inputs (Yan, et al., 2018).

Since such predictions can be based on the choice of process parameters and geometry, as well as on the recording of the process, the use cases are partly also applied in AM execution.

The work of Garg and Tai (2014) focuses on the prediction of wear resistance, while the work of Yan, et al. (2018) uses AI for the prediction of varying tensile strength based on selected manufacturing parameters.

Assessment of Powder Characteristics

In many additive processes, powder is used as a raw material that is successively bonded in layers by an energetic jet. For successful production, the powder must be distributed as evenly as possible in the powder bed beforehand. Often, anomalies or irregularities that negatively influence process reliability and stability occur. Since it is practically impossible to detect such anomalies with the naked eye, a combination of AI and computer vision is usually used for this purpose (Scime and Beuth, 2018a).

The use cases make use of AI in the planning process, during production, and in powder management, by testing the powder material.

Using AI, powder distribution can be predicted in order to control scatter defects, as was done in the work of Desai and Higgs (2019); the detection of the development of component defects from the observed powder distribution is also possible, as was done in the work of Scime and Beuth (2018a). In addition, in the work of DeCost, et al. (2016), AI was used for the evaluation of microsections for the classification of powder material.

Selection of the Additive Process

The choice of the AM process has a lasting influence on component behavior. AI can help to select a suitable AM process based on various selection factors (Munguia and Riba, 2008).

Munguia, Bernard and Erdal (2011) developed as system that uses AI to assist in the selection of a suitable AM process based on initial product design specifications. In another work by Munguia and Riba (2008), a computer-aided system was used to compare the additive processes with each other and with conventional manufacturing processes, and also to aid in the selection of suitable production parameters.

Prevention of Cyber-Attacks

Cyber-attacks are playing an increasingly important role in cyber-physical production systems, even though only two use cases with respect to prevention of cyber-attacks in AM could be identified here. The attackers' motives range from theft of intellectual property to sabotage of safety-critical systems, both of which can cause massive financial damage (Yeboah-Ofori, Abdulai and Katsriku, 2018).

While the use case developed by Al Faruque, et al. (2016) deals with the possibilities of component reconstruction based on noise emissions, the work of Wu, Song and Moon (2017) dealt with the use of Machine Learning (ML) methods to detect cyber-physical attacks .

Since both use cases also examine the ongoing process of production, this application area is also used in AM execution.

Prediction of Optimal Component Orientation

Optimal build orientation is an important parameter in AM, as it has a significant impact on accuracy, cost and build time. A good orientation can only be achieved by sufficiently experienced engineers, and even then such orientations are usually not optimal (Canellidis, Giannatsis and Dedoussis, 2009).

It is possible for AI to help with determination of an optimal build orientation, thus automating this process step. The only identified use case, which was developed by

Zhang, et al. (2018), deals with the determination, using ML methods, of an optimal component orientation based on the features of the component.

Prediction of Costs

The use of AI can also help with estimation of the costs incurred in the course of development and during the process of AM. Only one literature work, authored by Chan, Lu and Wang (2017), could be identified; it deals with cost estimation by means of ML, taking into account historical cost data on components that have already been manufactured.

Improvement of Post-Processing

Many additive processes still require post-processing of the surface and porosity (Richter and Wischmann, 2016). Using AI, the influence of this post-processing can be determined and also improved, as was the objective of Hatamleh, et al. (2019). Here, prediction of the influence of laser shock peening on varying residual stresses was investigated. Since post-processing data is also collected for this purpose, this application area also takes place in AM execution.

3.2.2 Artificial Intelligence in Additive Manufacturing Execution

Process Monitoring

Monitoring manufacturing processes by means of AI is an elementary application field in AM, a fact made clear by the presence of 21 identified use cases in our sample. AI helps to cope with the particularly high levels of complexity of additive processes. In AM, AI is used to identify and quantify process parameters that significantly influence process repeatability and product quality (Everton, et al., 2016).

For the most part, the use cases occurred in AM planning (when setting up the printer) and in AM execution (when printing the component), and involved recording data using imaging techniques. Often the use cases dealt with an optimization loop, so that in the future machines can adjust process parameters based on the observations they made of the process.

Many studies in the literature have worked to determine the influence of process parameters. The influence of process parameters on surface roughness was determined using AI in the work of Akhil, et al. (2020), while their influence on porosity was determined by Imani, et al. (2018), and their influence on tensile properties was determined by Marmarelis and Ghanem (2020). Some works only examined individual process parameters. For example, Douard, et al. (2018) investigated the influence of support structures on geometric quality. Raitanen and Ylander (2020) applied AI to detect faulty machine conditions and part porosity and to determine the correlation between these factors.

In other use cases, the focus was more on improving the process parameters. For this purpose, detection of errors by the machine itself was specifically used to improve process parameters in the work of Razaviarab, Sharifi and Banadaki (2019). A study by Mondal, et al. (2020) focused on control of the melt pool for improvements. In the work of Uhlmann, et al. (2017), targets of improvement included the reduction of energy consumption and emissions.

Other sources were more concerned with monitoring the process system as a whole. For example, the probability of a successful print can be predicted, as was done in the work of Amini and Chang (2018). In a use case by Wang, et al. (2018) system monitoring was used to stabilize the printing process by inspecting droplet behavior, while, Rafajlowicz (2017) developed a control system that examines images to make control decisions regarding laser power.

Monitoring of Defects

Due to their layered structure, additively manufactured components often tend to show anomalies and defects within their structure (Gobert, et al., 2018). Consequently, the detection of component defects during the additive manufacturing process is an elementary application area of AI, a fact made clear by the presence of 17 identified use cases in our sample. Input data were mostly collected by means of imaging techniques.

Many use cases were mainly concerned with the detection of component defects through the layer-by-layer recording of images using cameras, as in the work of Gobert, et al. (2018) . In the papers by Eschner, et al. (2019) and Okaro, et al. (2019), on the other hand,

acoustic and photodiode data were used. By evaluating thermographic images, it is also possible to detect delamination and splatter, as Baumgartl et al. demonstrated (2020).

Other authors, in addition to detection, also dealt with the classification of defects and pores, such as Angelone, et al. (2020) and Williams, et al. (2018).

Some sources dealt specifically with the monitoring of porosity, for which, among other methods, pyrometric data (Mitchell, et al., 2019) and micro x-ray computed tomography data (Zhu, et al., 2020) have been used.

Quality Monitoring

The quality of a component can often only be determined after the manufacturing process has been completed, which can result in a waste of time and material. Consequently, AI can help to reduce waste by processing process data and providing early warning of poor component quality, enabling corrective measures to be initiated (Delli and Chang, 2018).

For the monitoring of component quality, image data (Yuan, et al., 2019) as well as noise emissions (Wasmer, et al., 2019) and optical thermography of the melt pool (Yadav, et al., 2020) can be used. In a paper by Li, Yan and Zhang (2019), quality monitoring was used specifically to evaluate material behavior based on the detection of the material's microstructure. AI can also be used to predict and optimize quality (Stoyanov and Bailey, 2017).

Monitoring of the Melt Pool

Monitoring the melt pool is a significant area of application of AI, as the melt pool in particular is responsible for many defects in additive components (Scime and Beuth, 2018b).

Since monitoring with the naked eye is practically impossible, in the use cases AI was often used in combination with computer-vision-based approaches. These use cases took place in AM execution by monitoring the printing process, as well as by changing process parameters within an improvement loop.

Monitoring of the melt pool can enable the detection of anomalies and also determine the influence of the melt pool on porosity, as was examined in the work of Scime and

Beuth (2018b). In addition, in the work of Yeung, Yang and Yan (2020), AI was used to control the melt pool by regulating laser energy.

Monitoring of the Geometrical Shape of Components

Investigation of geometric shape is mostly carried out in AM execution when monitoring the printing process, but also allows conclusions to be drawn on how to improve geometry and the printing process.

Examination of the component's geometric shape can be used to control quality by avoiding geometric deviations. The variance in geometry should be within predefined tolerance limits. In addition, process parameters can be inferred by examining component shapes. In this way, AI can help provide a better understanding of the morphological formation of additive components, and thus also enable the prediction of systematic shape deviations to enable correct intervention if necessary (Francis and Bian, 2019).

For example, AI was used by Korneev, et al. (2020) to predict a component's "printed" shape, and by Francis and Bian (2019) to predict deviations due to heat-induced distortions.

Monitoring of the Machine Status

Condition monitoring of AM machines is an AI application area in which the main objective is to increase the productivity of the AM process. Work in this area mainly impacts product quality and manufacturing costs, which are significantly influenced by the reliability and performance of AM machines (Liu, et al., 2018). In this context, scientists believe that improved monitoring of machine conditions can lead to reduced waste as well as increased product quality (Wu, Wang and Yu, 2017).

Liu, et al. (2018) used AI to determine faulty machine conditions on the basis of acoustic emissions, while Wu, Wang and Yu (2017) applied AI to improve machine monitoring, which also enables machine maintenance predictions.

4 Conclusion

To answer the research question ("Where has artificial intelligence been applied in additive manufacturing?"), it is apparent that there are many different areas of application of AI in both AM planning and AM execution. AI is often combined with imaging and computer vision techniques that can automatically detect and process features. One of the main motives behind the use of AI seems to be ensuring and improving quality and preventing defects during design and production.

Investigation of the algorithms used also made it possible to ascertain further information. Supervised and deep learning algorithms were used especially frequently in the use cases investigated. The accumulation of supervised algorithms suggests that much of the data was collected in a structured manner based on classification criteria known by the researchers themselves, since these algorithms are particularly suitable if structuring criteria are already known. The fact that regression algorithms were less used makes it apparent that the focus of research was less on predicting the continuous evolution of data and more on classifying states. The combination of unsupervised and supervised learning algorithms was also used more frequently when classification criteria were not yet known in a use case, or when these criteria were first collected from external data. New and novel deep learning algorithms are capable of recognizing patterns on their own; the fact that many use cases made use of these algorithms highlights the important of such functionality with respect to AI's application in AM.

The number of use cases in AM planning was significantly lower than the number of cases in AM execution. In the cases that did involve AM planning, AI was most frequently used for assistance in the design process. Cases in the area of process selection were observed much less frequently. Also rare were use cases in which AI was used to predict optimal component orientation or to perform cost estimation. This suggests that these areas are either not very error-prone or not complex enough to require the use of AI. Another rarely occurring application of AI is for the prevention of cyber-attacks, which can probably be explained by the fact that AI is often applied to manufacturing systems in general, and not specifically to AM systems. Furthermore, AI has also been comparatively infrequently

used in the prediction of mechanical properties, although problems relating to mechanical properties are still common.

The application areas in which use cases appeared particularly frequently in AM execution were process and quality monitoring and the monitoring of defects. This can be explained by the fact that monitoring can prevent defects that still occur frequently, which in turn can improve quality. In particularly rare cases AI was used to assess powder properties – the lower frequency of such cases suggests that such monitoring may not be as critical as the aforementioned factors to final quality. Only one use case involving the use of AI to improve post-processing could be identified, which can probably be explained by the fact that it is more valuable to avoid post-processing than to improve it. It has also been rare for AI to be applied to machine monitoring in AM. This does not necessarily imply that AI is rarely used to monitor machines, but simply that studies have been more generalized, and have not looked specifically at machine monitoring in AM.

It should be stated that some use cases may not have been detected because they were not identified by the search string, or may have been excluded because they deal with plastic processing AM.

5 Implications and Further Research

Several things became clear as a result of this literature review. In general, the review showed that AI can significantly increase the added value of AM, as well added value in tangential areas, such as predictive maintenance.

Practical Implications

For the practical implementation of AI in AM, some implications can be inferred from this research. On the one hand, based on the distribution of algorithms, a need for data can be recognized – a need of which users of AI should be aware. In addition, knowledge of the algorithms used provides the means to infer the respective need for structured or unstructured data for the application in question.

Furthermore, analysis of the use cases made it clear what is possible through the use of AI in the area of AM planning, as well as in the operational implementation of AM, and

what different application areas result from this, such as quality monitoring and the determination of machine parameters. In addition, various possible use cases in the respective application areas were shown, including quality monitoring by means of various forms of data, such as images, acoustic measurements, and pyrometry.

Scientific Implications

This research also has some implications for research, meaning that scientists can also benefit from this review. The overview of the frequency of journal articles shows how established this topic is, and how high the level of scientific inquiry already is in this area. With the increase in conference papers, it is clear that a great deal of research is currently being conducted, which is also made evident by the use of advanced deep learning algorithms. In addition, the distribution of algorithms shows which algorithms are considered to be capable of solving previously identified problems. Additionally, it has also been shown that value can be added by combining algorithms.

The analysis of the application areas and the distribution of use cases in this review shows in which areas and how (i.e., with which data and algorithms) research has already been carried out. This has also highlighted particularly innovative use cases, as well as previously underrepresented application areas. In addition, the bridge to other research areas, such as economics, was also shown, which illustrates the importance of interdisciplinary research. Thus, among other things, this research shows that it is also worth looking at the value chain into which AM is integrated in order to improve the final AM product.

Further Research

From a research methodology perspective, all the identified articles were dedicated to the topic from a conceptual or experimental perspective. So far, none of the use cases studied have dealt with industrialization or implementation into a corporate structure, which could be one possible future research area.

Furthermore, the distribution of the use cases in the application areas also made clear in which application areas there is a need for further research. Consequently, it has become apparent that the greatest need still exists in AM planning. For example, there is still a need for application of AI in the assessment of raw material in powder form, as well as in

the improvement of post-processing (where post-processing cannot be avoided). Furthermore, there is room for additional important applications of AI in the prediction of mechanical properties, process selection and the estimation of costs.

Appendix

A.1 AM Planning Use Cases

Table 1: Assistance in Design Process

Authors	Title
Després et al. (2020)	Deep Learning and Design for Additive Manufacturing: A Framework for Microlattice Architecture
Gaikwad et al. (2019)	Design Rules and In-Situ Quality Monitoring of Thin-Wall Features Made Using Laser Powder Bed Fusion
Garrelts et al. (2019)	A Straightforward Approach to the Derivation of Topologies
Guo et al. (2020)	Semi-Supervised Deep Learning Based Framework for Assessing Manufacturability of Cellular Structures in Direct Metal Laser Sintering Process
Mahmoudi et al. (2018)	On the Printability and Transformation Behavior of Nickel-Titanium Shape Memory Alloys Fabricated Using Laser Powder-Bed Fusion Additive Manufacturing
Murphy et al. (2018)	Using Autoencoded Voxel Patterns to Predict Part Mass, Required Support Material, and Build Time
Mycroft et al. (2020)	A Data-Driven Approach for Predicting Printability in Metal Additive Manufacturing Processes
Page et al. (2019)	Automated Candidate Detection for Additive Manufacturing: A Framework Proposal

Authors	Title
Yang et al. (2020)	Towards an Automated Decision Support System for the Identification of Additive Manufacturing Part Candidates
Yao et al. (2017)	A Hybrid Machine Learning Approach for Additive Manufacturing Design Feature Recommendation
Zhang et al. (2019)	Machine Learning Assisted Prediction of the Manufacturability of Laser-Based Powder Bed Fusion Process

Table 2: Prediction of Mechanical Characteristics

Authors	Title
Garg, Tai (2014)	An Ensemble Approach of Machine Learning in Evaluation of Mechanical Property of the Rapid Prototyping Fabricated Prototype
Hassanin et al. (2020)	Controlling the Properties of Additively Manufactured Cellular Structures Using Machine Learning Approaches
Seifi et al. (2019)	In-Situ Fatigue Prediction of Direct Laser Deposition Parts Based on Thermal Profile
Yan et al. (2018)	Data-Driven Prediction of Mechanical Properties in Support of Rapid Certification of Additively Manufactured Alloys

Table 3: Assessment of Powder Characteristics

Authors	Title
DeCost et al. (2016)	Computer Vision and Machine Learning for Autonomous Characterization of AM Powder Feedstocks
Desai, Higgs (2019)	Spreading Process Maps for Powder-Bed Additive Manufacturing Derived from Physics Model-Based Machine Learning
Scime, Beuth (2018)	A Multi-Scale Convolutional Neural Network for Autonomous Anomaly Detection and Classification in a Laser Powder Bed Fusion Additive Manufacturing Process

Table 4: Selection of the Additive Process

Authors	Title
Munguia et al. (2011)	Proposal and Evaluation of a KBE-RM Selection System
Munguia, Riba (2008)	A Concurrent Rapid Manufacturing Advice System

Table 5: Prevention of Cyber Attacks

Authors	Title
Al Faruque et al. (2016)	Acoustic Side-Channel Attacks on Additive Manufacturing Systems

Authors	Title
Wu et al. (2017)	Detecting Cyber-Physical Attacks in CyberManufacturing Systems with Machine Learning Methods

Table 6: Prediction of the Optimal Component Orientation

Authors	Title
Zhang et al. (2018)	A Statistical Method for Build Orientation Determination in Additive Manufacturing

Table 7: Prediction of Costs

Authors	Title
Chan et al. (2017)	Data-Driven Cost Estimation for Additive Manufacturing in Cybermanufacturing

Table 8: Improvement of Post-Processing

Authors	Title
Hatamleh et al. (2019)	Prediction of Residual Stress Random Fields for Selective Laser Melted A357 Aluminum Alloy Subjected to Laser Shock Peening

A.2 AM Execution Use Cases

Table 9: Process Monitoring

Authors	Title
Akhil et al. (2020)	Image Data-Based Surface Texture Characterization and Prediction Using Machine Learning Approaches for Additive Manufacturing
Amini, Chang (2018)	MLCPM: A Process Monitoring Framework for 3D Metal Printing in Industrial Scale
Amini, Chang (2018)	Process Monitoring of 3D Metal Printing in Industrial Scale
Caiazzo, Caggiano (2018)	Laser Direct Metal Deposition of 2024 Al Alloy: Trace Geometry Prediction via Machine Learning
Douard et al. (2018)	An Example of Machine Learning Applied in Additive Manufacturing
Han et al. (2020)	Quantitative Microstructure Analysis for Solid-State Metal Additive Manufacturing via Deep Learning
Imani et al. (2018)	Process Mapping and In-Process Monitoring of Porosity in Laser Powder Bed Fusion Using Layerwise Optical Imaging
Kappes et al. (2018)	Machine Learning to Optimize Additive Manufacturing Parameters for Laser Powder Bed Fusion of Inconel 718

Authors	Title
Marmarelis, Ghanem (2020)	Data-Driven Stochastic Optimization on Manifolds for Additive Manufacturing
Mondal et al. (2020)	Investigation of Melt Pool Geometry Control in Additive Manufacturing Using Hybrid Modeling
Mozaffar et al. (2018)	Data-Driven Prediction of the High-Dimensional Thermal History in Directed Energy Deposition Processes via Recurrent Neural Networks
Olleak, Xi (2020)	Calibration and Validation Framework for Selective Laser Melting Process Based on Multi-Fidelity Models and Limited Experiment Data
Özel et al. (2019)	Focus Variation Measurement and Prediction of Surface Texture Parameters Using Machine Learning in Laser Powder Bed Fusion
Rafajłowicz (2017)	Image-Driven, Model-Free Control of Repetitive Processes Based on Machine Learning
Raitanen et al. (2020)	A Data-Driven Approach Based on Statistical Learning Modeling for Process Monitoring and Quality Assurance of Metal Powder Additive Manufacturing
Razaviarab et al. (2019)	Smart Additive Manufacturing Empowered by a Closed-Loop Machine Learning Algorithm
Silbernagel et al. (2019)	Using Machine Learning to Aid in the Parameter Optimisation Process for Metal-Based Additive Manufacturing
Uhlmann et al. (2017)	Intelligent Pattern Recognition of SLM Machine Energy Data

Authors	Title
Wang et al. (2018)	In-Situ Droplet Inspection and Closed-Loop Control System Using Machine Learning for Liquid Metal Jet Printing
Zhang et al. (2017)	Machine Learning Enabled Powder Spearding Process Map for Metal Additive Manufacturing
Zohdi (2018)	Electrodynamic Machine-Learning-Enhanced Fault-Tolerance of Robotic Free-Form Printing of Complex Mixtures

Table 10: Monitoring of Defects

Authors	Title
Angelone et al. (2020)	Bio-Intelligent Selective Laser Melting System based on Convolutional Neural Networks for In-Process Fault Identification
Baumgartl et al. (2020)	A Deep Learning-Based Model for Defect Detection in Laser-Powder Bed Fusion Using In-Situ Thermographic Monitoring
Caggiano et al. (2019)	Machine Learning-Based Image Processing for On-Line Defect Recognition in Additive Manufacturing
Cui et al. (2020)	Metal Additive Manufacturing Parts Inspection Using Convolutional Neural Network
Eschner et al. (2019)	Acoustic Process Monitoring for Selective Laser Melting (SLM) with Neural Networks: A Proof of Concept
Gobert et al. (2018)	Application of Supervised Machine Learning for Defect Detection during Metallic Powder Bed Fusion Additive Manufacturing Using High Resolution Imaging

Authors	Title
Imani et al. (2019)	Deep Learning of Variant Geometry in Layerwise Imaging Profiles for Additive Manufacturing Quality Control
Mitchell et al. (2019)	Linking Pyrometry to Porosity in Additively Manufactured Metals
Okaro et al. (2019)	Automatic Fault Detection for Laser Powder-Bed Fusion Using Semi-Supervised Machine Learning
Petrich et al. (2017)	Machine Learning for Defect Detection for PBFAM Using High Resolution Layerwise Imaging Coupled with Post-Build CT Scans
Scime et al. (2020)	Layer-Wise Anomaly Detection and Classification for Powder Bed Additive Manufacturing Processes: A Machine-agnostic Algorithm for Real-Time Pixel-Wise Semantic Segmentation
Snell et al. (2019)	Methods for Rapid Pore Classification in Metal Additive Manufacturing
Tang et al. (2017)	An Online Surface Defects Detection System for AWAM Based on Deep Learning
Williams et al. (2018)	Defect Detection and Monitoring in Metal Additive Manufactured Parts through Deep Learning of Spatially Resolved Acoustic Spectroscopy Signals
Wu et al. (2016)	Detecting Malicious Defects in 3D Printing Process Using Machine Learning and Image Classification
Zhang et al. (2019)	In-Process Monitoring of Porosity during Laser Additive Manufacturing Process

Authors	Title
Zhu et al. (2020)	Unraveling Pore Evolution in Post-Processing of Binder Jetting Materials: X-Ray Computed Tomography, Computer Vision, and Machine learning

Table 11: Quality Monitoring

Authors	Title
Han et al. (2019)	Image Classification and Analysis during the Additive Manufacturing Process Based on Deep Convolutional Neural Networks
Li et al. (2020)	Quality Analysis in Metal Additive Manufacturing with Deep Learning
Li et al. (2019)	A Deep Learning Method for Material Performance Recognition in Laser Additive Manufacturing
Özel et al. (2017)	Surface Topography Investigations on Nickel Alloy 625 Fabricated via Laser Powder Bed Fusion
Patel et al. (2019)	Using Machine Learning to Analyze Image Data from Advanced Manufacturing Processes
Ren et al. (2020)	Computational Fluid Dynamics-Based In-Situ Sensor Analytics of Direct Metal Laser Solidification Process Using Machine Learning
Shevchik et al. (2019)	Deep Learning for In Situ and Real-Time Quality Monitoring in Additive Manufacturing Using Acoustic Emission
Stoyanov, Bailey (2017)	Machine Learning for Additive Manufacturing of Electronics

Authors	Title
Wasmer et al. (2019)	In Situ Quality Monitoring in AM Using Acoustic Emission: A Reinforcement Learning Approach
Yadav et al. (2020)	Inline Drift Detection Using Monitoring Systems and Machine Learning in Selective Laser Melting
Yuan et al. (2019)	Semi-Supervised Convolutional Neural Networks for In-Situ Video Monitoring of Selective Laser Melting

Table 12: Monitoring of the Melt Pool

Authors	Title
Guo et al. (2020)	A Physics-Driven Deep Learning Model for Process-Porosity Causal Relationship and Porosity Prediction with Interpretability in Laser Metal Deposition
Khanzadeh et al. (2018)	Porosity Prediction: Supervised-Learning of Thermal History for Direct Laser Deposition
Lee et al. (2019)	Data Analytics Approach for Melt-Pool Geometries in Metal Additive Manufacturing
Scime, Beuth (2018)	Using Machine Learning to Identify In-Situ Melt Pool Signatures Indicative of Flaw Formation in a Laser Powder Bed Fusion Additive Manufacturing Process
Yang et al. (2019)	Investigation of Deep Learning for Real-Time Melt Pool Classification in Additive Manufacturing

Authors	Title
Yeung et al. (2020)	A Meltpool Prediction Based Scan Strategy for Powder Bed Fusion Additive Manufacturing
Yuan et al. (2018)	Machine-Learning-Based Monitoring of Laser Powder Bed Fusion

Table 13: Monitoring of the Geometrical Shape

Authors	Title
Elwarfalli et al. (2019)	In Situ Process Monitoring for Laser-Powder Bed Fusion using Convolutional Neural Networks and Infrared Tomography
Francis, Bian (2019)	Deep Learning for Distortion Prediction in Laser-Based Additive Manufacturing using Big Data
Korneev et al. (2020)	Fabricated Shape Estimation for Additive Manufacturing Processes with Uncertainty
Zhu et al. (2018)	Machine Learning in Tolerancing for Additive Manufacturing

Table 14: Monitoring of the Machine Status

Authors	Title
Liu et al. (2018)	An Improved Fault Diagnosis Approach for FDM Process with Acoustic Emission

Authors	Title
Wu et al. (2017)	In Situ Monitoring of FDM Machine Condition via Acoustic Emission

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Managing contract manufacturing relationships - An explorative research framework

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Purpose: *Contract manufacturing has established itself as a cornerstone of manufacturing practices across industries. The high degree of external value creation, operational interfaces, relational dynamics, and knowledge exchange coordination require demand-oriented management of contract manufacturing service providers from an outsourcing company's perspective.*

Methodology: *An explorative research framework for managing contract manufacturing organizations (CMOs) is developed through a literature review on inter-organizational relationships (IOR) and empirical validation. The framework draws on contingency theory and complex adaptive systems theory as structural theories to support the research process.*

Findings: *The need for a dedicated management approach of CMOs in distinction to other IORs is derived. The developed framework indicates the role of situational variables of contract manufacturing and their inherent dynamics for relationship management of CMOs.*

Originality: *Despite the strong practical relevance, the literature on the management of IORs does not adequately address the phenomenon against the background of the distinctive management challenges of contract manufacturing. In relationship management, the developed framework systematically addresses these challenges because of the dynamic growth of the contract manufacturing market.*

First received: 22. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Contract manufacturing organizations (CMOs) are taking over ever-larger shares of the value creation in the supply chains of brand-leading companies (Tsay et al., 2018, p. 1177; Kaiser and Obermaier, 2020, p. 28). Despite a high level of maturity of scientific and practical literature on the management of supplier relationships, a large share of outsourcing initiatives miss targeted performance goals or even fail (Wiengarten, Pagell, and Fyness, 2013, p. 630; Foerstl, Kirchoff and Bals, 2016, p. 493). It has been remarked that the ever more dynamic growth of outsourcing practices in contract manufacturing relationships (CMRs) has left research lagging behind practice (Busi and McIvor, 2008, p. 186). To better understand how CMRs can be successfully managed, this paper aims to derive the relevant specifics in the management of CMOs and consider them in an exploratory research framework. Accordingly, the following research questions are addressed:

RQ1: What are the distinctive features of the management of CMRs?

RQ2: How could a dedicated relationship management approach for CMRs be developed?

The paper is organized as follows: Chapter two provides an overview of the state of research and highlights the relevance of managing CMRs and particular challenges. Chapter three presents the research design. In chapter four, the research questions are answered, and the results are presented. Finally, chapter five critically reflects on the results and provides an outlook on further research opportunities.

2 State of research

Outsourcing can be defined as "the process by which a company subcontracts activities traditionally performed internally to external parties," with contract manufacturing being a specific form of outsourcing (Meira et al., 2010, pp. 153–154). The subcontracted activities can encompass the entire manufacturing process and involve "manufacturing-related processes" such as product design (Sousa and Voss, 2007, p. 975). In the organizational literature, contract manufacturing and outsourcing are considered

organizational choices to achieve an organization's objective according to its capabilities (Nassimbeni, 1998, p. 548; Cropper et al., 2009, p. 3). However, research on the coordination of strategic alliances and networks is generally scarce and short of operational aspects and contingencies (Park, 1996, p. 820; Nassimbeni, 1998, p. 548). While IORs are a growing research interest in management accounting, Meira et al. note that these studies have "concentrated on the general issues that cut across the various types of inter-firm relationships" (Meira et al., 2010, p. 154). It has been remarked that the heterogeneity of IORs creates unique conditions which need to be investigated separately (Dekker, 2004, p. 29). However, common features of contract manufacturing, such as "parallel production" (Nordigården et al., 2014, p. 974), have been largely neglected in research on the control of CMRs so far.

In outsourcing, the literature on production and operations management focuses on the antecedents and performance implications of outsourcing, while relationship management is mainly viewed as a mediator of performance (Tsay et al., 2018, p. 1186). Consequently, supplier relationship management follows this direction focusing solely on specific aspects or performance dimensions (Park et al., 2010, p. 496).

Hence, there are no conclusive results on the management of CMRs, as methodological approaches do not consider the specific aspects of CMRs, and dedicated research on contract manufacturing focuses on decisions before contracting (Busi and McIvor, 2008, p. 193). Especially the connection between strategic and operational activities in managing CMRs requires further research (Busi and McIvor, 2008, p. 191).

2.1 Relevance of management of CMRs

Contract manufacturing has experienced remarkable growth across industries over the past decades and is expected to continue (Busi and McIvor, 2008, p. 186; Handley and Gray, 2013, p. 1540). Recently Kaiser and Obermaier (2020) observed that outsourcing in German manufacturing companies continues despite mixed performance results. The commitment can be attributed to the development of contract manufacturing as a dynamic business model that offers manufacturing companies specialized services that exceed the traditional motivation of cost reduction (Tsay, et al., 2018, p. 1177). In addition, high complexity in technologies, processes, and capital are recognized as

drivers for outsourcing manufacturing, supporting the ongoing growth of contract manufacturing (544; Wüthrich and Philipp, 2001, p. 421).

The emergence of "strategic contract manufacturing relationships" (Tsay et al., 2018, p. 1178) indicates that CMRs exceed the management requirements of classic buyer-supplier relationships (BSRs) due to their strategic implications. CMRs are entered into upon various objectives that require long-term collaboration and dependency (Nassimbeni, 1998, p. 545). These objectives include cost savings, reduced capital lockup, flexibility, speed to market, access to technical expertise, and the ability for brand-leading companies to focus on their core competencies (Handley and Gray, 2013, p. 1540). Meanwhile, CMOs are integrating forward to offer clients an entire portfolio of services as a strategic partner, increasing the dependency between them (Tsay et al., 2018, pp. 1177–1178). As a result, contract manufacturing is already regarded as a competitive factor in specific industries, such as the pharmaceutical industry (Zhang et al., 2013, p. 1094). The management of CMRs can therefore be directly linked to corporate success: While on the one hand, appropriate management for CMRs leads to competitive advantages, studies show that inadequate management negatively affects company performance (Dekker, 2004, p. 28; Pernot and Roodhooft, 2014, p. 158).

2.2 Challenges in the management of CMRs

High failure rates of contract manufacturing arrangements indicate that their management is challenging (Kinkel, 2014, p. 64). Five types of challenges in managing CMRs are presented below to accentuate the topic's relevance to practitioners.

Inter-organizational Interfaces

Medium- to long-term improvement of operational metrics through management practices, such as business improvement, knowledge management, performance management, and change management, is not easily achieved in an inter-organizational context (Busi and McIvor, 2008, p. 193). Therefore, Handley and Gray (2013) have already advocated an "inter-organizational quality management" approach to outsourced manufacturing. However, entering into CMRs means that operational interfaces are overshadowed by intangible complexity drivers that must be reconciled to ensure a

stable relationship (Lamminmaki, 2008, p. 163). These interdependencies are rooted in social dynamics, organizational culture, and work ethics and interact with operations management in often opaque ways (Nassimbeni, 1998, p. 545; Zhang et al., 2013, p. 1082). Consequently, it has been described that the traditional "structure follows strategy" sequence is reversed in CMRs (van den Bogaard and Speklé, 2003, p. 92).

Knowledge Interconnection

Knowledge interconnection is seen as a decisive factor in long-term business relationships' success (Mandjak et al., 2021, p. 13). In CMRs, knowledge management extends to different types of knowledge, such as market, process, and material expertise, encompassing various layers of management, which operate according to different guiding patterns and objectives (Mandjak et al., 2021, p. 13). Revilla and Villena (2012) show that poor alignment of knowledge management across management layers results in unwanted performance results. However, practical knowledge management in CMRs must enable knowledge interconnection and counter appropriation concerns (Dekker, 2004, p. 28). Against the background of sharing sensitive product and manufacturing data, appropriation due to "coopetition" by CMOs, plays a crucial role in managing CMRs (Tsay et al., 2018, p. 1178). Coopetition describes a phenomenon in which there is simultaneously cooperation and competition between companies and is particularly prevalent in high-tech industries where contract manufacturing is also common practice (Chen, Wang, and Xia, 2019, p. 1447).

Trust

Another example of the complex intertwining between operational and strategic management layers is found in trust. In order to act flexibly in dynamic markets, it is necessary to strike a balance between formal control and trusting cooperation (Malmi and Brown, 2008, p. 296). However, studies have shown that inter-organizational trust is closely linked to interpersonal trust and cannot be easily standardized (Varoutsa and Scapens, 2018, p. 135). Pernot and Roodhooft (2014) show that staffing key positions in CMRs based on interpersonal trust has a critical impact on relationship performance. Consequently, communication about all issues is essential in managing CMRs (Wiengarten, Pagell, and Fyness, 2013, p. 640).

Heterogeneity

Contract manufacturing is not a concept with fixed parameters but moves on a scale between in-house and third-party manufacturing and encompasses various administrative forms (Nordigården et al., 2014, p. 994). Consequently, due to the high heterogeneity of CMRs, literature and practice focus on single aspects of relationship management, such as control (Kang et al., 2014, p. 179), knowledge management (Mandjak et al., 2021, p. 13), or quality management (Handley and Gray, 2013, pp. 1540–1541). However, Handley and Gray (2015) demonstrated that high heterogeneity of CMRs leads to little routine and more unsatisfactory quality compliance due to increased complexity across products.

Dynamics

Furthermore, the challenges cannot be viewed in a static light. As relationship characteristics change over time, the management of CMRs must also adapt its communication, coordination, and control measures (Mandjak et al., 2021, p. 5). Pernot and Roodhoft (2014) illustrated the effects of dynamic relationship development and the inadequate response of relationship management. Their study shows the impact of dynamics on managing CMRs and how a thorough understanding of the relationship variables is necessary for problem-solving. Therefore, a key challenge in managing CMRs is to align the management approach to the dynamics of the relationship variables and their interdependencies.

3 Methodology

The research design and data collection and analysis of the study are described below.

3.1 Research design

The research motivation is grounded in the assumption that the management of CMRs comprises dedicated challenges, which require a different approach to relationship management than in the case of BSRs and product-unrelated service outsourcing

relationships (SORs). Therefore, the unit of analysis is the management of CMRs within a dyad from the perspective of the outsourcing company.

Based on the premise that new forms are constantly evolving in practice, primary and secondary sources are used to answer the research questions (Busi and McIvor, 2008, p. 186;). A design science research approach was adopted to structure the research process and ensure the rigor and relevance of the exploratory research framework (Hevner, 2007, p. 3). The first distinctive features of CMRs were derived through literature research on IORs following the approach by Arksey and O'Malley (2005). Their scoping method aims to rapidly map an unexplored research area for fundamental concepts and relevant studies. It can be accompanied by parallel empirical validation. In line with their approach, these findings served as a knowledge base for empirical proof, which was conducted through a multiple case study design according to Yin (2018). Because CMRs are built on multilayered and complex relationships, only a small sample can be thoroughly analyzed. Therefore, an inductive qualitative case study approach is chosen (Eisenhardt, 1989, p. 533). The high dynamics and contingency, which require a deep understanding of CMRs, support a case study approach (Ketokivi and Choi, 2014, p. 236). The study can be characterized as a "theory generation" study based on Corbin and Strauss' (1990) grounded theory.

3.2 Data collection and analysis

For the empirical data collection, cases from different industries were collected in line with the objectives for case selection by Seawright and Gerring (2008) (see table 1). The pharmaceutical sector was chosen due to the high relevance of contract manufacturing and its industry-specific aspects, which indicate the occurrence of CMRs (Wüthrich and Philipp, 2001, p. 421; Zhang et al., 2013, p. 1081). In line with the study's exploratory nature, the pharmaceutical industry was considered the "polar case" for, particularly complex CMRs. Thus, a particular industry bias was tolerated in the sample selection to detect distinctive features of management of CMRs empirically. Two additional industries were included in the sample to reduce overweight. Consumer electronics and the food industry were selected due to their respective high and low maturity on contract manufacturing (Handley and Gray, 2015, p. 1024; Tsay et al., 2018, p. 1177).

Table 1 : Case Overview

ID	Industry	No. of Interviews	Interview Partners	Relationship Level
1	Pharmaceutical industry	3	Director Strategic Partnerships	Management
			Head Supply Chain Planning & Execution	Management
			Head Product Supply	Operations
			Product Supply Team	Operations
2	Food Industry	1	Head Contract Manufacturing	Management
3	Consumer Electronics	1	Logistics Management Specialist	Operations

The interviews were conducted with outsourcing companies for which external manufacturing by CMOs accounts for a significant share of value creation. In addition, to consider both operational and strategic perspectives, interviewees from the corresponding management levels were consulted.

The interviews followed a semi-structured approach according to the study's explorative design (Yin, 2018). The intention was first to understand the company's case. Then, based on the answers of the interview partners, individual findings from the literature research were raised and discussed. The questionnaire was sent to the interviewees in advance, but the literature search results were not released to not bias the participants. The duration of the interviews varied from 30 to 60 minutes. The interviews were recorded and later transcribed.

Analysis of the data was conducted through data triangulation. The first-order analysis was based on the individual cases, and the second-order analysis included a cross-case

analysis. It was then integrated with the literature review results following the approach by Gioia et al. (2013).

4 Results

The following section presents the findings from the literature review, which are then evaluated through case studies. Subsequently, the results are incorporated into an exploratory research framework.

4.1 Findings from literature

In the absence of studies that directly addressed the research question, the scoping study took two approaches: Firstly, typologies and taxonomies in IORs were examined to identify potential distinctive features. Secondly, studies related to supplier control in outsourcing were reviewed to determine specific challenges from which distinctive features could be derived. Relevant studies were identified by consulting electronic databases (Google Scholar, Science Direct, Emerald) and reference lists. Seven relevant studies of the first type and 118 of the second type were found. Through analysis of these studies, seven distinctive features of management of CMRs could be identified (see table 2). While four distinguishing characteristics could be derived from the classification of CMRs into existing typologies, three additional features were selected through studies of management challenges. These features impact the management of CMRs and place particular demands on companies when managing their CMOs. Moreover, the comparison with BSRs and SORs shows that these features are critical in managing CMRs.

Table 2: Distinctive features of CMRs in literature

ID	Feature	CMR	BSR	SOR
1	Asset specificity	High	Low	Medium
2	Share of value added	High	Low	Low

ID	Feature	CMR	BSR	SOR
3	Appropriation concerns	High	Low	Low
4	Disintegration orientation	Vertical / Horizontal	Vertical	None
5	Service delimitation	Complex	Simple	Simple
6	Operational interdependency	Coordinated / Collaborative division of labor	Exchange of information and results	Coordinated division of labor
7	Contract form	Framework agreements / Capital investments	Purchase / Framework agreements	Framework Agreements

Asset specificity

Asset specificity is high by default in CMRs because the CMO produces the goods in question for one client only. Physical assets and the manufacturing process may be new to either partner and require detailed knowledge interconnection and control for the setup and afterward (van den Bogaard and Speklé, 2003, p. 92). In BSRs and SORs, product or service asset specificity is much less distinct, making the assets used in the relationship easier to replace or transfer (Park, 1996, p. 801).

Share of value-added

Since quality risk is higher with externally supplied products, the concerned share of value-added relates to the required control intensity of the relationship (Handley and Gray, 2013, pp. 1540; Tsay et al., 2018, p. 1177). In retail BSRs, the value proposition lies in the product availability, and quality problems can be passed onto the brand-leading

manufacturer, giving it a greater interest in optimal product quality (Schuckel and Toporowski, 2007, p. 25).

Appropriation concerns

Appropriation concerns are especially relevant in CMRs due to the depth of knowledge interconnection over an extended amount of time (Dekker, 2004, p. 29). In BSRs and SORs, detailed knowledge on products is rarely shared, and incentives for opportunism are low. Prevalent appropriation concerns demand high control intensity and deliberate information sharing practices (Gerybadze, 2003, p. 452). Coopetition in CMRs puts additional matter on protecting intellectual property since incentives for opportunism are high (Tsay et al., 2018, p. 1178).

Disintegration orientation

While supply chain disintegration is strictly vertical in BSRs and SORs, horizontal disintegration is common in CMRs (Nordigården et al., 2014, p. 974). The diversity of disintegration forms leads to a high degree of heterogeneity among CMRs, affecting coordination efforts and hindering management standards and routines (Handley and Gray, 2015, p. 1034).

Delimitation of the service

As CMRs are turning more strategic, the delimitation of the service a CMO offers becomes more difficult compared to isolated value propositions in BSRs and SORs (Gerybadze, 2003, p. 452). While operational control mechanisms lose their effectiveness in a strategic setting, knowledge interconnection, trust, and informal control become decisive for performance management (Nassimbeni, 1998, p. 548; 158; Pernot and Roodhooft, 2014, p. 168).

Operational interdependence

An increasing economic value of the cooperation and strategic relationship objectives lead to strong interdependence in CMRs (Zhang et al., 2013, p. 1082). Hence, the relationship extends across several management layers, whose involvement must be coordinated (Nassimbeni, 1998, p. 540; Zentes, J.: Swoboda, B., Morschett, 2003, p. 21).

Since relationship activities in BSRs and SORs are primarily standardized, relationship intensity is significantly lower in these cases.

Contract form

Joint capital investment in facilities and development is typical for CMRs, unlike BSRs and SORs, and increases the relationship's commitment intensity and switching barriers (Morschett, 2003, p. 394). Therefore, financial interdependence needs to be considered in performance management to incentivize value-preserving use of dedicated equipment.

4.2 Empirical findings

The analysis of the case studies revealed nine management features that practitioners from different industries and management layers consider distinctive of CMR management which are displayed in figure 1. Among the nine characteristics stated, three extend the features already identified by the literature review, while the others can be attributed to them, thus validating them.

Product Ownership

Unlike in BSRs, the buyer in CMRs is the product owner. Therefore, product management and production management are dispersed between the contractual partners and coordinated along the product life cycle. Product ownership affects communication and planning of market and product launches, pricing strategies, quality, and knowledge management. Knowledge management can be especially crucial in the case of coopetition when the CMR also comprises competitive aspects. Additionally, performance management is affected since it is necessary to incentivize CMOs to actively support product development and improvement.

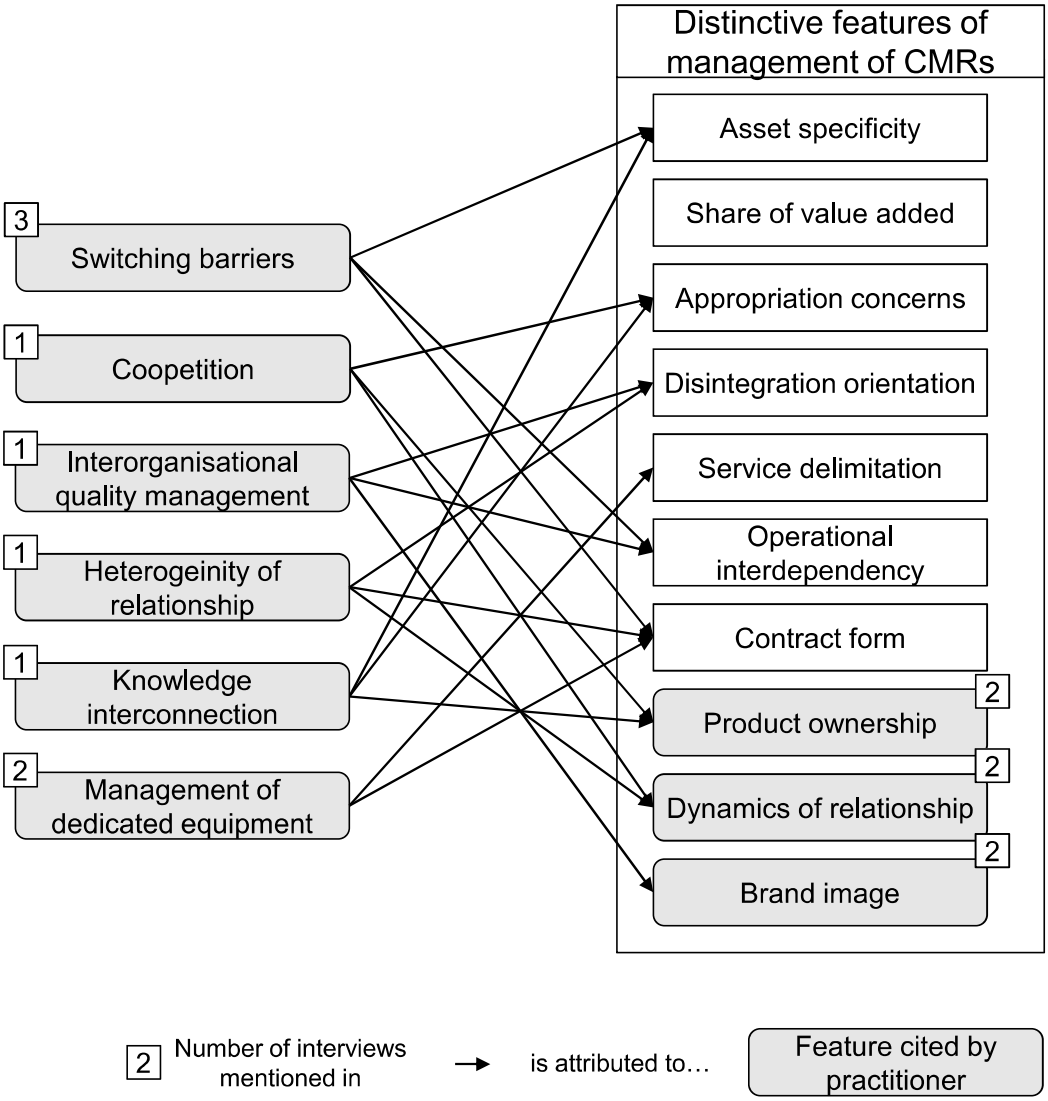


Figure 1: Empirical findings and validation of identified features

Relationship dynamics

Relationship dynamics have already been identified as management challenges in IORs in the literature, but the empirical findings have highlighted their particular intensity in CMRs. Due to the strategic nature of CMRs and the highly intertwined activities within the relationship, CMRs are particularly sensitive to dynamics. For example, sales dynamics are countered in CMRs by alternating contract forms and time-limited production

campaigns with varying relationship intensity. Changes in product and process maturity, routine and relational trust influence formality and control intensity in CMRs significantly. Finally, coopetition causes a particular dynamic, as competitive factors can fluctuate strongly even in the short term due to the activities of the contractual partner (new product launches, forward integration, partner portfolio). Relationship dynamics are a crucial challenge in CMRs as they require continuous adjustment of management activities across all management layers.

Brand image

Another distinctive feature to consider is the brand image, as brand-leading companies are held responsible by their customers for failures of the CMO. In addition, it can be observed that product-independent misconduct on the part of the CMO also impacts the company, as the consumer expects them to ensure compliance with ethical and ecological standards. Concerning the management of CMRs, this has a considerable impact on the necessary basis of trust, strategic fit, and inter-organizational quality management in the relationship.

Validation of findings from the literature

Practitioners cited barriers to switching as the most common differentiating characteristic of CMRs. The reasons given by the companies were joint investments, complex unbundling, and dependence on specific resources of the CMO, which are represented through asset specificity, operational interdependency, and the contract form. The management of dedicated equipment was separately named and can be attributed partially to service delimitation and the contract form.

Coopetition was particularly significant in the food industry, as there are virtually no pure CMOs, but brand-leading companies cooperate for resource and capacity reasons. Coopetition underpins both appropriation concerns and relationship dynamics in CMRs. The same applies to the need for inter-organizational quality management, which arises in CMRs because customers must not recognize any differences in quality regardless of the manufacturer. Systematic knowledge exchange is another differentiation factor covered by asset specificity, product ownership, and appropriation concerns. Ultimately, the heterogeneity of CMRs, which are all unique from a management perspective, was

argued. This point is taken up by the disintegration orientation, the contract form, and relationship dynamics. However, the empirical results could neither confirm nor disconfirm the value-added share as a distinctive feature of the management of CMRs.

4.3 Explorative framework

The identified features show that there are particular challenges in the management of CMRs. While some of the distinctive features are well established in relationship management, they require special consideration in the management of CMRs. Other features such as product ownership, investment-based contract forms, and relationship dynamics have not received sufficient attention.

Following the depiction of supply chain processes by Croxton et al. (2001), it can be concluded that the management of CMRs involves strategic and operational activities that exceed the scope of traditional supplier relationship management.

Cornerstones of management of CMRs

Consequently, a dedicated management approach has to be devised, which considers the particular challenges of CMRs. For this purpose, knowledge, risk, lifecycle, quality, contract, performance, asset, project and communications management, and sales & operations planning can be understood as essential cornerstones, as shown in figure 2.

Coordinating these cornerstones holistically is complex and poses significant challenges to companies due to the variability of the relevant features. In addition, each dyad is highly individual, and changes in planned and unplanned ways, causing high contingency. A dedicated management approach for CMRs must therefore consider contingency and dynamics as structural cornerstones.

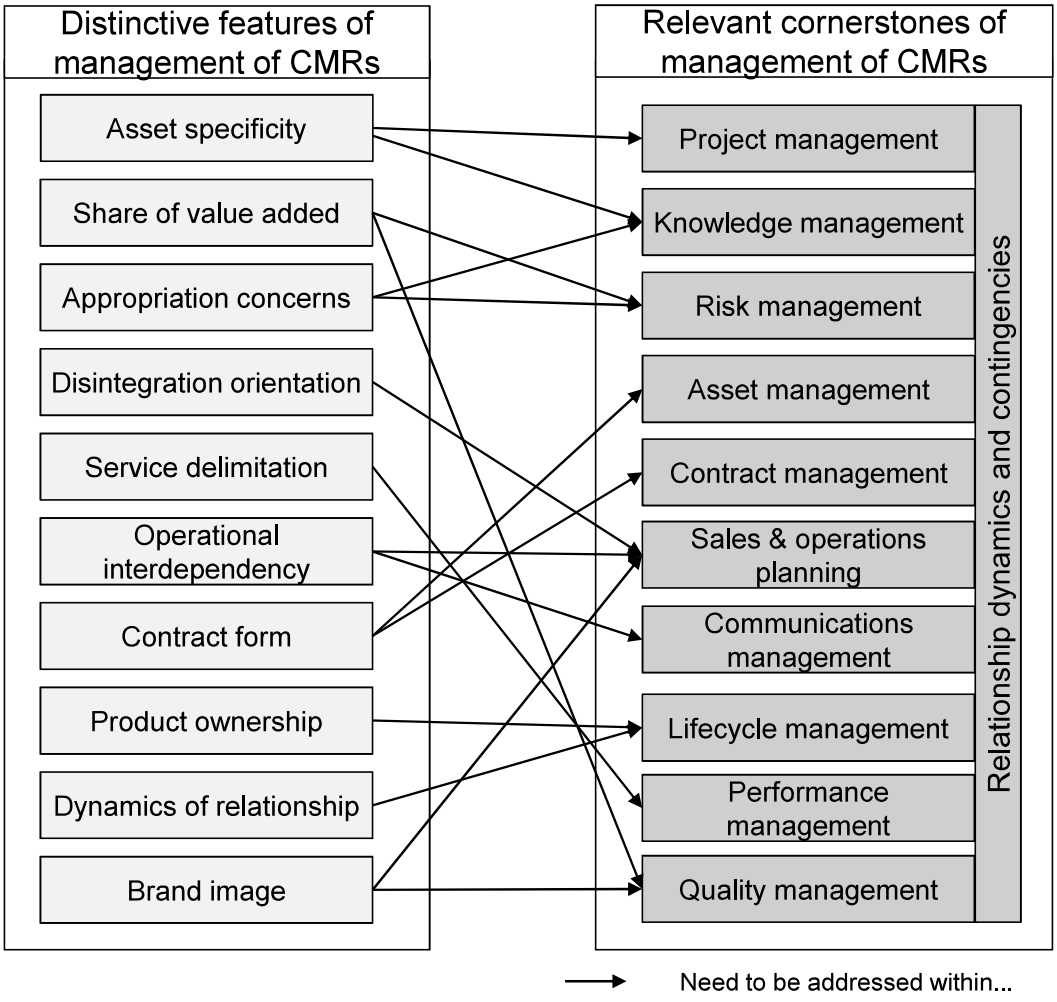


Figure 2: Distinctive features and cornerstones of management of CMRs

Although Dekker (2004) and Nordigården (2014) emphasize the almost infinite number of forms of collaboration in practice and that each of these places individual demands on management, it does not follow that there must be an endless number of according management approaches. By systematically identifying and analyzing the distinctive features of CMRs, "management archetypes" can be discovered, i.e., forms of CMRs whose management follows a similar pattern. It is expected that some of these archetypes will be geared toward the management of BSRs and SORs under traditional supplier relationship management. Also, the management approach needs to be adaptive to change over time along with the dynamic changes of the relationship,

possibly switching between different archetypes of management of CMRs (Meira et al., 2010, p. 158).

Theoretical Grounding

Since research on the management of CMRs is viewed as an exploratory research topic, looking at it through an established theoretical lens can help situate it in the research landscape. In supply chain management and outsourcing, transaction cost economics is the most commonly used theory (Busi and McIvor, 2008, p. 187). However, the explanatory power of transaction cost economics for value creation partnerships with intertwined ownership structures is viewed critically in the literature (Dekker, 2004, p. 30). Similarly, other standard theoretical lenses such as the resource-based view and principal-agent theory can be challenged because they might overemphasize certain aspects of relationship management at the expense of a holistic management perspective (Miles and Snow, 2007, p. 460; Busi and McIvor, 2008, p. 187).

In the context of increasing strategic integration of CMRs, Dyer & Singh's relational view (1998) may provide a valuable contribution to understanding the management of CMRs. They argue that competitive advantages can be generated from inter-firm resources and identify four potential levers: relationship-specific assets, knowledge-sharing routines, complementary resources/capabilities, and effective governance (Dyer and Singh, 1998, 663). The relational view explains how the success of a business relationship can be achieved by considering specific relational sub-processes that relate to the identified cornerstones. Due to CMR management's high heterogeneity, the contingency theory approach seems suitable as well (Drazin and van den Ven, 1985, 514). Likewise, consideration of relationship dynamics has emerged as a dominant background issue in the management of CMRs and should be integrated into theoretical considerations. Looking at CMRs as systems, an insightful approach from the engineering sciences could be the theory of complex adaptive systems, which assumes open systems with weak ties, continuous dynamic micro-changes, and decentralized actors (Friedli, 2005, p. 104).

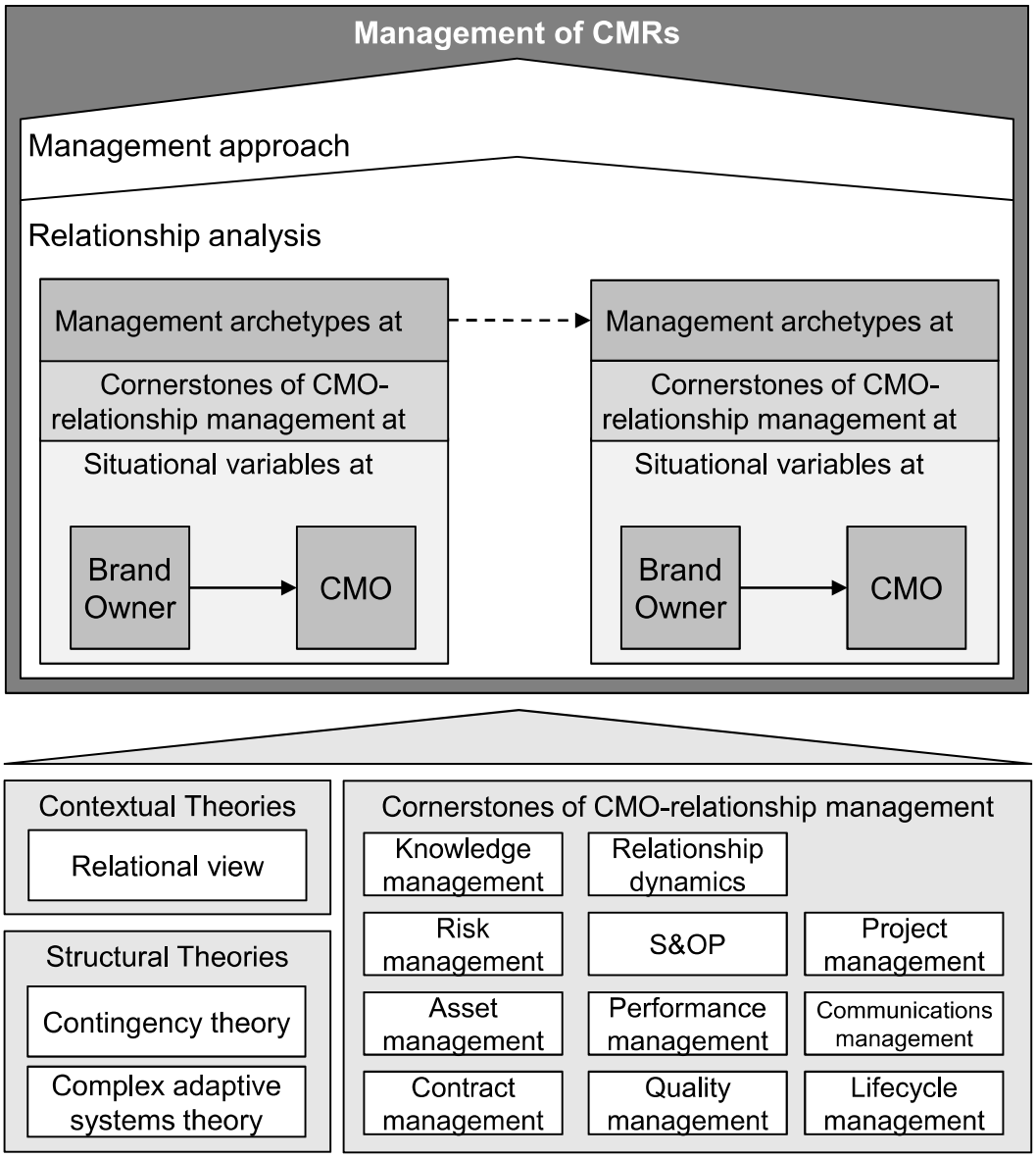


Figure 3: Exploratory research framework for the management of CMRs

The use of theoretical frameworks in outsourcing operations is considered an underexplored field as it is, and the combination of theories through an eclectic approach has already been suggested (Busi and McIvor, 2008, p. 192). The combined choice of relational view, contingency theory, and complex adaptive systems theory as context and structure theories is proposed, as they integrate approaches whose explanatory power is complementary (Friedli, 2005, p. 113).

As seen in figure 3, the developed research framework includes the derived cornerstones to translate the identified distinctive features of CMRs to their management task. The strong relevance of contingency and relational dynamics poses a challenge for research that could be addressed by management archetypes either in the development of management profiles or management approaches. Along the trajectory of a dynamic CMR, these archetypes must either be dynamic themselves or enable dynamic transitions. A theoretical foundation should structure further research in pursuit of a holistic, dedicated management approach for CMRs. Since the fit of the most used theories of the research field is debatable, the relational view is proposed for content structuring, complex adaptive systems theory is proposed for temporal structuring, and contingency theory is proposed for linking them together. The proposed exploratory research framework aims to capture the most relevant issues and challenges in managing CMRs and provide guidance to researchers to contribute to supply chain management and contract manufacturing management in both theory and practice.

5 Conclusion

This paper started from the assumption that, beyond the visual complexity, the management of CMRs is fundamentally different from the management of other business relationships and, therefore, needs a dedicated management approach. In the beginning, an overview of the theoretical and practical relevance of this issue was given. Subsequently, distinctive features of management of CMRs were identified through an exploratory literature review and case studies. Finally, fundamental cornerstones of the management of CMRs were derived and integrated into an exploratory research framework. In this way, the paper contributes to a deeper understanding of the management of CMRs, points out research gaps, and elaborates approaches for further research.

The study results should be subjected to further validation against the literature on the management of IORs and practice to address the limitation of the study design. The exploratory approach was chosen to map relevant research fields and include unstructured information from primary and secondary sources. While the semi-

structured approach to reviewing the literature helps identify relevant research fields and terms, it does not allow for in-depth analysis, limiting the rigor of the results and transparency of the research process. Exploratory literature analysis can be used in the research process as a preliminary step to systematic literature analysis, which is also recommended concerning the results of this study. Further research opportunities exist, for example, in a targeted classification of CMRs in IOR typologies and taxonomies, taxonomies on types of CMRs, and the analysis of management challenges in CMRs without the pretense of differentiation from other types of IORs.

Despite the early research stage, complementary empirical validation was chosen in line with the exploratory literature review to cover the method's weakness regarding the relevance and rigor of the results. Therefore, only a tiny sample with limited representativeness could be drawn compared to stand-alone studies. Broader empirical studies could reduce industry bias and increase projectability through a widened observed sample and specification and analysis of the settings of the CMRs. Further empirical research could focus on the management process and tasks in CMRs compared to other IORs, ideally within specific industries or even organizations, to detect differences in management approaches.

Conceptual research has the opportunity to deepen the understanding of CMRs by developing a holistic understanding of CMR management, exploring internal coordination and the role of cornerstones, or examining the theoretical foundations of CMR management.

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Scheduling Mobile Robots in Part Feeding Systems

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Purpose: *Industry 4.0 has increased the availability of real-time data in manufacturing systems, but scientific evidence about the value stemming from such data is still lacking in several fields. This paper studies data-driven approaches for the assignment of tasks to a fleet of mobile robots transporting parts to the stations of a mixed model assembly line. The approaches exploit real-time data concerning the robots and assembly stations state.*

Methodology: *An agent-based simulation model of the system, including factory warehouses, assembly stations, and robots, is developed and validated through a real case in the automotive industry.*

Findings: *The paper proposes a model that measures the part feeding system performance in terms of transportation tasks completion time, idle time of the assembly stations due to lack of materials, and amount of inventories at the assembly line. Different data-driven approaches are considered, differing among each other for the type of real-time data used and for the update frequency of the task assignment.*

Originality: *The developed model enriches the ones presented in previous literature by including new information (e.g., robots failures) and new data-driven approaches, such as the dynamic assignment of tasks to robots.*

First received: 23. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The transition towards Industry 4.0 is deeply changing production and logistics systems, relying on new paradigms such as Internet of Things (IoT) and Cyber Physical Systems (CPS). Factories are turning into networks of smart objects, equipped with sensing technologies and processing units, coupled with communication technologies, with the ability of real-time information perception, transmission, and processing (Qu, et al., 2017). More and more often, such real-time information is being fed to decision support systems, replacing stochastic data and enhancing the responsiveness of decisions. Some application fields have been extensively investigated in the scientific literature, spanning from real-time machine diagnosis for maintenance purposes (O'Donovan, et al. 2015) to production planning and control, driven by real-time information about the status of processes, equipment, and materials, combined with frequently updated customer requirements (Zhang et al. 2017; Müller, et al. 2018). However, the increasing adoption of new technologies makes a large amount of real-time data available also for supporting other decisions, still understudied in the extant literature, for which there is still a lack of scientific evidence about the value stemming from the use of real-time information. It is the case of the task assignment to logistics resources replenishing production stations with materials. In the current business scenario, this problem is becoming more and more complex given the increasing demand volatility and product personalization request coming from the market, which is leading to growing product variety and smaller batch dimensions, often managed with the adoption of mixed-model assembly lines (Faccio, 2014). Factory logistics resources are required to feed assembly stations with small quantities of a wide range of materials, delivered in time for the start of production operations but without piling up too much stock on the shop floor (Schmid and Limère, 2019). The exploitation of real-time data could be an effective way to manage this complexity, by dynamically scheduling logistics resources so as to accommodate the evolving requirements of customers and manufacturing systems, always knowing when, where, and in what way to deliver materials (Hofmann and Rüsch 2017; Tao and Qi, 2019). In literature, most contributions present offline scheduling methods, which generate schedules based on offline data like average part consumptions and layout distances (e.g., Choi and Lee, 2002; Rahman et al., 2020). Only few studies propose online

scheduling methods of tugger trains (Zhou and Xu, 2017) and mobile robots (Kousi et al., 2019), exploiting real-time data gathered on the shop floor. However, these studies do not present any tools to estimate the performance improvement resulting from the use of real-time data, compared with offline scheduling.

This paper presents a simulation-based tool for assessing the performance of different scheduling methods of the material handling equipment transporting materials to a mixed model assembly line. Following Kousi, et al. (2019), the problem of assigning replenishment tasks to a fleet of autonomous mobile robots (AMRs) is considered. AMRs are emerging as an alternative to traditional automated guided vehicles (AGVs). AGVs are extensively used in factories also for part feeding at mixed model assembly lines (Boysen, et al. 2015), but require great effort in coordination, lack flexibility, and often ask for human intervention for loading and unloading parts (Kousi, et al. 2019). Compared to AGVs, AMRs do not require expensive investments in navigation infrastructures, since they navigate thanks to simultaneous localization and mapping algorithms (Köseoğlu, Çelik and Pektaş, 2017). Moreover, they are becoming more and more collaborative with loading/unloading capabilities and have better built-in sensing and communication capabilities than AGVs (Liaqat et al. 2019), thus representing a more suitable technology when dealing with the use of real-time data.

The presented simulation tool allows assessing the value stemming from the use of real-time data in the task assignment to a fleet of AMRs, by comparing the performance of offline and online scheduling methods. Real-time data which might be exploited in the scheduling concerns both the AMRs and the assembly stations. The considered performance measures include task completion times, idle times at the production stations due to the lack of materials, and stock levels near the stations.

The remainder of the paper is organized as follows. Section 2 reports a literature review on the use of real-time data in factory logistics and on the scheduling methods of material handling vehicles. Section 3 describes the considered factory logistics system and scheduling methods, while Section 4 presents the simulation model and Section 5 reports its validation through a real case in the automotive industry. Finally, Section 6 includes conclusions and directions for further research.

2 Related literature

This section reports a literature review on the use of real-time data to support decisions in factory logistics systems (Section 2.1) and on the scheduling methods of material handling vehicles adopted in factories and warehouses (Section 2.2).

2.1 Real-time Data in Factory Logistics Systems

The extant literature encompasses a few studies which highlight the aims and potential benefits related to the use of real-time data within decision support systems in factory logistics. Most of these studies adopt qualitative methodologies, based on literature reviews (e.g., Zhang, Zhu and Lv, 2018) and case studies (e.g., Müller, et al. 2018), while only very few contributions present quantitative analyses (e.g., Zhou and Xu, 2017).

Two main purposes of the use of real-time data emerge from the extant literature, namely routing of material handling vehicles (e.g., Zhang, Zhu and Lv, 2018) and task assignment to logistics resources (e.g., Yan, Zhang and Fu, 2019). Different types of real-time data are considered in literature, gathered through different types of connected entities, intended as smart objects equipped with sensing and communication technologies. Three main categories of connected entities are found:

- the moved materials: raw materials, components, work-in-process, and/or finished goods (e.g., Mörth, et al., 2020). The real-time data they gather includes position, quantity, and consumption;
- the material handling equipment (e.g., Thoben, et al., 2017; Zhang, Zhu and Lv, 2018). The gathered real-time data includes the material handling equipment position, battery level, assigned tasks, speed, acceleration, blockages, and operating conditions;
- the destination or consumption points, i.e., warehouses and production stations (e.g., Zhou and Xu, 2017; Kousi, et al., 2019). The gathered real-time data includes inventory levels for each item, queues, cycle times, and stoppages.

The reviewed contributions also list the benefits which could be gained from the use of real-time data. These include: lower inventory levels (e.g., Zhang, et al., 2015), reduced travel time of logistics resources (e.g., Thoben, et al., 2017), reduced assembly errors, and

lower idle time of production stations (Kousi, et al., 2019). Nonetheless, the studies either provide only qualitative considerations or present quantitative insights concerning a specific case, without providing a tool to generalize their results. For instance, Thoben, et al. (2017) describe the case of a German gear manufacturer; they show that a dynamic routing of tugger trains, based on real-time vehicles positions and assembly stations states, allows reducing the number of replenishment cycles by more than 60% compared to the use of milk run tours with fixed routes.

2.2 Material Handling Equipment Scheduling

A wide body of literature is available on the scheduling of material handling vehicles in warehouses and factories, which represents one of the main operational decisions in material handling systems and also deeply affects the tactical problem of estimating the required number of vehicles (Le-Anh and de Koster, 2006). The scheduling methods can be grouped into two main classes: offline methods, according to which the scheduling is performed before the start of operations, and online methods, according to which tasks are assigned to material handling vehicles during the running of operations, based on data gathered on the shop floor. Most offline scheduling methods deal with the solution of the vehicle routing problem (VRP), which is a generalization of the traveling salesman problem with more than one agent and with limited capacity of the vehicles to which a series of tasks must be assigned. These problems are known to be NP-hard and literature presents a number of heuristics to cope with them (e.g., Laporte, 1992), using deterministic and static information known in advance. The developed schedule is very sensitive to changes in information (Mes, et al. 2007). In addition, the time required for the algorithms to update the schedule may not allow a timely response to unexpected events such as equipment failure or rush orders; therefore, it is not practically feasible to use offline methods in dynamic and stochastic environments (Le-Anh & De Koster, 2006; Li, et al., 2019). Online scheduling methods allow assigning tasks to vehicles based on real-time or nearly real-time information gathered on the shop floor (Li, et al., 2015). Egbelu and Tanchoco (1984) study alternative methods, where the load is assigned to a vehicle based on the optimization of one parameter which might be either the distance between the vehicle and the load, the vehicle idle time, or the vehicle mean utilization.

More recent studies present methods based on the combination of different parameters. For instance, Li, et al. (2019) present a mixed-integer programming model for AGVs scheduling in warehouse sorting operations, where the objective function to be minimized includes a weighted average of the makespan, the number of AGVs in the system, and the amount of electricity used by the AGVs. Shifting the focus to mobile robots, Nielsen, et al. (2017) consider a system where a single robot transports small unit loads from a supermarket to multiple-step feeders of a machine. When the stock level at a feeder reaches a threshold value, a material replenishment request is issued. A genetic algorithm is proposed for the scheduling problem, aiming at minimizing the total robot travel time and the total tardiness of the tasks. Kousi, et al. (2019) consider a fleet of AMRs feeding a mixed-model assembly line and present a service-oriented architecture that orchestrates the material replenishments at assembly stations and collects real-time data from the shop floor. Replenishment requests are issued based on real-time inventory levels, and the scheduling method assigns tasks to the AMRs so as to minimize the weighted average of the overall traveled distance and the tour duration, which are computed using the real-time position of robots and considering a fixed battery charging time for each robot.

3 System Description

This section describes the general layout of the system considered in this study (Section 3.1) and the scheduling process of mobile robots within this system (Section 3.2).

3.1 Main Components and Layout

The investigated system consists of a mixed-model assembly line and a number of supermarkets. The line, made of several assembly stations, can produce different types of finished products, using different types of materials. Each finished product type requires using a known quantity of one or more material types at each station and entails a certain service time. In every production shift, a target production should be achieved within the available time. Materials are handled in small boxes, containing multiple units of one material type each. At each assembly station, at least one box of every material

type used at that station is stored. Moreover, extra stock of each material type is kept at the supermarkets, which are decentralized warehouses located on the shop floor. AMRs are in charge of replenishing assembly stations with materials. Each robot can move up to multiple boxes simultaneously, and a typical robot movement involves the arrival at the supermarket, the load of one or more boxes, the travel to the stations requiring the boxes, and the unloading of the boxes. Robots might incur in failures (e.g., stoppages due to the presence of obstacles that cannot be avoided or mechanical failures) and have a certain level of battery autonomy, which is restored every time the robot is sent to a charging station. For the sake of example, a system with 4 assembly stations, 2 supermarkets, 6 types of materials, 2 robots, and 1 charging station is shown in Figure 1.

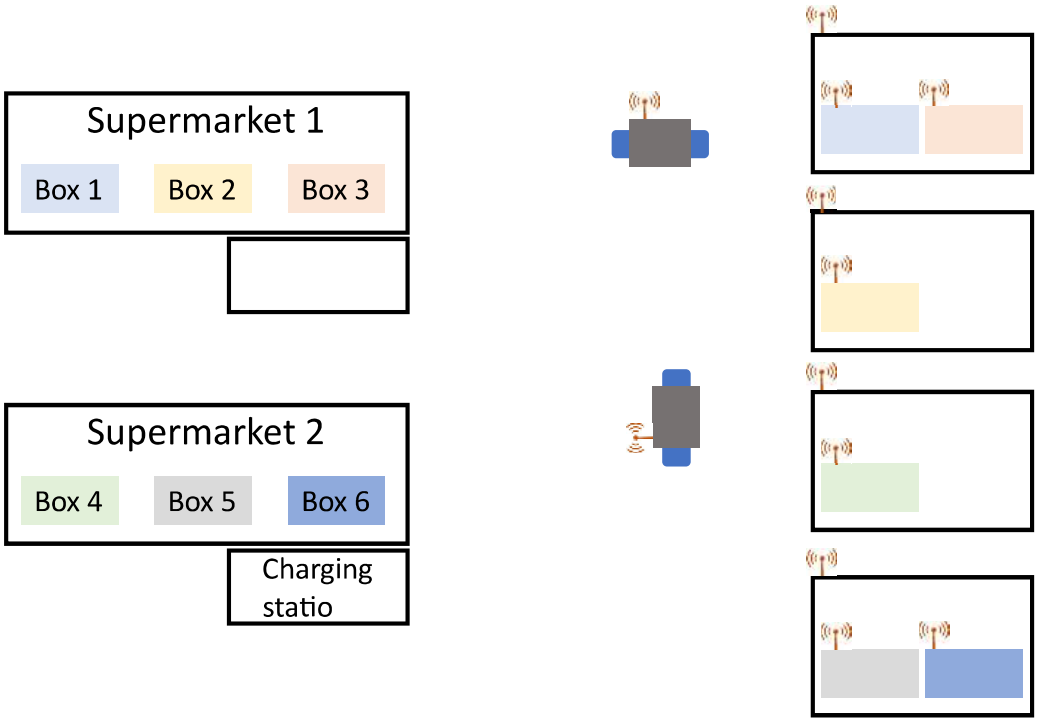


Figure 1: System layout – Example

Each supermarket or station can process one robot at a time. Therefore, robot queues in front of supermarkets and stations are taken into account.

The system also includes a central supervisor node assigning replenishment tasks to AMRs. Depending on the system configuration, the supervisor can also receive real-time data from robots (i.e., position, state, and battery level) and assembly stations (i.e., state and inventory levels inside each box stored at the station), and exploit such data in the scheduling process.

3.2 Scheduling Process

The central supervisor may assign tasks to AMRs according to three different scheduling methods, differing among each other for the task assignment logic, for the use of real-time data, and for the schedule update frequency based on such data. The simplest one, called Offline-First Available (OFF-FA) method, is an offline scheduling method that assigns replenishment tasks to the first available robot, without exploiting real-time data from the system. If all robots are busy, the task is assigned to the robot with the minimum number of already assigned tasks. The replenishment requests are generated according to a periodic review model and events such as station stoppages or robot failures are not taken into account.

The remaining three methods work according to the two-phase task assignment process described in the following. Whenever the inventory level of a material at an assembly station reaches a pre-defined threshold level, a replenishment request for a box of that material is issued and the task allocation procedure is initiated. The replenishment request is split into a pick-up and a drop-off task, executed by the same robot. Since each robot can be in charge of more than one replenishment request at a given time, a multi-load task assignment method is implemented. The aim is to assign tasks to robots in order to minimize the total execution time of the schedule and avoid idle times of the assembly stations due to lack of materials. More in detail, the scheduling process can be divided into two main phases (Figure 2).

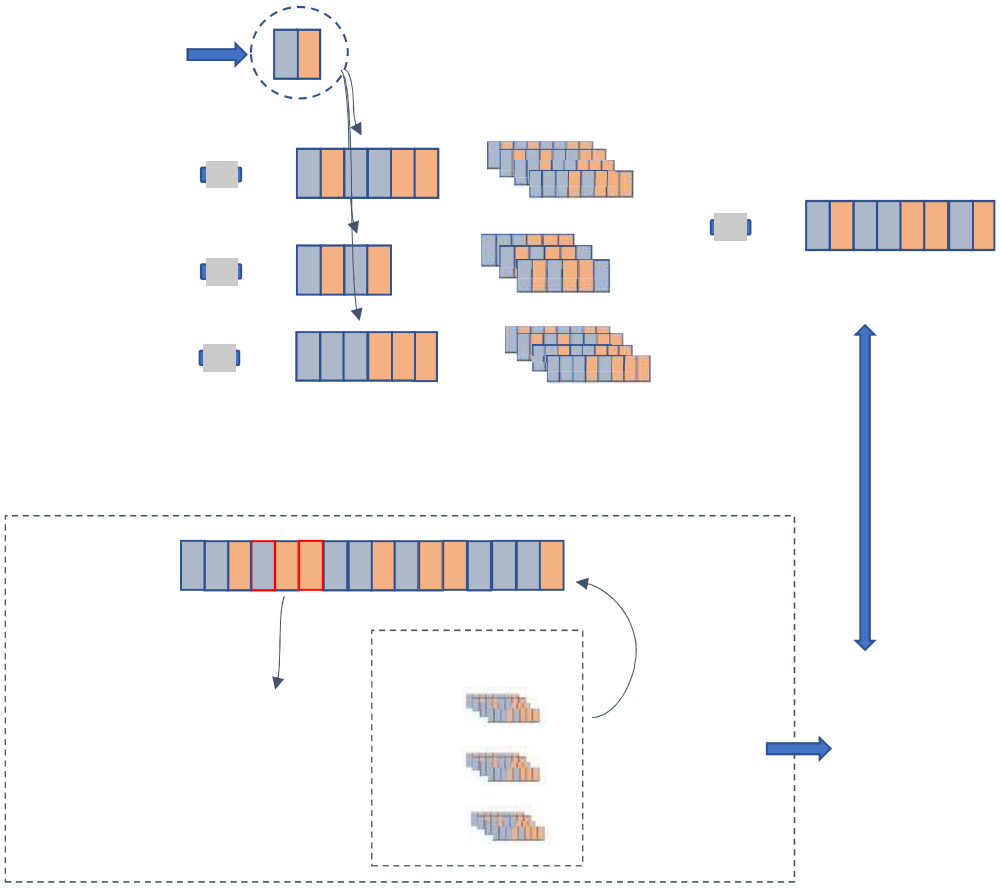


Figure 2: Scheduling process

In the Combinatorial phase, whenever new pick-up and drop-off tasks must be assigned, the method compares all possible tasks permutations for each robot. Permutations represent sequences of tasks created starting from the current schedule of each robot and adding the new tasks. Only feasible permutations are considered, i.e., sequences where pick-up locations (i.e., supermarkets) are visited before the corresponding drop-off locations (i.e., assembly stations). Moreover, permutations which imply the loading of more boxes than the actual capacity of the robot are excluded. The permutations are compared based on the total schedule time, an indicator corresponding to the time needed to complete the entire sequence of tasks, increased by a penalty every time a station is expected to be idle due to lack of materials. To compute such an indicator, the

finishing time of each replenishment request must be estimated and compared with the estimated time at which the station reaches the idle time. Thanks to the possibility to exploit real-time data, in online scheduling methods the finishing times of the requests are estimated based on the actual robots positions and states. Moreover, the time of station blockage is estimated starting from the actual inventory level. Besides pick-up and drop-off tasks, also battery charging times are included when computing the total schedule time. An opportunity charging strategy is adopted (Le-Anh & De Koster, 2006): a robot is charged either when it is idle and its battery level is below a certain threshold (e.g., 60%), or when it reaches a critical battery level (e.g., 20%). In the online methods, the time of charging end can be estimated with the real-time battery level and queues at the charging station, thus allowing to assign tasks to the robots while they are charging. At the end of the Combinatorial step, the permutation leading to the lowest total schedule time is identified and the task is assigned to the corresponding robot. In the ensuing Monte Carlo-based phase, reallocations of tasks among different AMRs are evaluated. In fact, given the stochasticity of events (e.g., robot failures and machine stoppages), a task previously assigned to a robot could provide a lower total schedule time if assigned to another robot. Therefore, a Monte Carlo simulation-based procedure consisting of multiple runs is followed. In each run, a couple of pick-up and drop-off tasks are randomly picked from the pool of all the tasks which have not started yet, and all possible task permutations are evaluated, considering all the AMRs. If this phase provides a better schedule than the previous one, tasks are re-allocated according to it.

The three scheduling methods are called Offline-Two-Phase assignment (OFF-TP), Real-time-Two-Phase assignment (RT-TP), and Real-time-Two-Phase Dynamic assignment (RT-TPD). The OFF-TP is an offline method that feeds the developed two-phase task allocation process with average and static data, like the average travel distances between each couple of elements in the system and the average consumption of each material. Although being an offline scheduling method, the OFF-TP differs from the simpler OFF-FA because it uses a higher amount of data and aims to minimize the total schedule time. The RT-TP is an online scheduling method according to which a new replenishment request for a box at a station is triggered when the actual level of inventory reaches the threshold value set for the corresponding material type. Schedule

times are computed based on actual AMRs positions and battery autonomy, AMRs and stations states, and actual queues. Finally, the RT-TPD is an online method that differs from the RT-TP for the schedule update frequency: the schedule is updated dynamically, based on real-time information continuously gathered on the shop floor. In other words, the two-phase task assignment process is run not only when a new replenishment request is issued, but also at defined time intervals; the shorter the time interval, the more the schedule is reactive to stochastic events.

4 Model Description

This section presents the agent-based simulation model developed to estimate the performance resulting from the use of the task assignment methods described in Section 3.2. Agent-based simulation has been deemed suitable due to the nature of the investigated system, where AMRs, supermarkets, stations, and the central supervisor interact with each other, driving operations planning and execution. In fact, differently from other simulation approaches used in this field such as discrete-event (Yin and Mckay, 2018), agent-based simulation allows representing complex interactions among the actors of a system, accounting for state variables that interrelate with one another and change on a continuous basis (Bonabeau, 2002).

The pivotal elements of an agent-based simulation model are the so-called agents, which attempt to maximize their utility functions by interacting with other agents and resources. Each agent is described by a series of attributes defining its state, which evolves in time as a reaction to external events. In the developed model, the agents are the AMRs, the assembly stations, the supermarkets, the charging stations, and the central supervisor. The other elements in the environment, namely boxes, tasks, and WIPs (i.e., products being assembled at the stations), are represented by data structures, rather than agents, since their relationship with the other entities is simpler and does not require evolution of states.

The model has been developed in Python language, using the Mesa module. In this module, a method called STEP is run at every simulation cycle for each agent and enables the progression of states of the agents. Three types of classes are defined in the

developed model. The Model class ensures that each other agent in the model progresses its state at every simulation cycle, by calling the STEP method for every agent. The Model class also populates the model with instances and supervises the production orders, thus stopping the simulation if the target production has been achieved or the defined maximum number of cycles (i.e., the available time for production) has been reached. The Space components class describes the space the agents operate in. Finally, the Agent classes describe the model agents. The following subsections (4.1 to 4.5) briefly describe the Agent classes defined in the developed model. Then, Section 4.6 explains how the model measures system performance.

4.1 Autonomous Mobile Robot Class

The AMR agent is in charge of transporting materials according to the tasks assigned to it by the supervisor. Three types of states are allowed for an AMR agent:

- Committed states: the AMR is either Charging or fulfilling replenishment tasks (i.e., Moving, Waiting to load, or Waiting to unload).
- Idle state: no tasks are assigned to the AMR. As soon as the supervisor assigns one or more tasks to the AMR, the agent transitions to a Moving state. Otherwise, if no tasks are assigned for a certain amount of time and the battery level is below a threshold, the AMR is sent to a charging station, thus transitioning to a Charging state.
- Error: the robot is in failure mode. After a certain time to repair, the AMR exits this state and enters the Idle state.

4.2 Assembly Station Class

Each assembly station agent represents one of the stations of the mixed-model line. Like the AMR agent, the assembly station can be described as a sequence of states reached upon fulfillment of certain conditions. Given the complexity and the number of activities it carries out, this agent is divided into three main parts (production, inventory, robot queue), described by a state each.

4.2.1 Production

Every station has a list of production orders that it must fulfill before the end of the available time. The possible states are:

- Production state: the station is processing a product.
- Waiting for production state: the station is tasked with a production order, but the required material is not fully available. As soon as the material is replenished, the agent transitions to the Production state.
- Idle state: the station is not processing any product. This is the starting state, which is also temporarily entered every time the station needs to transition from the Production state to the following state (Production or Waiting for production).

4.2.2 Inventory

Inventories consist of boxes with materials stored at the station. Each material inventory has its own state:

- Wait for robot state: inventory levels are checked every time the station finishes assembling one product. The agent enters this state when the inventory level is equal to or below the threshold triggering a replenishment request or below the quantity needed to process the following product. The state is exited as soon as the material is replenished.
- Full state: inventory is above the threshold level and is enough to fulfill the following production order.

4.2.3 Robot Queue

This part of the assembly station agent represents the queue of AMRs waiting to unload the boxes they are carrying. The possible states are:

- Idle state: no robots are unloading boxes and the robot queue is empty.
- Unloading boxes state: one or more robots are waiting to unload boxes. Every time an AMR approaches the assembly station, a function is called to evaluate the AMR state. If the AMR state is Waiting to unload (Section 4.1), the robot queue state transitions to Unloading boxes. Then, once the unloading time has passed, the station either waits for the next robot in the queue to unload or transitions to the Idle state if the queue becomes empty.

4.3 Supermarket Class

Supermarket agents are modeled as a simpler version of the assembly station agents, without the production and the inventory parts. Therefore, both the possible states (called Idle state and Loading boxes state) and the conditions for the transition from one state to another are analogous to the ones described in Section 4.2.3. The only difference is that the states are related to the loading, rather than the unloading, of boxes by the AMRs.

4.4 Charging Station Class

The charging station agents are modeled similarly to the supermarkets. Their possible states are:

- Idle state: no AMRs are currently charging and the robot queue in front of the charging station is empty.
- Charging state: the station is charging a robot. The agent enters this state when an AMR, whose state is Charging, approaches the charging station. Then, once the charging time has passed, the agent either remains in the Charging state, if there is at least one more robot in the queue waiting to be charged, or transitions to the Idle state.

4.5 Supervisor Class

The supervisor agent represents the central node that receives replenishment requests from assembly stations, identifies the target supermarket where the required materials are stored, translates replenishment requests into tasks, and assigns tasks to the fleet of AMRs. In case an online scheduling method is used, the supervisor also continuously monitors the states of all the other agents in the system, as well as the real-time positions and current task lists assigned to each robot and the queue lengths at all stations and supermarkets. Then, it uses such real-time information for the task assignment. The procedure and methods followed by the supervisor agent to assign tasks to AMRs are described in Section 3.2.

4.6 Performance Measures

The developed model allows assessing three system performance measures. First, the average completion time, measured as the average time needed by an AMR to fulfill a replenishment request, from the pick-up of the box at the supermarket to its drop-off at the target station. It includes movement, queuing, and loading/unloading times. The lower this measure, the better the ability of the AMR fleet to promptly react to replenishment requests. Second, the idle time, measured as the percentage of the available time in which stations are not producing due to unavailability of materials. The idle time, resulting from the material handling system performance, directly affects the efficiency of assembly operations and should be eliminated or kept to a minimum. Finally, the average stock level of each material at the assembly stations. An effective scheduling method should allow reducing this indicator, consequently decreasing the amount of floor space on the shop floor dedicated to storage purposes, hence maintaining a high efficiency of assembly operations.

5 Model Validation

This section describes the validation of the developed agent-based simulation model. The model is validated through its application to a real industrial case concerning a car assembly plant where a fleet of 11 AMRs replenish assembly stations with kits. For this purpose, both the considered layout and the model parameters are adapted to the case. The layout consists of: a U-shaped assembly line, supermarkets located all around the line, and one AMR charging station placed next to each supermarket. The line is made of 23 stations and its takt time is 36 minutes. Supermarkets are organized so that the materials needed at an assembly station are stored in the closest supermarket. The distance between a supermarket and the closest station is 9 meters, while the distance between two neighboring stations is 8.5 meters. Kits, i.e., small trolleys containing the parts needed to assemble one product, are prepared at the supermarkets. The assembly of each product requires two different kits at each station. Two kits of each type are stored at a station and every time one of the kits is emptied, a replenishment request is issued. Then, replenishment tasks are allocated to AMRs based on the OFF-FA scheduling

method (Section 3.2). After the task assignment, the AMR reaches the supermarket input point, autonomously loads the kit, transports it to the station, unloads the kit, loads an empty trolley, and transports it back to the closest supermarket. An average speed of 0.9 meters/second and fixed loading/unloading times of 30 seconds are considered for the AMRs. Moreover, every 36 minutes, each robot goes to the closest free charging station, where it remains until its battery level is restored to full.

In order to validate the model, its outputs are compared with the real values measured in the industrial case. The outputs are the average task completion time, the average distance traveled by AMRs to fulfill a replenishment request, and the average robot utilization (i.e., percentage of the available time in which a robot is performing replenishment tasks). As shown in Table 1, the model provides a satisfactory estimation of the real values, which are only slightly underestimated. The percentage difference is around 3% for the average task completion time and robots utilization, while it increases to 4.7% for the average distance traveled by robots. This last value is explained by the deviations between the simulated paths, assumed to be straight, and the real ones, which are affected by obstacles that the AMRs might need to avoid.

Table 1: Validation results

Output	Real case	Simulation	% difference (Simulation vs. Real case)
Avg task completion time [min]	7.41	7.2	– 2.8%
Avg distance travelled [m/task]	270.9	258.1	– 4.7%
Avg AMR utilization	86.1%	83.6%	– 3.0%

6 Conclusions

The growing adoption of data sensing, transmission, and processing technologies is increasing the amount of real-time information available to support decisions within modern factories. Considering mobile robots feeding parts to assembly lines, this paper provides, for the first time in literature, a model for estimating the performance improvements resulting from the use of real-time data in the scheduling of material handling activities. The developed model also accounts for new type of data, never considered in previous studies (e.g., robot failures), and new data-driven approaches, such as the dynamic assignment of tasks to robots.

From an academic viewpoint, this study stimulates further research on the value stemming from the real-time data availability offered by the Industry 4.0 paradigm. From a practitioner viewpoint, the developed model can be applied in industrial contexts to support both the comparison of alternative scheduling methods and the sizing of the mobile robots fleet.

Some limitations should be acknowledged, mainly related to the model assumptions. In particular, the model considers only one type of production system (i.e., mixed-model assembly line) and a specific layout of the factory logistics system, consisting of a set of supermarkets from which all material replenishments originate. Future studies could adjust the model to take into account also different kinds of systems, like job shops, and alternative layouts. For instance, they could consider a setting in which direct replenishments of materials from the central factory warehouse are possible. Future research should also focus on applications of the developed model, so as to compare the proposed scheduling methods and develop insights on the value stemming from the use of real-time data. Moreover, economic analyses could be performed, thus comparing the methods in terms of overall investments in the robot fleet and in data gathering, transmission, and processing technologies. Finally, sensitivity analyses could be carried out to investigate how performance is affected by critical parameters and choices like the demand level, the inventory reorder policies, and the robots capacity.

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Application of Industry 4.0 in the Automotive Sector

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Purpose: *This paper aims to analyze the current state of Industry 4.0 in the automotive sector to show the associated expectations, opportunities, risks, and challenges. Requirements and concrete approaches for future research needs are derived within the framework of a research agenda.*

Methodology: *The methodology includes a systematic literature review, establishing a well-founded definition of the Industry 4.0 term for the automotive industry. Expectations, opportunities, risks, and challenges are answered in the context of a PESTEL analysis. In addition, elements of a research agenda based on the belief-action-outcome model are highlighted.*

Findings: *Our paper includes 180 identified publications and an industry-specific definition in the context of a concept matrix. The concept matrix comprises three main clusters and fifteen interdisciplinary technologies and concepts. Using a PESTEL analysis, publications are categorized into six defined perspectives. As part of a research agenda for future investigation, 32 open research questions are proposed, grouped into three themes and four subcategories.*

Originality: *In the current literature, to the best of our knowledge no approaches provide even deeper insights into the status quo of Industry 4.0 applications in the automotive sector. Thus, this paper is one of the first to provide a substantial approach to key Industry 4.0 technologies and concepts in this sector using a PESTEL analysis.*

First received: 23. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The intensified competition in the global market and the rapid development of demand have prompted enterprises to adopt modern technologies to make production more intelligent (Lin et al., 2018, p. 589). Industry 4.0 is the current trend towards progressive automation and shared information exchange in the manufacturing and technology sectors such as the automotive industry (Lin et al., 2018, p. 589). In the context of the fourth industrial revolution, Industry 4.0 extends modern digital technologies to a more comprehensive scope, which primarily includes cyber-physical systems (CPS), the Internet of Things (IoT), and cloud computing (Lin et al., 2018, p. 589). From the perspective of companies, a major challenge to overcome is that constantly changing conditions for the adaptation of products and services should be taken into account, and value chains should be continuously analyzed and improved using modern technologies (Biahmou et al., 2016, pp. 672–673). Gao et al. (2016, p. 1) argue that disruptive changes are to be expected in the automotive and logistics industry. Based on these challenges, new Industry 4.0 technologies and concepts are constantly being researched to ensure smooth production in the automotive industry. Against this background, this paper aims to clarify the following research questions:

- Research question 1: What status quo is currently associated with Industry 4.0 technologies and concepts in the automotive sector?
- Research question 2: What expectations, opportunities, risks, and challenges are associated with the concept of Industry 4.0 in the automotive sector?

2 Industry 4.0 in the automotive sector: classification and conceptualization

2.1 Concept of Industry 4.0

The term Industry 4.0 is widely used concerning the variety of production concepts that are firmly established in the scientific literature (e.g., advanced manufacturing or lean production) (Oesterreich and Teuteberg, 2016, p. 122). From a technological perspective, Industry 4.0 is understood as the increasing digitalization and automation of the

production environment and the design of a digital value chain between products and their respective working environment and business partners (Lasi et al., 2014, p. 240). Kagermann, Wahlster, and Helbig (2013, p. 6) posit the following elements as crucial prerequisites for the implementation of Industry 4.0:

- *horizontal integration across value networks* to enable cross-company networking of information technologies, processes, and data flows across business partners, and suppliers to promote intensive partnership-based cooperation within the value chain (Oesterreich and Teuteberg, 2016, p. 123);
- *continuous and digital integration of engineering within the complete value chain processes* to enable a high degree of customer-oriented design of the end products and thus considerable savings opportunities concerning a company's internal expenses (Oesterreich and Teuteberg, 2016, p. 123);
- *networked production systems and vertical integration* to ensure an integrated and intelligent manufacturing environment due to the integration and consistency of IT systems, processes, and data flows within an organization, starting from the development area through production to the logistics and sales process (Oesterreich and Teuteberg, 2016, p. 123).

2.2 Special features and economic impact on the automotive sector

The automotive industry is an important industrial sector in Germany and it has a significant impact on economic development. Specifically, in the production environment of companies, this sector promotes innovation, development, and employment (Barthel et al., 2010, p. 6). Schwarz-Kocher and Stieler (2019, p. 36) state that the German automotive industry is facing major changes due to the digitalization of products and manufacturing. Adapting all fields of activity to the framework of Industry 4.0 will likely place increased performance requirements on all employees in terms of complexity, generalization skills, and the ability to implement digital solutions. Furthermore, a much stronger level of independence, communication skills, and the willingness to take personal responsibility will be necessary (Butollo, Jürgens, and Krzywdzinski, 2018, p. 75). Ganschar et al. (2013, p. 20) state that the demands to innovate are growing exponentially due to the rapidly advancing technological development. Another significant challenge is the demand for flexibility, for which a

highly short reaction time is required regarding the respective circumstances (e.g., fluctuating market or customer requirements). Specifically, the available data and information must be compiled and processed in a relatively short amount of time (Ganschar et al., 2013, p. 21).

3 Research methodology

3.1 Systematic literature review

A preliminary overview of the current state of science and practice is presented in this paper based on a systematic literature review that follows vom Brocke et al.'s (2009) and Webster and Watson's (2002) guidelines. This research process is divided into the *definition of the research scope*, *conceptualization*, *literature search and selection*, *literature analysis*, and *deduction of challenges*. The scope of the analysis is outlined in Section 2. Furthermore, in Section 2, the concept of Industry 4.0 is presented, and thus the conceptualization is considered. The literature search and selection led to a database that reviews the most relevant publications, ensuring analyzability. The databases ScienceDirect, IEEE Xplore Digital Library, EBSCOhost (Business Source Premier Database), and Scopus were searched to assess the existing literature and address the interdisciplinarity of Industry 4.0. In particular, EBSCOhost, and Scopus covered a wide range of scientific and practical journals, magazines, conferences proceedings, field notes, and any other kind of related works. To be considered for further investigation, the publications had to contain the term "Industrie 4.0" or "Industry 4.0" in the title. Since expressions referring to Industry 4.0 have become established outside of Germany (Oesterreich, Schuir, and Teuteberg, 2020, p. 5), terms such as "Industrial Internet," coined by the American Industrial Internet Consortium, the Chinese initiative "Internet Plus," the Japanese initiative "Industrial Value-Chain" or the French activities under the name "Industrie du futur" (Lu and Li, 2004; Müller and Voigt, 2018; Evans and Annunziata, 2021) were also searched. The literature search was conducted between January and February 2021.

3.2 Qualitative and quantitative content analysis

Content analysis comprises concentrating several text words into reduced content classes based on explicit coding guidelines and systematically condensing them in a repeatable manner (Stemler, 2000, p. 5), and it is useful to analyze developmental trends and behavioral patterns in different texts with large amounts of data. For this reason, qualitative content analysis is applied for category-based text interpretation (Mayring, 2000) and frequency analysis (Sidorova et al., 2008) is applied for statistics-based text interpretation (Berelson, 1952) to combine the potential of both methods. Regarding qualitative content analysis, the recommended actions derived from Mayring's (2000) stage model were followed. For the frequency analysis, Sidorova et al.'s (2008) approach was followed to examine the information obtained using the software QDA Miner (Provalis Research, 2011) and its extension WordStat (Provalis Research, 2014). The results of the software-based content analysis are presented in Section 4.

3.3 Related work

Overall, 10,054 hits were determined via a search in the title of the databases. All identified publications are extracted in a second step using the export function of ScienceDirect, IEEE Xplore Digital Library, EBSCOhost, and Scopus with the corresponding bibliographic data including their abstracts. Given the high number of publications to be reviewed, manual coding in the subsequent content analysis required extensive time (Oesterreich, Schuir, and Teuteberg, 2020, p. 6). We therefore adopted a systematic text analysis approach by employing the text analysis tool QDA Miner (Provalis Research, 2011) and its extension WordStat (Provalis Research, 2014) for the subsequent analysis steps. For this purpose, the abstracts were imported into QDA Miner, followed by an analysis of the word stems *automotive*, *automobiles,* and *car*, which filtered out 305 possible publications for our research topic. This was followed by a data cleaning step, a check for possible duplicates, and an analysis of the relevance and quality with respect to our research topic in the title, abstract, and articles' keywords. If a publication demonstrated insufficient thematic and substantiated relevance, it was sorted out. Specifically, a contribution was classified as not relevant if it did not fit into the focus of this scientific work, namely the application of Industry 4.0 in the automotive

sector. Within the scope of this cleaning step in addition to the relevance and quality analysis step, a total of 132 contributions were identified and excluded from the entire sample. Hence, a backward and forward search was performed across the remaining 173 publications, the results of which were filtered according to the same pattern. Using the backward and forward search, seven additional publications were identified. The 180 papers deemed relevant served as the basis for the literature review presented in Section 4. The list of identified papers can be found at: https://tinyurl.com/3njhcad5.

The related works published between 2013–2021 were summarized and divided based on the topic area in the context of Industry 4.0 and the applied research methods. The papers can be found at: https://tinyurl.com/3njhcad5 (position 2), where “LA” stands for literature analysis, “ES” for empirical study, “CS” for case study, “Su” for survey, “In” for interview, “SA” for scenario analysis, and “Ex” for experiment.

Most of the publications focused on the effects and challenges of Industry 4.0 in the automotive industry, similar to our contribution (see https://tinyurl.com/3njhcad5 (position 2)). However, there is no deeper investigation available concerning the expectations, opportunities, risks, and challenges associated with the concept of Industry 4.0 in the automotive industry. Thus, this paper is the first to provide a substantial approach to crucial Industry 4.0 technologies and concepts in the automotive industry. Additional statistical results of this research and the results of the subsequent content analysis are provided in Section 4, which form the basis for the research agenda presented in Section 5.

4 Results

4.1 Literature analysis

Based on the quantitative analysis of previously-published papers on Industry 4.0 topics, the aim is to investigate the extent to which the development process follows the characteristic behavioral patterns (Oesterreich, Schuir, and Teuteberg, 2020, p. 7), including in the automotive industry. Our results indicate a similar progression to that outlined by Abrahamson and Fairchild (1999, p. 708), who proved in their study on

management fashions that there is typically a long dormant phase before a short-lived increase, leading to a symmetrical, bell-shaped popularity curve (Abrahamson, 1996, p. 257). Following Abrahamson and Fairchild (1999), this research paper distinguishes between two types of publications:

- Academic publications, such as academic journals, conference proceedings, working papers, and book chapters;
- Practical publications, namely articles published in practical and hands-on journals, and other types of publications, such as magazines or reports.

The absolute and relative frequency distributions of each publication type between 2013 and 2021 is presented in Figure 1.

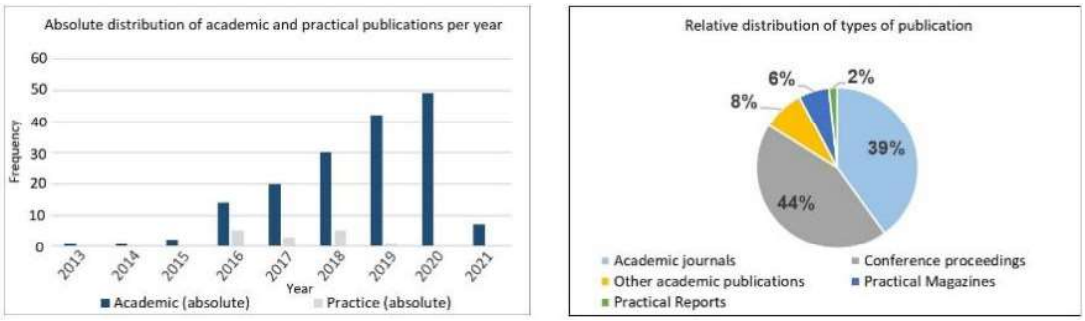


Figure 1: Absolute and relative distribution of academic and practical publications

The results of the literature analysis reveal that the scientific discourse began in 2013 and increased significantly from 2016. The relative frequency distribution shows that the preferred publication venues are scholarly publications, such as conference papers, journal articles, and other scientific papers, accounting for more than 90% of the total literature sample. This is followed by practical publication venues, such as magazines and reports. In sum, the results of the literature review show that Industry 4.0 for the automotive industry is at the peak of a discussion and development cycle (Oesterreich, Schuir, and Teuteberg, 2020, p. 8).

Subsequently, we examined which Industry 4.0 technologies and concepts pertaining to the automotive industry were mentioned in the identified publications (Figure 2). The qualitative content analysis revealed that 78 out of 180 articles examined mentioned

simulation and modeling, implying that these technologies or concepts of Industry 4.0 are considered essential in the automotive industry, followed by IoT, or Internet of Services. Other typical technologies and concepts in the context of Industry 4.0 in the automotive industry include CPS or embedded systems, automation, big data and data analytics, and platforms. Meanwhile, classic basic technologies and concepts of Industry 4.0 are cloud computing, smart factory, 3D printing, or additive manufacturing (AM) (Oesterreich and Teuteberg, 2016, p. 126), virtual reality (VR), virtual validation, virtual engineering, augmented reality (AR), digitization, or digital twin.

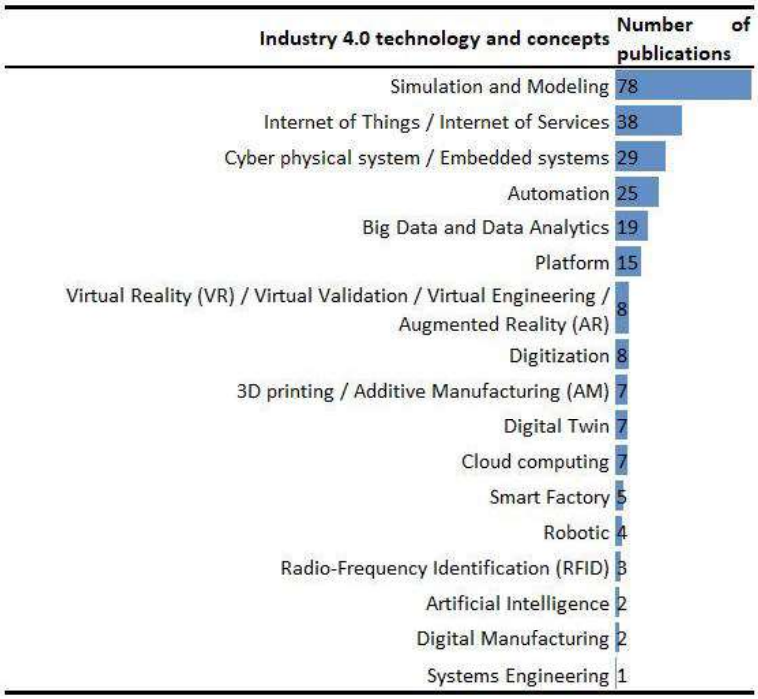


Figure 2: Industry 4.0 technologies and concepts in the identified publications

Additionally, robotic, radio-frequency identification (RFID), artificial intelligence, digital manufacturing, and systems engineering are essential components for enabling Industry 4.0 in the automotive industry.

In response to the first research question and based on the findings from the content analysis, it can be claimed that the industry-specific definition of Industry 4.0 in the automotive industry encompasses a broad spectrum of interdisciplinary technologies

and concepts that enable digitization and automation in the automotive industry at individual stages of development. The term Industry 4.0 is sometimes used and understood as synonymous with the increasing provision of information and communication technologies and other technologies in the manufacturing industry, without further specification (Oesterreich and Teuteberg, 2016, p. 127).

The identified technologies, concepts, synonyms, and terminologies were grouped into three main clusters and fifteen concepts/technologies were then summarized in a concept matrix following Webster and Watson (2002) based on Oesterreich and Teuteberg (2016, p. 128). The defined groups occasionally overlapped, as several contributions were assigned to more than one group. Specifically, 105 publications were assigned to different concepts and groups. For example, if an article involved IoT and CPS, it was integrated into both concepts. The statistical results of the analyzed publications are illustrated in the concept matrix in Figure 3.

Cluster	Significant Industry 4.0 technologies and concepts	Number of relevant publications
Smart Factory (C1)	Internet of Things (IoT) / Internet of Services (IoS)	37
	Cyber physical systems (CPS) / Embedded systems	27
	Automation	25
	3D printing / Additive Manufacturing (AM)	7
	Robotic	4
	Digital Manufacturing	2
	Systems Engineering	1
	Radio-Frequency Identification	3
Simulation and Modeling (C2)	Simulation tools / Simulation models	13
	Digital Twin	7
	Virtual Reality (VR) / Virtual Validation / Virtual Engineering / Augmented Reality (AR)	7
Digitization and Virtualization (C3)	Big Data and Data Analytics	15
	Platform	14
	Cloud computing	7
	Digitization	8
	Total	**177**

Figure 3: Concept matrix following Webster and Watson (2002) based on Oesterreich and Teuteberg (2016, p. 128)

Qualitative results:

Cluster 1: Smart Factory

The first cluster (C1) in Figure 3 presents a comprehensive set of technologies and concepts that lie at the heart of Industry 4.0 for the automotive industry and aim at automating production and creating a *smart factory*. Essentially, some approaches to the creation of a smart factory in the automotive industry prevail (e.g., Häußler, 2020, p. 1). EOS (2020) explains that manufacturing companies are reaching their own performance limits regarding adaptability, the feasibility of complicated components, and product individualization. With 3D printing, the possibilities for integrated, smart, and, above all, digitally supported manufacturing (EOS, 2020) can be realized in the context of *digital manufacturing*. Digital manufacturing is featured by the use of technologies for digital model generation and replication in planning and production processes (Siemens PLS Software, 2008, p. 2). Additionally, *3D printing,* or *additive manufacturing,* has gained considerable importance in the automotive industry, and it is difficult to imagine production and improvement without this technology (Grohmann, 2019). The central technologies in Cluster 1 are *CPS* and *embedded systems*. The interaction of intelligent components and manufacturing machines to be produced in the manufacturing process with CPS can significantly change production, as these components and manufacturing machines can constantly communicate with each other, and thus independently recognize where and when a manufacturing process is carried out. Moreover, they can do so in a coordinated manner (Wolff and Schulze, 2013, p. 24), as in the automotive industry, for example. The *IoT,* or *Internet of Services,* is one of the most significant technologies in C1. From a technological perspective, the IoT is a combination of sensor technology such as RFID, further communication, cloud applications, ERP, and business intelligence technologies (Oesterreich and Teuteberg, 2016, p. 129). In this context, the corresponding sensors are integrated into the physical and technical components of vehicles, working machines, robotics, or equipment components to realize connections with the internet (Oesterreich and Teuteberg, 2016, p. 129). According to BMWI (2021, p. 1), RFID is one of the core technologies in the realization of Industry 4.0, but it has not yet consistently established itself in the automotive industry. Volkswagen AG illustrates the group-wide use of RFID technology with the exemplary transparent prototype in a first

model test (BMWI, 2021, p. 1). An equally essential component of the smart factory vision in the context of Industry 4.0 is *automation*. Based on Nüßle (2018), the automotive industry among the sectors in the field of manufacturing and assembly technology has the highest levels of maturity in automation. An interdisciplinary approach to economical and effective product design involving diverse subject matter experts is ensured by *systems engineering* (Bretting, 2017) (e.g., as support for the production process of the automotive industry). *Robotics* is equally worth mentioning, as according to Einertshofer (2018) numerous companies in the automotive industry already use collaborative robots, also known as cobots, in their manufacturing environments.

Cluster 2: Simulation and Modeling

Cluster 2 (C2) concerns *simulation and modeling*, two further core topics in the context of Industry 4.0 in the automotive industry. *Simulations* allow representing plants and production processes as models and thus analyzing and optimizing the work sequences in the production environment in a targeted manner (Gora, 2003, p. 18). Through *modeling*, requirements are checked for correctness at an early stage, which makes error detection and correction much more cost-effective (Iqbal et al., 2020, p. 8698). *Simulation tools* and *simulation models* for virtual commissioning promise comprehensive interfaces for the implementation of existing partial models when modeling a digital twin of a machine or robot (Völker, 2020, p. 1). The *digital twin* is another core technology or concept of C2, and it offers significant opportunities for simulation-based planning and optimization in the industrial environments of the automotive industry (Kritzinger et al., 2018, p. 1016). Other critical technologies in C2 are *VR, virtual validation, virtual engineering, and AR*. Against the backdrop of increasing competitive pressure on automotive manufacturers to reduce production times and strive for ongoing quality improvement, VR has proven its advantages in numerous fields (e.g., development, production, assembly, and training) (Lawson, Salanitri, and Waterfield, 2016, p. 323). For the early phases of product development, especially before the actual product manufacturing and the start of production, virtual validation methods (Damrath et al., 2016, p. 307) can provide additional support. Damrath et al. (2016) propose a procedure for the energy-efficient design of an assembly system through virtual validation.

Moreover, AR technologies can be used for service and customer support training in the automotive industry (Lima et al., 2017, p. 100).

Cluster 3: Digitization and Virtualization

The third cluster (C3) in Figure 3 comprises *digitization and virtualization*. According to the BMBF (2020, p. 85), advancing digitization is crucial for the introduction of new types of products and services. Meanwhile, according to Brücker (2014), the provision of high-quality visual solutions (e.g., 3D visualizations) across the entire value chain causes a generalization process of workflows in product development and launch. *Big data and data analytics* represent a broad spectrum in the automotive industry whose applications are highly extensive (Rampelli, Vadlamani, and Nukala, 2014, p. 24) (e.g., in the area of production, in the context of quality control, or to increase productivity (Kampker et al., 2018, pp. 122–126)). Another significant component in C3 is *cloud computing*, whose importance in the automotive industry continues to grow relative to networking, electromobility, and PLM, among others, as Schäfer and Fricke (2013, p. 52) explain. Additionally, *digitization* is an essential approach in C3. Digital technologies optimize existing process flows based on improved customer approach, optimal planning of needs, or better interpretation of the customer's individual wishes (Sedan and Gissler, 2015, p. 1). C3 ends with the central technology *platform*. In terms of products, several companies currently rely on a platform and a design corresponding product groups on this basis (Simpson, Siddique, and Jiao, 2006, p. 3). Based on the results, it can be concluded that the articles analyzed in the systematic literature review primarily concern the technical aspects of Industry 4.0-related technologies. Economy-, society-related, and ethical or legal issues are only addressed to a limited degree. According to the first research question, the status quo of Industry 4.0 technologies and concepts in the automotive industry is at different levels of maturity. However, various solutions have been presented to digitize production and logistics processes in the automotive industry and significantly improve productivity.

4.2 Expectations, opportunities, risks, and challenges of Industry 4.0 in the automotive industry

Based on the definition of the term, a further objective is to address the expectations, opportunities, risks, and challenges associated with Industry 4.0 in the automotive industry. The publications derived from the 180 sources through literature research were categorized into six defined perspectives using a PESTEL analysis (Kaplan and Norton, 2008). Specifically, the expectations and opportunities were assigned to political (P), economic (E), sociocultural (S), technological (T), environmental (E*), and legal (L) perspectives (Table 1 and Table 2), which allowed us to reflect on changes and trends in our topic.

Table 1: Opportunities of Industry 4.0 in the automotive industry

	Opportunities
P	**Increased public relations:** By linking Industry 4.0 and science communication, an interface between industry and the public can be created, contributing to fluid and effective change and positive interaction for both partners (Becerir and Peschke, 2019, p. 288).
E	**Improved collaboration and communication:** Applying a digital platform in the automotive industry 4.0 context and involving the customer in various processes such as service configuration can ultimately enhance customer experience (Silva et al., 2018, p. 2; da Silva et al., 2018). **Increased productivity and quality:** Implementing Industry 4.0 from the perspective of costs and benefits and incorporating the process failure mode effects analysis (PFMEA) can improve productivity in the automotive industry (Bermúdez and Juárez, 2017, p. 737). Additionally, technologies such as the IoT or CPS can increase quality performance in the context of Industry 4.0 in the automotive industry (Tasmin et al., 2020, p. 160). **Reduced costs:** The analysis of critical factors (e.g., data management) prior to the implementation of Industry 4.0 technologies in the automotive industry can reduce costs in the long term (Bhatia and Kumar, 2020, p. 1). Similarly,

	Opportunities
	Maintenance 4.0 (Nissoul et al., 2020, p. 1) effects can have a cost-saving impact on the automotive sector.
S	**Improved decision-making processes:** A suitable framework for the introduction of Industry 4.0 technologies in manufacturing companies (e.g., in the automotive industry) can benefits for decision-makers (Yadav et al., 2020a, p. 1). In addition, the application of a web visualization platform in the context of Industry 4.0 can be used to support decision-making in organizations (Rebelo et al., 2019, p. 71).
	Reduced complexity and dynamics in human-computer interaction systems: Designing an efficient and user-friendly human-IoT interaction mechanism can reduce the complexity and dynamics in the Industry 4.0 context of the automotive industry (Yang et al., 2018, p. 463).
T	**Improved data evaluation:** Analyzing the performance of the Edge OBD-II device using Industry 4.0 technologies such as the IoT can provide independent vehicle data for customer feedback and tracking (Silva et al., 2020, p. 88).
	Improved infrastructure: The implementation of Industry 4.0 can increase facilities automation and adaptability during the production processes in the automotive industry (Ruggero et al., 2020, p. 131).
E*	**Improved resource usage:** Following the promotion of the understanding of sustainability as part of Industry 4.0, renewable energy can reduce manufacturing costs and increase revenues (Becerir and Peschke, 2019, p. 288) in the automotive sector.
	Improved energy efficiency: Energy efficiency can be increased as a result of reducing overarching structural difficulties within the automotive sector, identifying relevant viewpoints and influencing variables relative to accelerating the adoption of Industry 4.0 technologies (Hidayatno, Rahman, and Daniyasti, 2019, p. 334).
	Reduced energy consumption: Energy consumption can be reduced by efficient manufacturing facilities and by incorporating energy efficiency software (EES). Moreover, continuous optimization in the field of big data analytics can significantly reduce energy costs (Adenuga, Mpofu, and Boitumelo, 2019, p. 735).

	Opportunities
L	**Improved fulfillment of target agreements:** Globalization, digitalization (e.g., technologies such as Digital Master or 3D Master), and the digital transformation in the automotive industry can help to better meet changing customer behavior and demands (Biahmou et al., 2016, p. 672).

By contrast, automotive companies must consider a variety of challenges or difficulties before implementing digital transformation (cf. Table 2).

Table 2: Challenges of Industry 4.0 in the automotive industry

	Challenges
P	**Job market changes:** Major difficulties for foreign investors in investing in Industry 4.0 technologies or concepts within the automotive industry can be caused by local conditions, such as strongly increasing wage trends and declining employment (Olejniczak, Miszczynski, and Itohisa, 2020, p. 196). These prospects for the industry must be considered as part of Industry 4.0 implementation.
E	**Adhere to the highest quality standards at competitive prices:** Detecting defects is a major challenge in the production of electronic components in the automotive industry, because failures in this field can contribute to damage and fatal consequences (Schwebig and Tutsch, 2020, p. 167). Similarly, it is necessary to address the challenges regarding the quality assurance of the essential components in the context of future development trends in engine manufacturing (Obara and Guedes, 2017, p. 1).
	Risk and uncertainty regarding strategic planning activities: A challenge is posed to automotive industry in the context of Industry 4.0 by high-risk potential and the associated planning uncertainty of manufacturing companies (Riel and Flatscher, 2017, p. 323).
	High resource requirements and loss of speed in data transmission due to large data volumes: The collection, networking, securing, evaluation, and analysis of extensive data sets from various information sources, such as machine controllers, sensor systems, production systems (Santos et al., 2017, p. 750) is

	Challenges
	leading to a crucial challenge in the automotive industry in the course of Industry 4.0.
S	**Horizontal and vertical cooperation in the context of manufacturing and assembly optimization:** One of the main challenges facing automotive companies in the digital environment and Industry 4.0 is the lack of technical tools and methods, such as CPS (Silva et al., 2018, p. 6; da Silva et al., 2018). Similarly, a fundamental challenge is to design and support industrial automation applications with respect to the IoT so that they exhibit real-time mode performance at different stages (Gidlund et al., 2018, p. 2194). **Supplier paradigm:** A significant challenge to be solved is the just-in-sequence supply in the entire supply chain of manufacturing and service processes in the automotive industry (Juhász and Bányai, 2018, p. 226). **Organizational redesign and process changes:** The implementation of Industry 4.0 in the automotive industry should be deepened and sustained across all prevailing organizational processes to be positioned for new ways of working and organizational concepts in the factories of the future (Bader et al., 2019, p. 756). **Insufficient employee competence:** A fundamental challenge for many automotive companies will be the insufficient employee know-how regarding Industry 4.0 technologies, which can be overcome by applying new aspects in education and research (e.g., human and social sciences) (Bryon-Portet, Montastruc, and Le Lann, 2016, pp. 24).
T	**Adhere to technological standards and reference architectures:** Regardless of the current state of maturity and operational capabilities of most technologies, many of them do not meet satisfactory standards, such as security standards, in the context of Industry 4.0 (MacRae, 2016) or they require a uniform user interface regarding the flexible design of acquisition processes (Beckers et al., 2020, p. 1444). Furthermore, a reference architecture specifically geared to the industry to implement Industry 4.0 is missing (Lasi et al., 2014, p. 241). This reference architecture should be developed with the specific environment of the automotive sector in mind and with a particular focus on their organizational aspects (e.g., customer management). **Security and data protection issues:** A key requirement for Industry 4.0 in the automotive industry is to address security and data protection issues against, for

	Challenges
	example, autonomous vehicle cyberattacks associated with implementation issues (Gupta et al., 2020, p. 1).
E*	**Energy efficiency and sustainability:** To counter the reliability challenges related to the quality of services (QoS) within the network infrastructure in the manufacturing process, latency should be minimized (Muliawan, 2019, p. 1) and sustainably optimized.
L	**“Legal Framework” as a “brake”/enabler:** Legal issues impacted by the implementation of Industry 4.0 in the automotive industry are liability (product/ contractual liability, risk distribution), labor law, regulations, intellectual property, data protection, IT security, EU legislation, standards and (smart) contracts, and autonomous systems.

Considering these diverse research challenges, it can be deduced that the automotive industry should include more than just technical adjustments. From a scientific perspective, the opportunities and challenges presented yield research topics that should be included in a research agenda.

5 Elements of a research agenda

The results show that current research streams focus on analyzing the technical aspects of Industry 4.0 in the automotive industry. In many cases, economic, social, ethical, or legal issues are not considered. For example, there is a need to apply reference modeling regarding Industry 4.0 in the automotive industry. Approaches to the design and implementation of Industry 4.0 in the automotive sector can be derived against this background (Ickerott, Teuteberg, and Süßmuth, 2018, p. 1631). Methodologically, the structure is based on the belief-action-outcome (BAO) model (Melville, 2010).

Subject / Topic		Research question / Reference	Potential impacts
Humans	Functions	(1) What competencies does an Industry 4.0 leader need? (2) What is the mode of operation and the system sequence? (3) What is the I4.0 reconfiguration strategy? (4) Does the DMS work during I4.0 disruptions? (5) To whom is the info system designed? (6) How is work evolving under Industry 4.0? (7) How does the program work under Industry 4.0? (8) With whom does the I4.0 work developed resonate? Based on Łupicka and Grzybowska (2018); Milisavljevic-Syed et al. (2019); Pereira et al. (2019)	Process model
Organizations	Added value of IT investments	(1) What can improved production through Industry 4.0 look like? (2) What does the Industrial IoT mean for business models? (3) What are the differences between Industry 4.0 technologies? (4) How effective are Industry 4.0 technologies? (5) What characterizes the user and provider view of I4.0 in business models? (6) What are the specifics and strategies of Industry 4.0? (7) How can the maturity of Industry 4.0 be measured? (8) To what extent does an assessment help promote I4.0? (9) What are models trained to do in the cloud? (10) What do Industry 4.0 technologies bring and how can they contribute to sustainability? Based on Arnold et al. (2016); Müller and Voigt (2017); Moica et al. (2018); Lucato et al. (2019); Müller (2019); Elnagar and Thomas (2020)	Benefits of the innovation, cost-benefit analysis, Industry 4.0 decision criteria
	Risk Management	(1) How can digitization be integrated into IT risk management? (2) In which way is the I4.0 transformation of manufacturing systems realized? (3) What are the demands and competitiveness of I4.0? (4) What are companies' expectations regarding economic policy and Industry 4.0? Based on da Silva et al. (2018); Milisavljevic-Syed et al. (2019); Nick et al. (2019)	Risk management model, alignment
Technology	IT structures and applications	(1) What does the concept of I4.0 involve for networks? (2) What is the deficit between collaborative networks and I4.0? (3) How can I4.0 be realized with regard to networks? (4) Which functionalities/user requirements are relevant for I4.0? (5) What about the performance of the RFID system? (6) What are the benefits of using a collaborative robot? (7) What sensors do vehicles rely on? (8) What parameters influence costs and stability? (9) For which cars fit smart design customizations? (10) How important will big data, IoT, etc. be in the future? Based on Saldivar et al. (2016b); Velandia et al. (2016); Cisneros-Cabrera, Sampaio, and Mehandjie (2018); da Silva et al. (2018); Silva et al. (2018); Lima et al. (2019); Liu et al. (2019); Milisavljevic-Syed et al. (2019); Nick et al. (2019); Pereira et al. (2019); Perzyk, Dybowski, and Kozłowski (2019); Zakoldaev et al. (2019); Beke, Horvath, and Takacs-Gyorgy (2020); Elnagar and Thomas (2020); Roman and Bunsen (2021)	IT architecture model, IT security, model, software prototype

Figure 4: Research questions derived from the results

The focus here is on the dominant beliefs about human-technology interaction. It serves as a model for the development, realization, and evaluation of actions. Furthermore, the BAO framework is suitable for user-specific development and the use of methods to measure the results of initiated transformation processes. According to Webster and Watson (2002, pp. xv–xix), the starting point of any academic research project should be to review existing scientific knowledge through a systematic literature search and a subsequent content analysis to identify the status quo of the research area, further areas to explore, and research gaps. The currently open research questions that emerged from the analysis of the literature are presented in Figure 4.

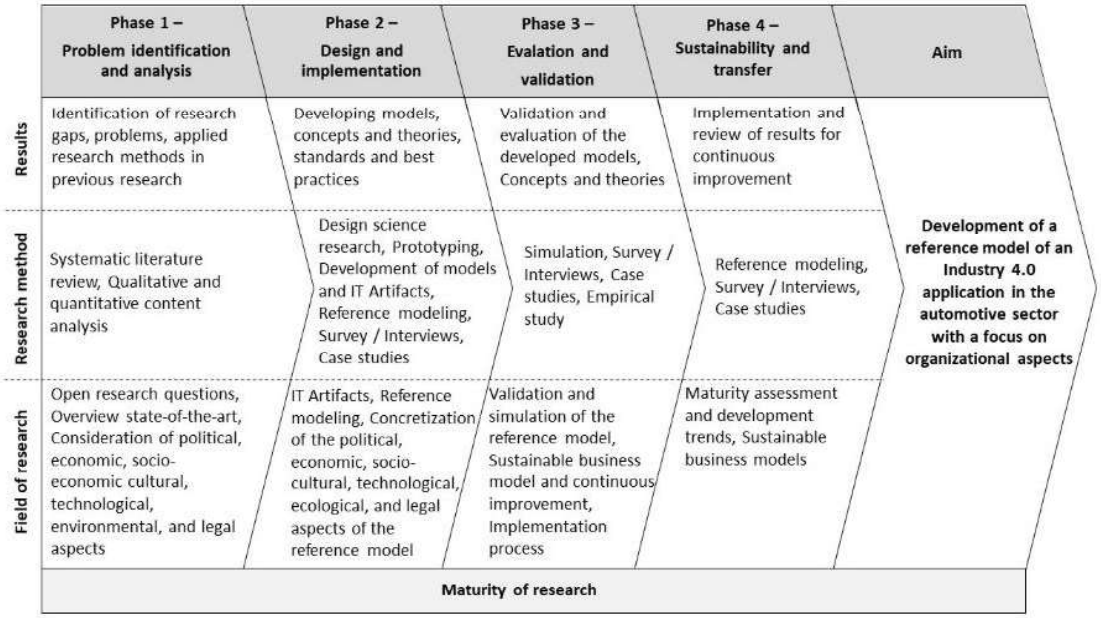


Figure 5: Proposed research agenda

We advise an iterative approach based on the design science approach to meet the rapid pace of the research within the available time (Hevner et al., 2004). Exemplary challenges and problem aspects are presented as part of the research agenda in Figure 5. Another element of the proposed research agenda includes activities to develop the concept and reference model. An empirical research approach and structured approach are suitable to explore the questions in this section in greater depth. To explore the economic and technical aspects of the questions (e.g., the construction of a technical system architecture), an expert-oriented approach based on interviews would be useful to develop reasoned responses based on a concentration and evaluation of expert knowledge. For the socio-cultural aspects of the questions, surveys would be useful since they enable simulating extensive evaluation and decision problems of a socio-scientific nature (Oesterreich and Teuteberg, 2016, p. 137). The validation of the constructed reference model should be carried out based on factors such as significance, transferability, and robustness (Burda and Teuteberg, 2013, p. 449). Validation can be realized through analytical and theoretical research methods, which are primarily based on deductive reasoning. On the other hand, empirical analysis is proposed to validate the model through experience (Fettke and Loos, 2003, p. 2945). Following its

implementation, the developed reference model should be constantly reviewed and optimized in the direction of sustainability through using development trends and maturity models, among others.

6 Conclusion and outlook

6.1 Implications for research and practice

This research paper has analyzed the state of science and technology related to Industry 4.0 in the automotive sector and presented the main implications from a wide range of perspectives. The results are listed in Table 3.

Table 3: Main findings, implications, and propositions

Main finding (MF)	Implications and propositions
Research question 1: What status quo is currently associated with Industry 4.0 technologies and concepts in the automotive sector?	
MF1a: Industry 4.0 for the automotive sector refers to a variety of interdisciplinary technologies and concepts (e.g., the IoT, CPS, Big Data, and Data Analytics) that support the digitalization, automation, and integration of the production process at all levels of the value chain to ensure vehicle production. MF1b: The development statuses of these Industry 4.0 technologies and concepts in the automotive industry are at different levels of maturity.	• Companies should not only focus on the technical aspects of Industry 4.0-related technologies, but also discuss economic, social, ethical, and legal issues. • Companies should mobilize horizontal and vertical collaborations (e.g., with suppliers) to simultaneously foster communication and collaboration with these partners.

Main finding (MF)	Implications and propositions
MF1c: Some technologies (e.g., cloud computing or software for visualizations or 3D simulations) have reached a certain level of market maturity and are in use, whereas other technologies are in the development phase. Prototypes and application capabilities are being designed for mainstream use (e.g., digital twin, AR, VR).	• Companies should be guided by established practical examples, showing practicable approaches to the introduction of Industry 4.0 applications for digitization and automation in the automotive sector.
Research question 2: What expectations, opportunities, risks, and challenges are associated with the concept of Industry 4.0 in the automotive sector?	
MF2a: The use of Industry 4.0 technologies has a profound impact on the entire automotive sector, the industrial companies involved, suppliers, the environment, and employees. MF2b: The economic benefits of Industry 4.0 in the automotive sector are not only improved productivity, efficiency, quality, and collaboration, but also increased safety and sustainability.	• Companies should address a wide range of political, economic, social, technological, environmental, and legal challenges (e.g., organizational redesigns and process changes). • Companies should confront employees with increasing job requirements to allay anxiety about job loss and computers (e.g., artificial intelligence). • Companies should clarify unresolved issues, such as the lack of technical standards for many technologies.

6.2 Limitations

In addition to the knowledge gained as described above, this study has some limitations, which offer suggestions for approaches for future research. First, the results of the analysis of Industry 4.0 applications in the automotive sector are based on a sample of 180 scientific and practice-oriented publications that were considered significant for this study. The search was based on various interdisciplinary literature databases, although such an approach cannot ensure the completeness of the relevant publications. Furthermore, given that the sample only included English- and German-language publications, the results reflect only technologies and concepts of the automotive sector on Industry 4.0 in English- and German-speaking countries. As such, the discussion of other areas, including those that are economically distinctive in some cases, is not considered in this work. This analysis should be expanded to publications in other languages to obtain a comprehensive understanding of applications in the automotive industry. Although Industry 4.0 represents an interesting research subject due to its intensified consideration, other digitization initiatives also require analysis. Further research is thus needed to deepen the research results and validate them with the results from other areas of the automotive sector.

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Framework for indicator-based, sociotechnical project risk monitoring

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Purpose: *Many Industry 4.0 projects fail because impending sociotechnical risks are managed insufficiently. An indicator-based, sociotechnical risk monitoring can help to overcome this challenge. However, its effectiveness depends significantly on selecting appropriate risk indicators. This paper outlines a framework that helps decision-makers with the necessary structuring, allowing for subsequent indicator definition.*

Methodology: *Indicators must be embedded in specific contexts to be meaningful. The design of indicator-based monitoring systems, therefore, first requires an appropriate framework. For this purpose, specific requirements related to digitization projects are derived from both literature and practitioners' needs.*

Findings: *Risks in the context of Industry 4.0 projects are systemic risks. For efficient monitoring, new approaches are needed that can manage this high complexity. Systems theory is found suitable to develop a new framework for indicator-based, sociotechnical project risk monitoring. The framework considers the characteristics of projects and enterprises as complex, open, and sociotechnical systems.*

Originality: *Especially in complex projects like those of Industry 4.0, situational risk awareness can contribute crucially to project success. However, achieving this awareness always requires tailored approaches addressing the unique project characteristics. To help solve this challenge for digitization projects, the proposed framework sets both a science-based and practitioner-relevant foundation for subsequent derivation of sociotechnical risk indicators.*

First received: 25. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Companies nowadays find themselves in an increasingly volatile, uncertain, complex, and ambiguous (VUCA) environment, characterized through e. g. shortening product lifecycles and fluctuating order volumes (Millar, Groth and Mahon, 2018, pp. 5–8; Romeike and Hager, 2020, pp. 9–10; Westkämper and Zahn, 2009, pp. 7–12). To remain competitive, a continuous adaption to changing conditions is necessary (Westkämper and Zahn, 2009; Gareis and Gareis, 2018, pp. 10–11). One lever for this purpose is the successful realization of Industry 4.0 projects (Kagermann, Wahlster and Helbig, 2013).

Industry 4.0 describes the utilization of new, digital technologies to achieve intelligent automation, vertical networking within companies, and horizontal connectivity along entire value chains. For companies, this opens up countless potentials for improving their competitiveness: through the development of new products, services, and business models, as well as through the optimization of their existing business processes (Kagermann, Wahlster and Helbig, 2013, pp. 9–11; Obermaier, 2019; Reinhart, 2017).

However, many companies fail to successfully take the step toward digital transformation (FUJITSU, 2017, pp. 2–5 and 22–24; Petit, et al., 2019, p. 20). The root of this issue, and the key to solving it, is the insight that Industry 4.0 projects are technology-driven, but have a direct impact on people, processes, and entire enterprises (FUJITSU, 2017, pp. 6–21; Petit, et al., 2019, pp. 20–37). This is also underlined by the sociotechnical systems approach to Industry 4.0. This concept is based on the understanding that enterprises are sociotechnical systems, consisting of the three interlinked, sociotechnical dimensions of human, technology, and organization (Ulich, 2011, pp. 198–201). Therefore, successful digitization projects require an integrated and equal consideration of the sociotechnical dimensions (Henke, et al., 2020, pp. 280–282; Hirsch-Kreinsen and Weyer, 2014; Hirsch-Kreinsen and ten Hompel, 2017; Ittermann, et al., 2016).

Against this background, the sociotechnical changes driven by Industry 4.0 provide a breeding ground for complex risks that endanger the projects' success (Gabriel, et al., 2021; Schnasse, et al., 2020; Schnasse, Menzefricke and Dumitrescu, 2021). These risks as well as their causes and effects affect all three sociotechnical dimensions (Gabriel, et al.,

2021, pp. 244–245; Schnasse, Menzefricke and Dumitrescu, 2021, pp. 162–163). However, projects and enterprises are both open systems (e. g. DIN ISO 21500, 2016, pp. 9–10). Thus, the risks, causes, and effects are not limited to the core of the digitization project itself, but also relate to the project's environment and are not limited to the sociotechnical nature of enterprises (e. g. exogenous political risks) (Birkel, et al., 2019, pp. 6–22; Gabriel, et al., 2021, pp. 243–244; Schnasse, Menzefricke and Dumitrescu, 2021, pp. 161–162; Menzefricke, et al., in print, p. 2). Especially with regard to the intended horizontal and vertical networking by Industry 4.0 projects, this can lead to a multitude of complex causalities (Knoll, 2017, pp. 5–8).

To enable companies to meet these challenges and successfully realize their digitization projects, practical approaches to sociotechnical project risk management are needed.

1.1 Aim of the paper and observation scope limitation

Awareness that project risk management is a key success factor is well established in project management practice (e. g. DIN IEC 62198, 2002; Project Management Institute, 2017, pp. 395–457; 2019). However, no blanket guidance on how to implement an effective project risk management can be provided. Although the underlying processes are essentially identical in all project types, the actual design has always to be adapted to the specific circumstances (e. g. Project Management Institute, 2019, Chapter 2.4 (E-Book)).

With regard to the special requirements of digital transformation projects, a very recent exploration by Menzefricke, et al. (2021) found that especially for the sociotechnical risk analysis and assessment already various suitable approaches exist. At least initial approaches are available for risk treatment, yet they still should be further developed. At the same time, though, sociotechnical project risk monitoring is still highly underrepresented in current research (Menzefricke, et al., 2021, pp. 711–712).

To help bridge this gap, this paper focuses on this very sociotechnical project risk monitoring. In general, risk monitoring aims at tracking identified risks by identifying and analyzing risk-changing developments, and at reviewing the effectiveness of risk treatment measures (DIN IEC 62198, 2002, pp. 18–19; DIN ISO 21500, 2016, p. 36). To fulfill

these tasks, early warning systems (EWS) have proven their value in various risk monitoring domains, e. g. healthcare (Umar, et al., 2019), climate change (Zommers and Singh, 2014), supply chain management (Sheffi, 2015), and corporate crisis management (Hahn and Krystak, 1984). EWS use qualitative and quantitative indicators that capture signals on risk-changing developments at an early stage, transform them into meaningful information, and, thus, create situational awareness and enable for proactive reaction (Hahn and Krystak, 1979, pp. 24–27; Romeike and Hager, 2020, 329--333).

However, the first step towards every indicator system for monitoring purposes is the establishment of an appropriate framework that defines the areas to be observed (Hahn and Krystak, 1979, pp. 24–25; lustat - statistik luzern, 2012, pp. 6–9). Against this background, the aim of this paper is to develop an integrated sociotechnical project risk monitoring framework that illustrates the dimensions to be monitored within Industry 4.0 projects. Thereby, systems theory is intended to serve as the basis for systematic development. As a first step towards an indicator-based, sociotechnical project risk monitoring, the result shall help decision-makers with the required pre-structuring, thus allowing for a subsequent indicator definition.

With respect to the iterative risk management process, this paper's objective can be placed at the intersection between activity I (Risk framing), activity II (Risk analysis & assessment) and activity IV (Risk monitoring) (see Figure 1). It addresses the establishment of a framework (activity I) for use in risk monitoring (activity IV). The subsequent risk indicator definition, however, depends on input data on the cause-risk-effect-relations (lustat - statistik luzern, 2012, pp. 7–8). Since this information results from risk analysis and assessment (activity II) (DIN IEC 62198, 2002, pp. 12–15), the model to be developed in turn formulates demands on information needs to be collected during (a possibly extended or repeated run through) activity II.

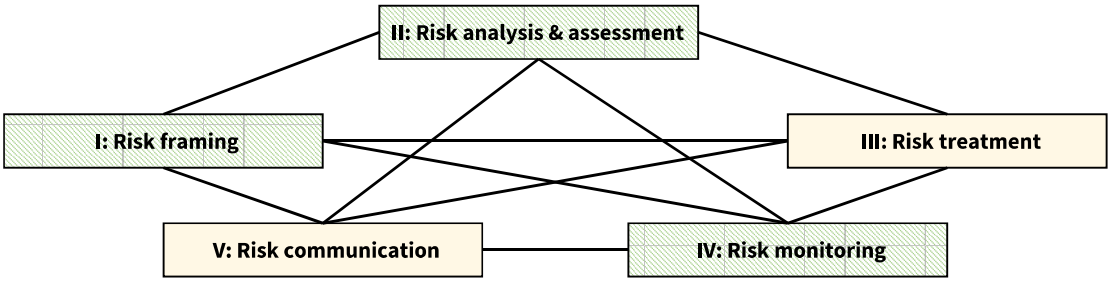


Figure 1: Fitting of the paper objective into the iterative project risk management activities (highlighted in green)

Since the intended indicator-based, socio-technical risk monitoring framework is a first attempt to solve the presented issues, the scope of application refers only to individual Industry 4.0 projects within a single company from the manufacturing industry. Project risk monitoring as part of digital transformation portfolio or program management, cross-company digitization projects, and other sectors are not yet the focus of this paper.

1.2 Research questions and structure of the paper

To guide the research, the following two research questions are formulated:

1. Which requirements have to be met by an integrated monitoring framework for Industry 4.0 projects to allow for a subsequent risk indicator definition?
2. How can an integrated sociotechnical project risk monitoring framework be designed that meets the requirements?

To address these research questions, the remainder of this paper is structured into four more sections. Section 2 provides an introduction on sociotechnical risks as systemic risks and the resulting need for new approaches to project risk monitoring that can handle this high level of complexity. In this context, the fundamentals of systems theory are also presented, which is very suitable as a solution approach.

The following section 3 then serves to define the requirements towards an integrated framework for indicator-based, sociotechnical risk monitoring (research question 1). On the one hand, content-related requirements are derived that describe the dimensions to be included in the targeted framework. Therefore, a literature-based review on the characteristics of projects and enterprises as open, complex, and sociotechnical systems

is conducted. Second, based on experiences from real life case studies further application-related requirements are defined that are representing practitioners' needs.

Within section 4, a new developed sociotechnical project risk monitoring framework is presented (research question 2). First, the proposed model and its individual components are described and visually illustrated. Second, an exemplary case study is introduced to consider practical aspects and to give starting points for a validation.

The final section 5 summarizes the content of this paper, points out the limitations, and gives an outlook on future research possibilities.

2 Systems theory as a key to enable indicator-based monitoring of systemic, sociotechnical risks

As will be described in more detail in the course of this section, the risks in the context of Industry 4.0 projects are so-called systemic risks. According to Renn, et al. (2007, pp. 176–177), such systemic risks are characterized by the following four attributes:

- a high degree of complexity of the cause-effect chains,
- a high degree of uncertainty,
- a high degree of ambiguity, and
- Radiation to other, indirectly connected systems that are also put at risk.

However, before a deeper explanation of the connections to and challenges for building indicator systems for digitization projects is provided, a brief introduction to the fundamentals of systems theory is first given below to ensure a uniform understanding.

In general, a system is defined as an entity consisting of a set of elements. These elements have specific properties and can be both of material nature (e. g. buildings, machines, people) and immaterial nature (e. g. events, processes, departments). Between the different system elements, a set of relationships exists, giving the system a certain structure (Haberfellner, et al., 2019; Patzak, 1982, pp. 18–19; Rüegg-Stürm, 2004, pp. 65–66). According to Patzak (1982, pp. 39–54), two types of system structures can be distinguished in this context: a processual structure (input-output-relationships between system elements) and a hierarchical structure (static hierarchical ordering of the system elements).

Regarding the hierarchical structure, it should be taken into account that each system consists not only of elements that form lower-order subsystems, but is at the same time also an element of a higher-order suprasystem. Therefore, system boundaries can be defined to separate an observed system from its environment. If there are input-output relations between the system and its environment across the system boundary, then such a system is called an open system. If none of these relations exist, then it is considered to be a closed system (Haberfellner, et al., 2019, pp. 5–7; Patzak, 1982, p. 20).

The following Figure 2 schematically illustrates the fundamentals of the systems theory, using the example of an open system.

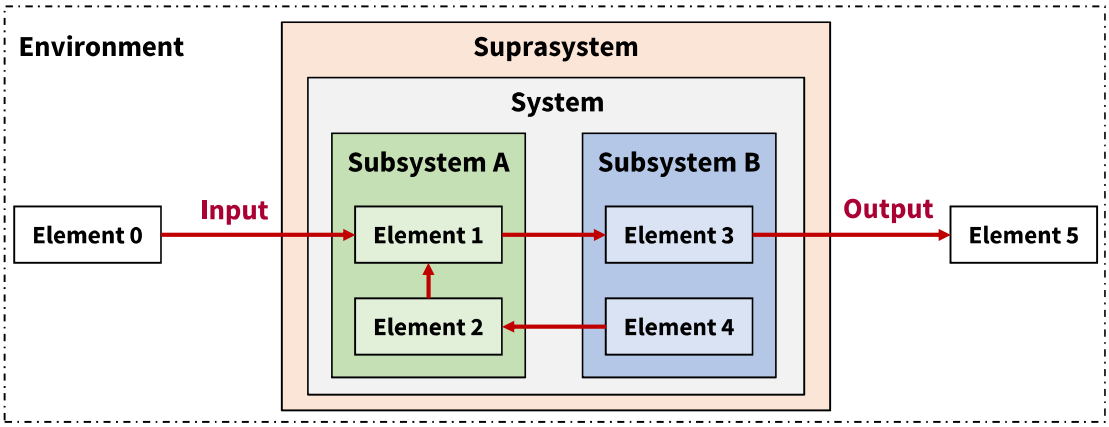


Figure 2: Fundamentals of the systems theory

The systems theory approach is very well suited to get deeper insights into complex constructs and their inner interrelationships. This concept opens the possibility to decompose a real issue and to abstract and restructure it in the form of a simplified model (Ehrlenspiel and Meerkamm, 2013, p. 21). With special regard to sociotechnical project risk monitoring, a deep understanding of the underlying cause-risk-effect relationships related to the intended change is particularly necessary and valuable.

This becomes more evident against the background of the fact that it is not always possible to assign isolated risk sources to a particular risk. Often a certain risk scenario only occurs through a combination of several causes. Moreover, one risk can also lead to a series of subsequent events. Thus, risks may not only be caused, but may themselves be causes for other risk occurrences (DIN ISO 31000, 2018, pp. 7–8; DIN 69901-5, 2009, p. 18; Romeike and Hager, 2020, p. 306).

These multi-layered interrelationships can trigger domino effects in which even initially minor events might lead to serious consequences. Such domino effects are also referred to as the before mentioned systemic risks (Romeike, 2018, pp. 206–209; Romeike and Hager, 2020, p. 306). With reference to systems theory, such systemic risks can occur in two different ways (Romeike and Hager, 2020, p. 306):

1. When an event that affects one system element due to its interactions also affects other system elements and, thus, affects the whole system or
2. when multiple events that affect individual, but interconnected system elements overlap in such a way that they affect the whole system.

For the early detection of risk-changing developments, it is necessary to know the underlying cause-effect chains in order to be able to define targeted indicators (Knappe, 1991, pp. 5–6; lustat - statistik luzern, 2012, pp. 7–8). The fact that risks relating to Industry 4.0 projects are at least partially systemic risks was demonstrated by Gabriel, et al. (2021, p. 245) using the example of the risk "lack of acceptance". Classical approaches used in risk management cannot handle this high degree of complexity (Romeike, 2018, p. 209). Systems theory with its holistic approach, nevertheless, provides a suitable approach to face this challenge and establish an appropriate EWS for digital transformation projects.

Below, Figure 3 shows a schematic visualization for such an envisioned indicator system designed to monitor sociotechnical risks. Thereby, sociotechnical risks are illustrated as complex, systemic risks, penetrating several subsystems of a closed overall system. The objective of the plotted indicators (black boxes) is to monitor the developments related to the exemplary presented causalities. However, it should be noted that projects and enterprises are open systems (DIN ISO 21500, 2016, pp. 9–10; Gareis and Gareis, 2018, pp. 3–6; Rüegg-Stürm, 2004). Under this view, there would also be cause-risk-effect relationships that go beyond the system boundary and do not necessarily have a company-internal, sociotechnical origin or sink.

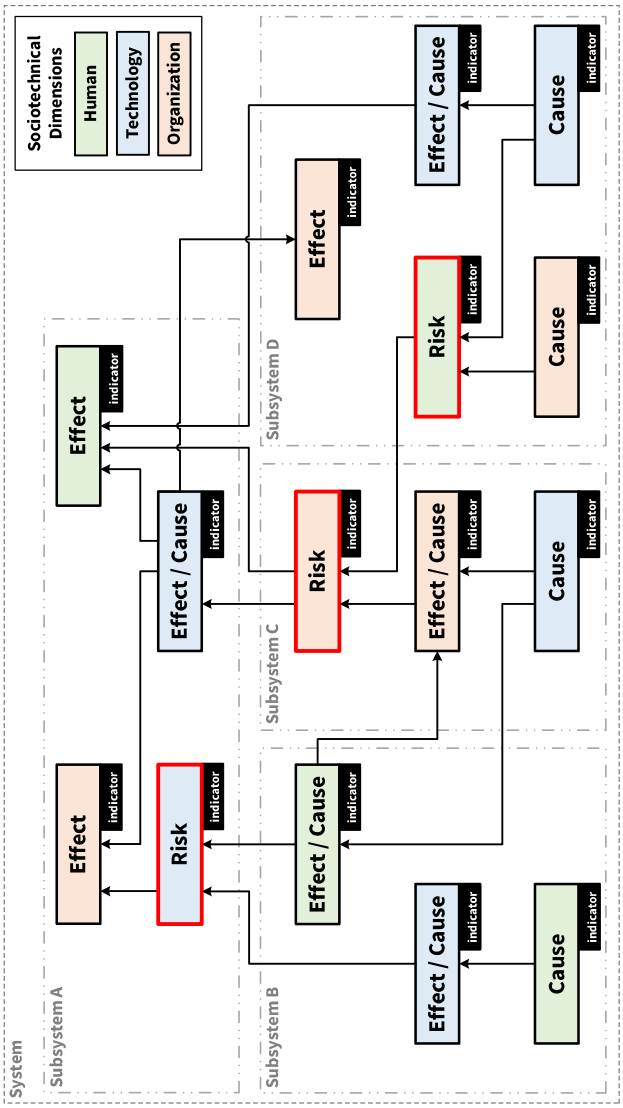


Figure 3: Schematical indicator system to monitor systemic, sociotechnical risks within a closed system

3 Requirements definition for an indicator-based, sociotechnical project risk monitoring framework

In this chapter, research question 1 is addressed. Thus, it aims at defining the requirements to be met by an integrated sociotechnical project risk monitoring framework to allow for a subsequent risk indicator derivation (see Figure 4). In general, the following rules apply in the context of indicator definitions (lustat - statistik luzern, 2012, p. 7):

- The better the definition of the dimensions to be observed, the better knowledge on inter-dimensional dependencies can be gained.
- The better the level of knowledge on dependencies, the better indicators can be formed.

According to this, to build an effective EWS the observation area has to be defined as precisely as possible. This step is critical because indicators can only become meaningful when they are embedded into a specific context (lustat - statistik luzern, 2012, p. 7).

The dimensions to be included in the targeted framework are identified based on a literature review on review on the characteristics of projects and enterprises as open, complex, and sociotechnical systems. The results are converted into content-related requirements R_C in parallel (section 3.1). Moreover, further application-related requirements R_A are derived based on insights from focus group discussions within the “SORISMA” research project and from numerous SME case studies in the context of the “Mittelstand 4.0 Kompetenzzentrum Dortmund” (section 3.2). For a final overview, the defined requirements are summarized in tabular form (section 3.3).

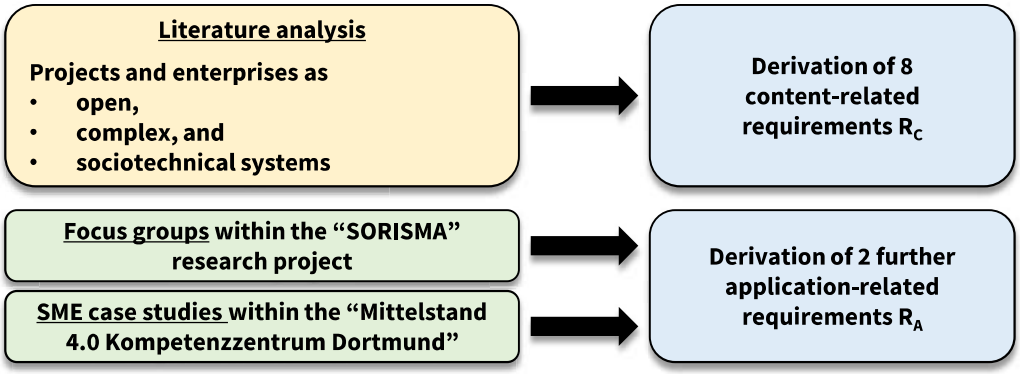


Figure 4: Definition of the framework requirements

3.1 Content-related requirements definition

According to (lustat - statistik luzern, 2012, p. 7), it has proven useful to base a dimensional analysis on a recognized theoretical concept. As already outlined in the previous section 2, systems theory is very well suited to the research questions addressed in this paper and is, therefore, the used approach here.

Throughout the next sections, the characteristics of projects and enterprises are explored as complex and open systems (section 3.1.1) and as sociotechnical systems (section 3.1.2). This approach is designed to provide a combined black-box and white-box perspective on projects and companies respectively as well as on their interrelationships. In this way, a structured decomposition and classification of the interwoven system elements affected by Industry 4.0 projects is intended to be made possible.

In the following, where necessary, there is a reference to "unique classification", which shall be made possible by the framework. This formulation was chosen since unambiguous classification is targeted to embed risks, causes, and effects into specific contexts.

3.1.1 Projects and enterprises as complex, open systems

According to the Project Management Institute (2017, p. 4), a project is defined as "[…] a temporary endeavor undertaken to create a unique product, service, or result." Projects

are, hence, time limited with a defined start and end point. Between these two points in time, an objective is pursued while transforming a current as-is state into a designated to-be state (DIN ISO 10006, 2020, p. 9; Project Management Institute, 2017, pp. 4–6).

From a systems theory point of view, projects as well as enterprises represent complex, open systems. Thereby, single-enterprise projects, as considered in this paper, form a subsystem of an enterprise as they are embedded into it. Moreover, projects as well as enterprises consist of diverse, social relationships and interact with their environment (DIN ISO 21500, 2016, pp. 9–10; Gareis and Gareis, 2018, pp. 3–6; Rüegg-Stürm, 2004).

The mentioned openness allows the project environment to impact the success of the project. Thereby, a fundamental distinction can be made between risk factors internal to the company and risk factors external to the company. Such a differentiation typically forms the starting point for the development of any EWS (Hahn and Krystak, 1979, p. 24). This also makes sense in the context of project risk monitoring. External risk factors usually lie outside the influence sphere of companies and projects. However, for holistic project risk management they should still be considered (DIN ISO 21500, 2016, pp. 11–12).

Requirement R_C 1: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects are located internally or externally to the company.

Moreover, not even all internal risk factors can be directly influenced by project responsibles. Two examples for such internal factors are the enterprise strategy and culture (Project Management Institute, 2017, p. 38). However, as with the external factors, these non-influenceable internal factors should also be included for completeness.

Requirement R_C 2: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects, that are located internally to the company, can be directly influenced or not.

Because of their temporary attribute, projects are to be differentiated from lasting ongoing business operations (DIN ISO 21500, 2016, pp. 11–13; Project Management Institute, 2017, p. 16). For the execution of projects, often specific project organizations

are created that only exist for the limited project duration (DIN ISO 21500, 2016, pp. 13–14; DIN 69901-5, 2009, p. 15). Such a temporary project organization is referred to as a project system in the following, in contrast to the lasting operating system for ongoing operations.

Project systems and operating systems can interact in several ways. For instance, the members of the project system can be members of the operating system at the same time, but they do not have to be (DIN 69901-5, 2009, p. 15). Another example is the case, that the project objective is to optimize an operations process. For this second example, it should be noted that the project object itself (the operations process) is, however, part of the operating system (Project Management Institute, 2017, p. 16). It is obvious, that these complex interrelationships can be seed for risks, causes, and effects. But since the people affected vary in the different areas, this can result in different causalities. For the creation of a meaningful context, differentiation should take place here for the subsequent indicator definition.

Requirement R_C 3: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects are located within the project system or the operating system.

The execution of activities in a company takes place in work systems (REFA-Institut, 2016, pp. 184–185). Different work systems are thereby interconnected via processes (REFA-Institut, 2016, pp. 177–178). As a result, changes in a work system that is transformed through an Industry 4.0 project might also have indirect effects on other work systems. Again, this can result in different cause-risk-effect chains, so another distinction should be made for a clear context.

Requirement R_C 4: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects, located within the operating system, relate to a directly or indirectly affected operating subsystem.

However, not the entire operating system has to be directly or indirectly affected by a digital transformation project. There are also numerous other work systems in a company that might not be influenced at all. Nonetheless, it cannot be precluded that these operating subsystems will not also be involved in the cause-risk-effect-chains of

Industry 4.0 projects. In this regard, a further differentiation seems beneficial to be able to map an entire company in the project risk monitoring framework

Requirement R_C 5: The framework shall also consider those work systems, that are not affected by the Industry 4.0 project.

Digitization projects drive change. To do so, processes of three different hierarchies are applied within the project system (DIN ISO 21500, 2016, p. 16):

- Project management processes, contributing to the management and control of the project;
- Product processes, leading to the value creation of the project objectives;
- Support processes, providing assistance for product and project management processes.

A similar classification of processes can be made for operating systems (Rüegg-Stürm, 2004, pp. 110–118; Wagner and Patzak, 2015, pp. 2-3 and 56-58):

- Management processes, contributing to the management and control of the ongoing operations;
- Business processes, leading directly to the value creation of the company;
- Support processes, providing the necessary infrastructure and offering internal services.

Since this hierarchical classification can be done for both, project systems and operating systems, it may be useful to classify the risks, causes, and effects on which hierarchical level they are located to enable more precise classification for meaningful indicators.

Requirement R_C 6: The framework shall allow unique classification regarding the question on which hierarchical level the risks, causes, and effects are located within the project system or the operating system.

3.1.2 Projects and enterprises as sociotechnical systems

In addition to the so far mentioned characteristics, enterprises are sociotechnical systems, in which people perform certain tasks using technical aids while following particular structures (Rüegg-Stürm, 2004, p. 69; Ulich, 2011, pp. 198–201). Since the four components task, human, technology, and structure are closely interconnected, a change in one of the elements directly affects the others (Leavitt, 1965, pp. 1144–1146).

Thus, successful technology-driven change always requires the joint consideration of technological as well as social factors (Clegg, 2000, p. 464; Ulich, 2011, p. 111).

In this context, Ulich (2011) developed the sociotechnical Human-Technology-Organization (MTO) concept. The approach is based on the "primacy of the task", as it forms the core of the sociotechnical system. The task links the human being with the technology and characterizes the human-machine interface. In connection with the activities to be performed and defined hierarchies, the work task also links the human being with the organizational structure of the company (Ulich, 2011, pp. 198–203). The figure below illustrates the described, sociotechnical MTO concept.

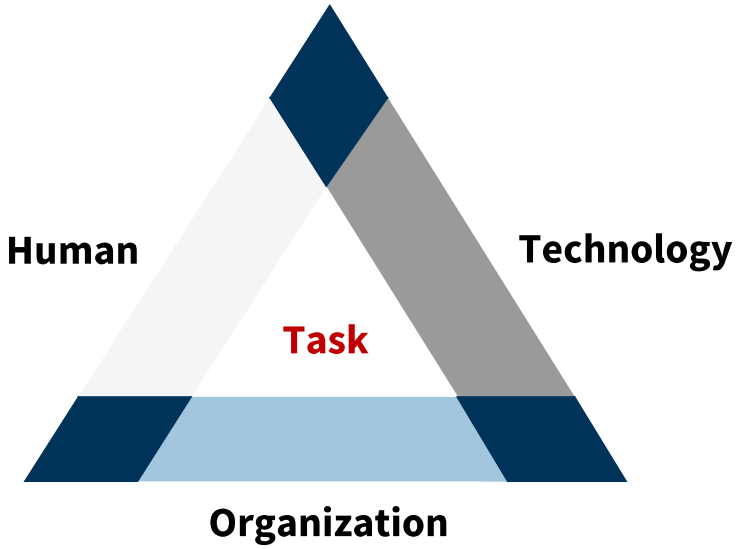


Figure 5: Sociotechnical MTO concept, based on Ulich (2011, p. 202)

Since projects are subsystems of enterprises, as described above, projects are to be considered as sociotechnical systems as well. With the special regard to Industry 4.0 projects in this paper, this attribute is of particular importance (see section 1) (Henke, et al., 2020, pp. 280–282; Hirsch-Kreinsen and Weyer, 2014; Hirsch-Kreinsen and ten Hompel, 2017; Ittermann, et al., 2016; Schuh, et al., 2020).

Requirement R_C 7: The framework shall allow unique classification regarding the question from which sociotechnical MTO dimension the risks, causes, and effects originate.

Henke, et al. (2020) also propose to consider a fourth dimension, information, in addition to the three classical MTO dimensions. The authors justify this with the increasing importance of big data and the availability of real-time information in the course of Industry 4.0 (Henke, et al., 2020, p. 281).

These considerations make sense in the context of sociotechnical project risk management against yet another background. Communication and information exchange play an essential role in both, risk management and project management, and are integral parts of the respective processes. Appropriate information sharing is essential to engage and inform all stakeholders involved (DIN ISO 21500, 2016, pp. 40–41; DIN ISO 31000, 2018, pp. 15–17; DIN IEC 62198, 2002, pp. 10–11). Conversely, it can be deduced that a lack of information exchange can lead to project failure.

Requirement R_C 8: The framework shall include the dimension information as a fourth, extended dimension of the sociotechnical system.

3.2 Application-related requirements definition

To supplement the content-related requirements from the previous section 3.1, this section defines additional application-related requirements R_A. These supplementary requirements are derived from two different origins.

First, within the “SORISMA” research project (Sociotechnical risk management in the introduction of Industry 4.0) regular focus groups take place. These focus groups have been taking place regularly at intervals of approximately two months since December 2019. The almost constant group of participants comprises 15-20 people each time, consisting of scientists from various research institutions and representatives from industrial companies. The latter are composed of a mixture of experienced project managers and members of the executive management, who again represent companies of different sectors and sizes – from SMEs to large international corporations.

Second, the findings from the discussions in the research project are additionally supported by experience from the "Mittelstand 4.0 Kompetenzzentrum Dortmund", where in recent years hundreds of SMEs were already supported in their digitization projects.

From all the lessons learned in the focus groups and the case studies, with reference to the framework to be developed, it can be derived that

- the framework to be developed should be as generic as possible to enable versatile application for a wide range of Industry 4.0 projects, according to the defined scope of application (see section 1.1) and that
- a framework development is an evolution that has to be conducted iteratively in order to regularly re-integrate new findings.

For this reason, two additional application-related requirements are defined. They are:

Requirement R_A 1: Universality - The framework shall allow the greatest possible versatility of use for individual and single-enterprise digitization projects within the manufacturing industry.

Requirement R_A 2: Modularity - The framework shall be composed of several subsystems and could be developed and expanded in modules. Thus, the framework could be adapted to new or changed conditions or findings.

3.3 Consolidation of the defined requirements

To summarize the previously elaborated results, the following Table 1 provides a concluding and condensed overview of the derived requirements.

Table 1: Consolidated overview of the defined requirements

Type	ID	Description – The framework shall …
Content-related	R_C 1	… allow unique classification whether the risks, causes, and effects are located internally or externally to the company.
	R_C 2	… allow unique classification whether the risks, causes, and effects, that are located internally to the company, can be directly influenced or not.
	R_C 3	… allow unique classification whether the risks, causes, and effects are located within the project system or the operating system.
	R_C 4	… allow unique classification whether the risks, causes, and effects, located within the operating system, relate to a directly or indirectly affected operating subsystem.
	R_C 5	… also consider those work systems, that are not affected by the Industry 4.0 project.
	R_C 6	… allow unique classification on which hierarchical level the risks, causes, and effects are located within the project system or the operating system.
	R_C 7	… allow unique classification from which sociotechnical MTO dimension the risks, causes, and effects originate.
	R_C 8	… include the dimension information as a fourth, extended dimension of the sociotechnical system.
Application-related	R_A 1	… allow the greatest possible versatility of use for individual and single-enterprise digitization projects within the manufacturing industry. (Universality)
	R_A 2	… be composed of several subsystems and could be developed and expanded in modules. Thus, the framework could be adapted to new or changed conditions or findings. (Modularity)

4 Proposed framework for indicator-based, sociotechnical project risk monitoring

In this section, the designed framework for indicator-based, sociotechnical project risk monitoring is presented (research question 2). The literature does not provide similar work yet, although efficient project risk management and monitoring is known to be a key to project success. This insight is also supported by the finding of Menzefricke, et al. (2021, pp. 711–712) according to whose study sociotechnical project risk management basically has not yet been part of the scientific discourse.

Below, the proposed framework with its individual building blocks is described as well as graphically illustrated (section 4.1). Subsequently, an exemplary case study from the SORISMA research project is presented, based on which first starting points for a validation with practical reference are given (section 4.2).

4.1 Introduction of the developed framework

In developing the framework, emphasis was placed on meeting all of the derived requirements (see section 3). Furthermore, it was intended to make the framework tangible by means of a visual representation. Here, care was taken to find a balance between a visualization that is simple, but does justice to the underlying complexity

The final model is illustrated in Figure 6 below. It consists of five major building blocks, defining the context to be explored for causalities for subsequent indicator derivation:

- enterprise subsystems,
- process-related hierarchy levels,
- sociotechnical dimensions,
- elements of order, and
- external actors.

The first three are placed in the center of the framework as a three-dimensional cube that simplified represents the internal structure of enterprises. In general, the basic setup of the model is inspired by the St. Gallen Management Model (Rüegg-Stürm, 2004, p. 70), a well-reputed reference framework in system-oriented management theory.

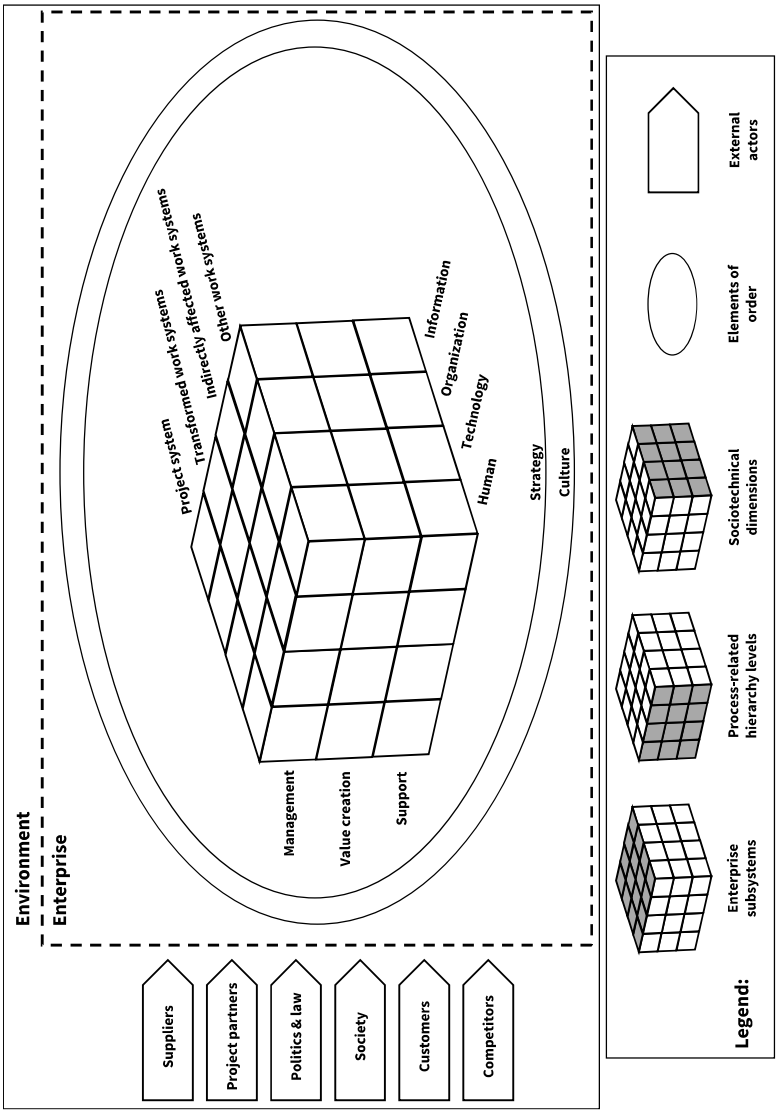


Figure 6: Proposed framework for indicator-based, sociotechnical project risk monitoring

As already stated above, the core of the designed model is a three-dimensional cube. Here, it was intended to bring the character of the risks in Industry 4.0 projects as systemic, sociotechnical risks to the center of attention to enable a context-specific classification of the risks, causes and effects. To this end, not only the related sociotechnical dimensions, but also the respective enterprise subsystems systems that are permeated by the cause-risk-effect chains as well as the hierarchical level of the

processes affected therein shall be considered to enable a meaningful derivation of indicators.

The respective enterprise subsystems are illustrated on the top side of the cube. Next to the project system, the coexisting operating system is listed here (requirement R_C 3). However, in the framework the operating system is further divided into work systems that are transformed (the project object), indirectly affected, and not at all affected by the project activities (requirements R_C 4 and R_C 5). Thus, all operating work systems are considered in their entity.

On the left side of the cube, the different process-related hierarchy levels that can be found within an enterprise are plotted (requirement R_C 6). Here, a generic three-way split was made into management processes, value creation processes, and support processes as often found classification for projects as well as enterprises (e. g. DIN ISO 21500, 2016, p. 16; Rüegg-Stürm, 2004, pp. 110–118). A further subdivision, for instance into strategic, tactical, and operative management processes, has been omitted at this point for simplicity. The processes of all three hierarchy levels run through the entire enterprise subsystems.

The sociotechnical dimensions are represented on the right side of the cube. In addition to the classical MTO dimensions of human, technology, and organization, the dimension information is included as a fourth extended, sociotechnical dimension as initially suggested by Henke, et al. (2020, p. 281) (requirement R_C 7 and R_C 8). All enterprise subsystems (upper side) with the processes running through them (left side) each represent a separate, sociotechnical system with these four dimensions.

The central cube is held together by elliptically illustrated elements of order, which are essential for the viability of a company, but also represent internal risk factors that may not be immediately influenceable (requirement R_C 2). The elements of order listed here are the corporate strategy and the corporate culture, as frequently mentioned, non-tangible internal risk factors in the literature (e. g. DIN ISO 21500, 2016, p. 11; Project Management Institute, 2019, Chapter 7.1.1 (E-Book); Rüegg-Stürm, 2004, p. 70).

The cube and the elements of order together form the enterprise system, which is separated from its environment by a system boundary (requirement R_C 1). As external risk

factors, suppliers, project partners, politics and law, society, customers as well as competitors are listed at the very left, as these were frequently mentioned in the literature (e.g. DIN IEC 62198, 2002, p. 5; DIN ISO 21500, 2016, p. 11; Gabriel, et al., 2021, p. 244).

The modular and generic structure of the five major elements as well as the unspecific naming without reference to any particular Industry 4.0 projects are chosen to ensure compliance with the application-related requirements R_A 1 and R_A 2.

4.2 Case study application of the proposed framework

In this section, first starting points for a validation of the developed framework are given. For this purpose, the framework is applicated to an exemplary and real-life case study from the SORISMA research project. As a first step in the evaluation process, the goal here is to map a sociotechnical risk to the framework and, thus, to embed it into a concrete context. The findings as well as further evaluation steps will be discussed afterwards.

Case study introduction: The objective of the examined Industry 4.0 project, which is being pursued by a family-owned SME, is to implement an automated guided vehicle (AGV) system. The AGVs are to convey load carriers with raw materials which are manually provided from a high-bay warehouse to the production department and to transport finished goods from there back to a finished goods warehouse.

For this use case, nine primary risks were initially identified, out of which the risk "lack of competencies" is examined in more detail here to provide a first step towards the framework evaluation.

Mapping the risk to the framework: The risk "lack of competencies" can be generally assigned to the sociotechnical dimension “Human” (Gabriel, et al., 2021, p. 244). However, to allow for a more specific context and to ensure a meaningful indicator derivation, further investigations are necessary. Therefore, further consultations with the industry partner were held, during which it became apparent that different groups of people can be associated with the risk “lack of competencies”. Three examples on who is affected are provided below.

1. First, the employees whose previous transport tasks are substituted by the AGVs and who are to be retrained as control station users and control station key users.
2. Second, the production workers who in the future need to trigger digital transport orders for the AGVs. Currently, the finished goods transports are triggered by verbal call.
3. Third, the employees in the high-bay warehouse, who need to pay increased attention to damaged load carriers in order to avoid errors in the sensitive AGV process.

The previous descriptions already show that the AGV project influences several work systems. But this is true to varying degrees.

The transport system, which is being transformed by the industry 4.0 project, is directly affected. Thus, example 1 reflects to the framework dimension “Transformed work systems” of the enterprise subsystems.

The two work systems high-bay warehouse and production are also affected by the change, but only indirectly. Within the framework, the examples 2 and 3 are accordingly assigned to the enterprise subsystems dimension "Indirectly affected work systems".

Regarding the mapping to the process-related hierarchy levels, it is important to note that the risk “lack of competencies” relate to the desired target state. For this reason, the classification with respect to the process-related hierarchy levels should also refer to this target state. Example 1 above makes it clear that the risk here stems from the changing work profile, from value creation to operational management.

Following this, example 1 relates to the process-related hierarchy level dimension of “Management”, while examples 2 and 3 relate to the dimension of “Value creation”.

In the following Figure 7, the results of the described mapping process are illustrated. Thereby, example 1 is visually highlighted in green, example 2 in orange and example 3 in blue.

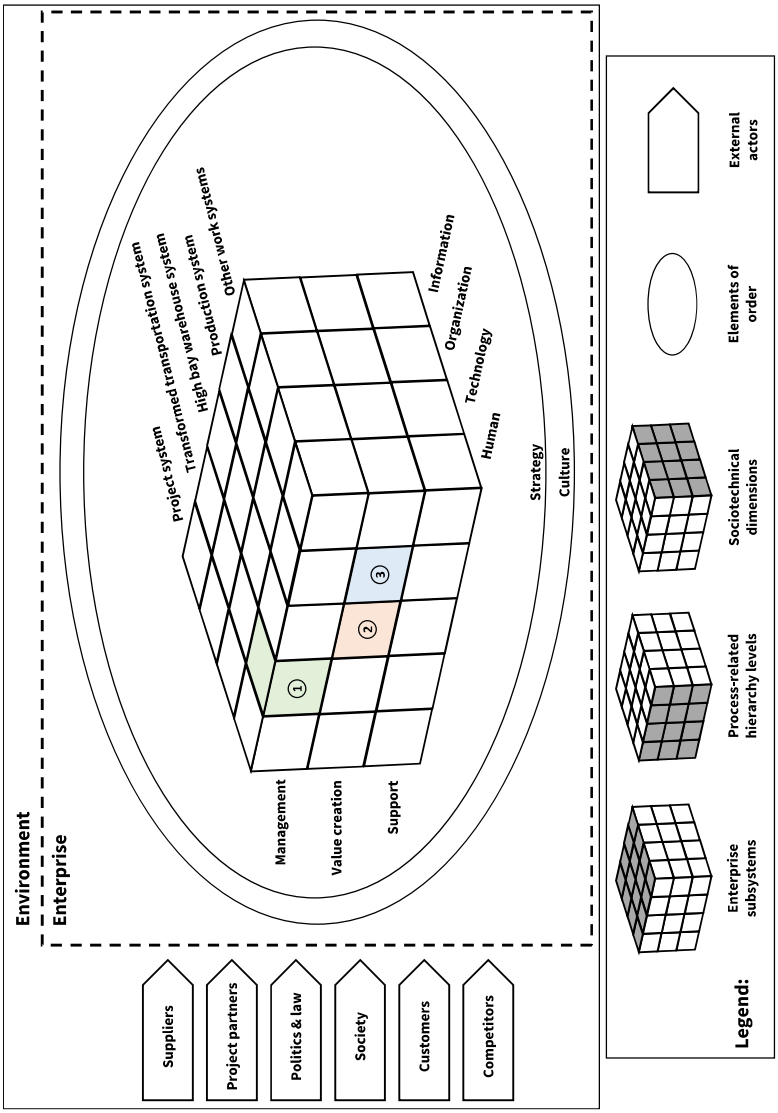


Figure 7: Case study application results – The unspecific risk “lack of competencies” evolved into three specific, contextual risks

Findings on the model: As a first result, it was found that the framework could be smoothly tailored to the specific use case under consideration. Due to the modular and generic structure of the model, the one non-specific dimension "Indirectly affected work systems" could be transformed into the two case study specific operating subsystems "High bay warehouse system" and “Production system”. This gives a first indication that the framework indeed meets the application-related requirements R_A 1 and R_A 2.

With a view on the objectives of the framework, it was found that by applying the framework, it was possible to bring the unspecific risk “lack of competencies” into a more specific context for the particular use case under consideration. Guided by the proposed dimensions of the framework, it was found that this very risk affects several enterprise subsystems on different hierarchy levels. So, the one initial risk “lack of competencies” in this example evolved into three specific risks.

As a next step, it would be necessary to investigate the underlying causalities of the three specific risks and to map them to the framework as well. The insights from the presented case study form a solid foundation for this analysis, as they give guidelines on where to start and on what to focus (e. g. the control stations users to-be in example 1).

The elements of order and the external actors were not relevant for mapping the examined risk “lack of competencies”. However, this does not mean that they cannot still become so with reference to the causes and effects of this risk.

The presented results from the case study, as well as the forthcoming results on specific causalities, should finally enable the derivation of suitable indicators on the basis of the contextual information obtained.

5 Conclusion, limitations, and further research

Many companies still fail on their digital transformation endeavors. The fact that Industry 4.0 projects affect entire enterprises as a sociotechnical system provides a breeding ground for various risks. Project risk monitoring as integrated part of project management is key to successful projects. However, the special requirements of project risk monitoring for Industry 4.0 projects have not yet been the focus of scientific investigations.

In general, indicator-based early warning systems have proven themselves in various risk monitoring domains. Since indicators can only become meaningful when brought into a specific context, the first step towards building any indicator-based monitoring system is to establish an appropriate framework that defines the area under consideration. Accordingly, as a first step towards closing the research gap, this paper aimed at the development of such a framework for indicator-based, sociotechnical project risk monitoring.

To find a suitable approach, in section 2 the sociotechnical risks endangering digitization projects have been examined in more detail. As a result, they were characterized as cascading, systemic risks. To be able to handle the underlying high degree of complexity, systems theory with its holistic concept is found as a promising solution approach.

In a next step, requirements have been derived that shall be met by the framework to be designed. A total of ten requirements was defined in section 3: eight content-related and additional two application-related requirements. To derive the former, projects and enterprises were both explored as complex, open, and sociotechnical systems by conducting a literature analysis. The latter were derived based on insights gained in focus groups within the SORISMA research project as well as in numerous previous SME case studies.

In the following section 4, the framework developed in accordance with the set requirements was presented. The proposed model consists of five major building blocks to embed risks, causes, and effects into a specific context, namely: enterprise subsystems, process-related hierarchy levels, sociotechnical dimensions, elements of

order, and external actors. The basic framework structure was inspired by the St. Gallen Management Model as renowned reference framework in system-oriented management theory. Furthermore, the designed framework was subjected to an initial evaluation using a real-life case study. However, so far only initial starting points for an evaluation could be given. In this regard, limitations as well as further research possibilities have to be considered.

First, limitations have to be considered with respect to the framework itself. The building blocks and especially the elements of order and the external actors were identified hands-on by analyzing the literature used for this paper. To enrich the proposed framework and to evolve it in an iterative process, further research could focus on in depth investigation of the building blocks, e. g. by performing structured literature analyzes.

In addition, the scope of application has been limited in section 1.1 since the proposed framework is a first attempt to help bridge the existing research gap. In this regard, it could be examined if or to which degree the designed framework is applicable to those excluded application domains, e. g. the monitoring of digitization portfolios or programs.

Moreover, it was not possible to provide an overall evaluation since it was not yet possible to actually derive indicators for tracing the underlying cause-risk-effect relationships. To be able to do this, the causalities must be known in the first place. And obtaining this information on risks and their cause-and-effect chains is the task of Risk analysis and assessment (see section 1.1). Accordingly, the designed framework formulates information demands on the risk analysis and assessment to finally allow for a subsequent indicator derivation.

However, since sociotechnical project risk monitoring was not in the focus of the scientific discourse so far, implications of this new information demand on existing approaches to sociotechnical risk analysis and assessment should be analyzed in further research.

Financial Disclosure

The results of this paper are based on the research project SORISMA (Sociotechnical risk management in the introduction of Industry 4.0), funded for three years with around 2.7 million euros by the European Regional Development Fund (ERDF).

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II.
Artificial Intelligence and Blockchain

The State of Artificial Intelligence: Procurement versus Sales and Marketing

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Purpose: *Sales and procurement are the main boundary spanning functions of an organization – each with a specific focus and partly different views and objectives. They are often considered as two sides of a coin that struggle with one another for relative competitive advantage. The digitalization of procurement functions and the introduction of enterprise resource systems have led to a seeming data abundance. However, the results especially in the area of artificial intelligence are not yet satisfactory in practical application. In addition, few academic works are steered towards procurement. In fact, some expect that procurement is less likely to benefit from the application of methods of artificial intelligence (AI) emphasizing the potential benefits in functions such as finance, production, marketing and sales. Why is that? What can we do about it?*

Methodology: *Explanatory study considering the needed decisions and available data of procurement in contrast to sales and marketing. The manuscript is structured in three sections based upon the "Memorandum of Design-Orientated Business Informatics" with analysis, draft, evaluation and diffusion (Österle et al., 2010).*

Findings: *There is a need for research on the purchasing-marketing interface, not just for AI but also for AI applications and analytics in general. Procurement scholars and managers must speed up data and analytical development, especially since our negotiation partners are benefiting from the rapid development of AI technology. Five propositions have been derived from a master thesis analyzing the needed decision and available data as well as during discussions at the 2021 European Research Seminar to facilitate practical application for management and direct further research. These are more perceived value, more data, better technological solutions, more skills and training, and different role in the value chain.*

Originality: *This is an original work of in-progress research.*

First received: 25. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Analysis

Artificial intelligence (AI) is a research area that attempts to design mechanisms allowing machines to develop intelligent behavior (Russell et al., 2009). In McKinsey's (Balakrishnan et al., 2020) as well as Deloitte's (Ammanath et al., 2020) "The state of AI" survey the business functions in which organizations adopt AI are over time largely consistent with service operations, product development, marketing and sales. Since sales seem to have a faster pace, procurement must speed up in the analytics race (Chae et al., 2014, Allal-Chérif et al., 2021). Why, for instance, is procurement not at large using AI for supplier risk assessment when sales is using AI for demand forecasting?

For big data analytics in general, research has shown that procurement is also lagging (Nguyen et al., 2018, Vollmer et al., 2019). Searches on academic and popular databases utilizing keywords such as procurement as well as sales and marketing respectively with artificial intelligence / machine learning / big data analytics further indicate that there is more research and application in sales and marketing. In addition, there are many search hits, what salespeople can learn from buyers but interestingly not the other way around. Maybe now is the right time to turn the coin on the other side also from a procurement perspective! One example is an article in the magazine Spend Matters, which urges management to concentrate on information sharing throughout the value chain with common metrics. Based on data from the Association of National Advertisers in the United States of America in the article it is highlighted that while marketers are concerned with strengthening marketing performance, buyers are focused on reducing costs and making internal processes less risky and more efficient (Wyld, 2014).

Research question: Why is procurement lagging in AI adoption versus marketing / sales?

Procurement as a discipline sometimes still feels inferior to other disciplines, however, that is not per se a good enough reason to compare and postulate that procurement should be as advanced, i.e., there could be supply chain alignment reasons. Technology adoption processes, in general, have been divergent (Venkatesh et al., 2003), and no commonly accepted view exists still today. On the contrary, there are numerous models available, some of which complement each other and some that are contradictory (Mahlamäki et al., 2021). It could also be a matter of internal integration as the use of AI

in sales and marketing somehow influence the use of AI in procurement. Some view purchasing as reverse marketing (Leenders and Blenkhorn, 1988). In this sense, this work contributes to the management of the purchasing-marketing interface, provides practical ideas, and directs future research.

2 Draft

Procurement and sales are the main boundary spanning functions of an organization - next to human resources on the labor market and finance on the money market - each with a specific focus and partly different views and objectives (Katz and Kahn, 1978). There is, in general, more visibility internally and externally on sales and marketing that for instance has a seat on the board of management of almost every organization, which is not yet true for procurement. In many buying organizations today, data is often still not recorded in a consistent and strategic manner and, generally, there are more solution providers for customer relational management than for supplier relationship management (Guida et al., 2021). Overall, sales and marketing seem more professionally developed, e.g., training expenses for salesmen are several times higher than for buyers (CAPS Research, 2014).

Digitalization changes both buying processes and sales processes and, consequently, the dynamics and division of work between buyers and suppliers in the supply chain. This has major implications for industrial marketing and supply chain management (Mahlamäki et al., 2021). Procurement can be defined as the acquisition from an external source at the best possible cost to meet the needs in terms of quality, quantity, time, and location and must deal with conflicting targets including time, cost, and quality constraints (van Weele, 2018). While marketing is the process by which companies engage customers, build strong customer relationships, and create customer value in order to capture value from customers in return (Kotler and Armstrong, 2018), sales is generally considered to be part of marketing and can be defined as a business system required to effectively develop, manage, enable, and execute a mutually beneficial, interpersonal exchange of goods or services for equitable value (ATD, 2008). Now, what are the differences between these functions? By consideration of the industrial buying

process model as well as the comparison between consumer markets and industrial markets (van Weele, 2018), the needed decisions and available data are summarized in the Table below along the strategic, tactical, and operational levels:

Table 1: Comparing procurement with sales and marketing along the needed decisions and available data on the strategic, tactical, and operational level

Dimension	Procurement		Sales / marketing	
	Decisions	Data	Decisions	Data
Strategic	Value network	Overall costs and quality	Value proposition	Overall profits and revenue
Tactical	Supplier selection	Achieved savings	Project bidding	Achieved projects
Operational	Supplier evaluation	Performance measurement	Project control	Performance measurement

Thus, five propositions were derived by contrasting and comparing the needed decisions and available data in a master thesis at the University of Mannheim (Zhong, 2021) as well as during discussions at the 2021 European Research Seminar (Spreitzenbarth et al., 2021a). These are more perceived value, more data, better technological solutions, more skills and training, and different role in the value chain described in this chapter.

3 Proposition I "more perceived value"

The digitalization of procurement and the introduction of electronic procurement has led to a seeming data abundance. Yet, few contributions are steered toward the implementation of AI in supply management (Moretto et al., 2017, Handfield et al., 2019). For instance, AI methods can reduce the time spent in unnecessary negotiation, and thus improve negotiation efficiency (Son et al., 2014). A digital twin of a salesperson can be

used to train and improve decisions (Karlinsky-Shichor and Netzer, 2019) to evaluate whether a bid should be accepted or rejected (Zhang et al., 2014). However, in a study with machine learning models for sales predictions, the role of procurement was only described by only one attribute namely whether the procurement department is involved in the sales opportunity (Bohanec et al., 2017). Therefore, there is a need for procurement scholars and managers to speed up data and analytical development, especially when the negotiation partners are benefiting from the rapid development of AI technology (Nowosel et al., 2015, Handfield et al., 2019, Schulze-Horn et al., 2020).

At the 2021 IPSERA conference, a review of artificial intelligence and machine learning in procurement was presented in which eleven use case clusters were assigned along the strategic, tactical, and operational level illustrated in the Figure below:

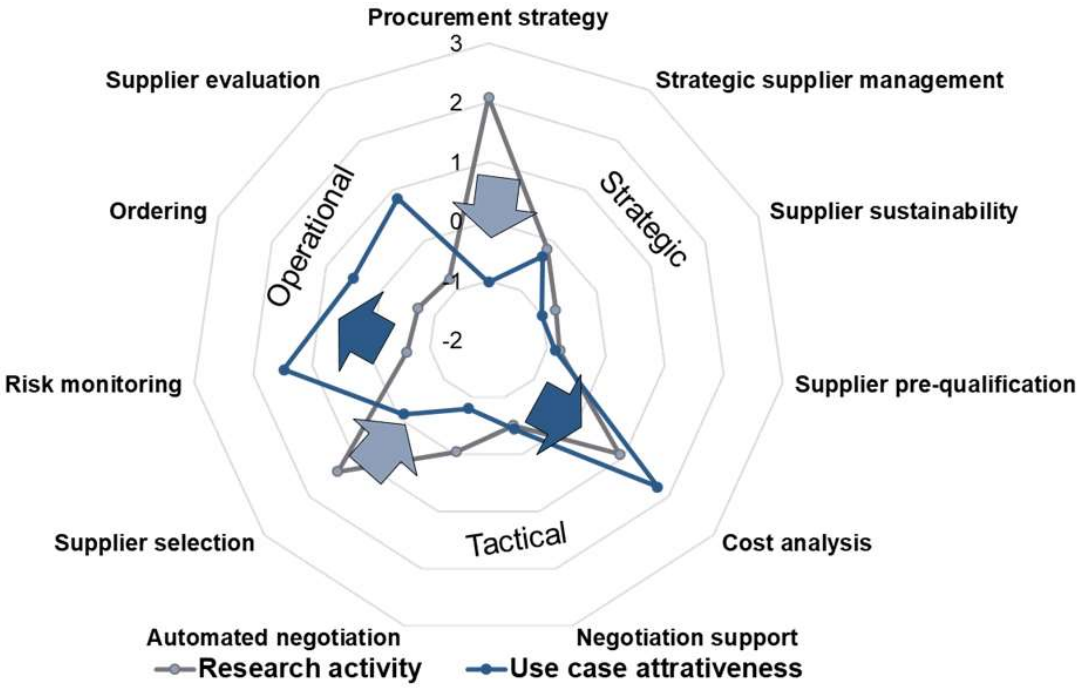


Figure 1: Research activity and attractiveness in standard deviations (Spreitzenbarth et al, 2021b)

Based on this analysis, the most attractive use cases seem to be cost analytics and risk management. AI methods may be applied to pricing behavior analysis, raw material price forecasting, in-depth comparison of offers, benchmarking, and tiered pricing proposals

(Maltaverne and Dieringer, 2017). Considering Kraljic's classification (Kraljic, 1983) for requisitions with low supply risks, use cases such as supplier scouting as well as automated negotiation are probably more relevant while risk monitoring is essential for high supply risk requisitions. For instance, the German start-up riskmethods has developed a solution to anticipate purchasing risk (Enthoven, 2020). Advantages are, for example, the ability to act quickly based on keyword and location search - especially with complex sub-supplier management such as semiconductors. In addition, a world café was conducted at a German automotive manufacturer where twenty experts discussed the potentials of AI for purchasing indicating that AI methods can facilitate mechanism design-based negotiations (Schulze-Horn et al., 2020).

In sales and marketing, AI can be used from price optimization, forecasting, up-selling and cross-selling, to performance management. If data is the new oil, those who can generate actionable insights will be able to close more deals, more often (Antonio, 2018). AI excels at solving problems for customer relationship management (Nam et al., 2019). Swift data processing provides the opportunity to monitor markets in real-time (Xu et al., 2016). In addition, AI methods can find patterns in data and develop new business models to secure customer relationships (Syam and Sharma, 2018). Thus, projects in sales and marketing utilizing data to optimize what products and services should be offered at which price can directly increase revenue and profit margins. The business case of analytics projects in procurement is in practice more difficult to justify as it often leads to process quality improvements that provide value to the organization but are more difficult to measure. Therefore, this could contribute to sales functions adopting the technology sooner than procurement from a financial perspective.

To sum up, there seems to be the perception that AI in sales and marketing contributes a higher value proposition to the organization than AI in procurement. However, this may change in time if more data, technology, and training lead to a higher perceived value proposition. Recommendation I: Consider closely the value that procurement delivers to the organization when evaluating where to invest in data, technology, and skill.

4 Proposition II “more and better data”

AI techniques are based on one of the most important building blocks, data. In procurement much data is generated (Handfield et al., 2019); however, available data is not always enough to have an overall view (Connaughton and Sawchuk, 2017). For example, external data not yet readily available could help to anticipate delays in the supplier production cycle, sudden changes in the raw materials market or regulation (Brintrup et al., 2019). Many procurement practitioners, consultants, and academics report that important data is not gathered in a sufficiently consistent and strategic manner in order to make it useful for advanced analytical techniques (Handfield et al., 2019, Spreitzenbarth et al., 2021b). For instance, if data for quality defects or logistics costs is not linked to the project, this may hinder gaining a deeper understanding based on data to make better decisions in the future. Thereby, data quality is an important aspect that has been highlighting as a major roadblock for AI implementation in procurement (Hazen et al., 2014, Chopra, 2019, Guida et al., 2021).

Organizational information processing theory compares information processing needs with information process capabilities (Galbraith, 2014). The competition between sales and procurement is also the competition between the amount of valid information and the means to interpret this information. Sellers most likely understand their products better than the buyers, hence creating an information asymmetry. Today, buyers typically spend over half of their time on transactional activities (Vollmer et al., 2018). As highlighted in the Spend Matters article in the previous chapter, data sharing and data integration with supply chain partners along the network could be one way with high-level supplier integration may lead to more data with a higher degree of data quality, i.e., for better demand forecasting leading to process improvements in the whole network (Huber and Stuckenschmidt, 2020). For example, the Chief Information Officer of Porsche, Matthias Ulbrich highlighted the importance of demand forecasting for functions spanning from sales, procurement, and production (MIT Sloan, 2020).

To sum up, there seems to be more data with higher quality for AI in sales available. However, procurement can design the tendering process and actively manage the expectations of the internal and external stakeholders. Recommendation II: Gather data

with a consistent strategy aligned with the overall strategy where especially data sharing within the value chain is one interesting way to obtain better information.

5 Proposition III “better technological solutions”

Supplier relationship management (SRM) and customer relationship management (CRM) are increasingly utilized to obtain, store, and analyze data (Chopra, 2019). Thereby, important SRM and CRM systems such as SAP, Oracle, and Salesforce provide not just an information system but an ecosystem (Straub et al., 2021). Procurement normally can only take part in the business-to-business (B2B) market while sales can also take part in the business-to-customer (B2C) market. Given that the number of customers in the B2B market is normally smaller than in the B2C market (Hallikainen et al., 2020), in general, more data is available for scholars and firms in the sales area. Some CRM solution providers such as XiaoE Tech from China offer flexible application programming interfaces so that their systems can be linked to other platforms such as social media (Zhong, 2021). The coverage of the B2C market creates a cross-sector cooperation opportunity between the social media companies and sales functions.

The solution provider Celonis highlights use cases in procurement for process mining and optimization, e.g., a case study of 279.000 orders that have been loaded into a to-be process model. A conformance checker scans the actual process, providing key statistics about the conformance and a list of violations sorted by their frequency. Thereby, on average the throughput time of non-compliant cases was significantly higher than of compliant cases (Veit et al., 2017). Another example is SAP NetWeaver, which also provides real-time insights into the process data. For instance, when purchasing new material, users can evaluate the delivery performance to choose the best-performing vendors. As another example from China, Fitow offers supply chain quality management services for the automotive industry. It developed an early warning system for quality defects giving the buying organization an information advantage (Zhong, 2021).

AI methods can intelligently find and extract information across thousands of sources (Chopra, 2019). For example, the German start-up Scoutbee focuses on identifying potential new suppliers through search methodologies (Scoutbee, 2021). Another start-

up from Germany, Botfriends, is providing chatbots for use cases from providing requestor support to order handling, automated negotiation, and billing support (Botfriends, 2021). The multinational corporation Siemens is utilizing a sourcing bot that finds the contracted rate, provides the next best available rate or the option to start a new request for quotations (Straub, 2019). Automated negotiation is likely to play an important role in future buyer-supplier relationships change the types, design, and frequencies of interactions between organizations (Schulze-Horn et al., 2020).

Furthermore, procurement could utilize CRM tools such as Salesforce to manage actively internal and external stakeholders (Conga, 2020). Currently, the majority of procurement organization's supplier risk assessment and supplier collaboration are time-consuming activities. Mirroring email marketing automation could help to automate an operational task while developing a foundation of insight for strategic decisions (Jenks, 2019). In addition, a world café was conducted during the Ph.D. project of an Italian colleague with thirteen experts followed by a questionnaire comparing and highlighting emerging AI-enabled service platforms such as Suplari AI-Automated Analytics & Insights, Coupa Risk Aware, and Zycus Merlin AI Suite (Guida et al., 2021). Another colleague described five case studies of AI technology in procurement: Firstly, Synertrade provides automation and optimization of purchasing processes. Secondly, Siley develops a global matching system that links purchasing requests to suppliers. Thirdly, the widely used software suite SAP Ariba for data analysis and decision support. Fourthly, the SRM provider Jaggaer that supports the management of supplier relations. Lastly, Ideapoke facilitates collaborative project management and open innovation (Allal-Chérif et al., 2021).

To sum up, there seems to be better technology for AI in sales available than for AI in procurement. However, there are interesting solutions available from startups and providers are extending existing tools with AI capabilities. Recommendation III: AI adoption should be seen as a long-term process of constructing an ecosystem whereby choosing the right technology partners is key to future success where in particular utilizing tools such as Salesforce could be a leapfrog for procurement.

6 Proposition IV “more skills and training”

Having both the domain knowledge and the technology toolbox is an important skill set for future buyers (Chopra, 2019). Analytical methods allow the firms to enhance their decision quality during business operations (Gunasekaran et al., 2017, Balakrishnan et al., 2020). Talent gaps could be a possible factor that prevents procurement from implementing and fully utilizing AI (Schoenherr and Speier-Pero, 2015, Ammanath et al., 2020); however, this also holds true for sales and marketing. A data-centered decision process can be applied in different ways; however, the actual implementation is still far from mature (Guida et al., 2021). Hence, procurement needs to change the decision-making culture and speed up the digitalization process (Batran et al., 2017, BME, 2018, Shefford and Holland, 2018).

AI can lead to a different approach of purchasing, more agile, reactive, and efficient. Buyers can focus on more strategic and creative missions putting purchasing at the heart of innovation (Allal-Chérif et al., 2021). Overall, sales and marketing are seemingly more professionally developed, e.g., training expense for salesmen is several times higher than for buyers (CAPS Research, 2014). The example of Fitow shows that human intelligence such as senior workers combined with AI can be an efficient way to break down the information barrier between different sectors. Humans are strong in integrating information from different sources generating insights (Saenz et al., 2020).

To sum up, buyers are in general skilled in data analysis and used to learn new skills and techniques - just like people in sales roles. Recommendation IV: Set up organizational structures and processes to effectively combine human skills and artificial intelligence to achieve maximum efficiency with human-AI collaboration.

7 Proposition V “different role in the value chain”

The positioning in the value chain is important to sustain competitive advantages (Porter, 1998, Walters and Lancaster, 2000). One important aspect is the risk-averse and cost-focused identity, which hits the mark of procurement self-perception and external valuation (Murfield et al., 2021). Since procurement is at the beginning of the value chain,

any disruptions passed down the value chain may lead to fatal results (Bode et al., 2011). Hence, the change management of implementing AI in procurement might be more demanding than sales. As an example, Nike implemented a new enterprise resource system, which led to a severe disruption along the supply chain. Managers tend to avoid abrupt changes in technology or may even develop algorithm aversion (Dietvorst et al., 2018). Moreover, buyers are often still associated in the organization with negotiation and a narrow view of trying to achieve better prices at all costs.

The value proposition of procurement can be increased by bundling various demands. However, in complex organizations such as the Volkswagen Group, cross-supplier potential is not always visible until the final decisions' committees, often too late to achieve further savings. A system was drafted that takes as an input the sourcing planning from different formats across the organization, and generates recommendations to bundle requisitions, e.g., through Word2Vec similarity analysis that can be assessed, e.g., through factor machines along with three vectors projects, components or services, and suppliers visualized below (Spreitzenbarth et al., 2021c). By evaluating the bundling options, feedback can be used to train the scoring model through supervised learning, e.g., logistic regression. Next to savings, the communication between the teams may lead to further process efficiencies. In addition, the bundling generator could be part of a larger AI module adjunct to the tendering system, for instance, to propose potential bidders. Yet, this approach requires transparency within the organization to succeed with openness to share information, openness for joint negotiations, and the openness to share the savings (van Weele, 2018).

To sum up, the perception of procurement with a risk-averse cost-focused identity (Murfield et al., 2021) seems to play a role in the adoption of AI and more generally analytical tools. This also pertains to the external valuation of the function that is important to obtain managerial support in investing in skill development, new technology, and data foundation. Recommendation V: Develop the skills, technology, and data in procurement functions to provide more value to the organization.

8 Evaluation and diffusion

AI can lead to a different approach of purchasing, more agile, reactive, and efficient. Buyers can focus on more strategic and creative missions putting purchasing at the heart of innovation (Allal-Chérif et al., 2021). If procurement wants to catch with sales on analytical maturity, it may be the right time to reconsider the often still risk-averse cost-focused identity (Murfield et al., 2021). In addition, there are many search hits, what salespeople can learn from buyers but interestingly not the other way around. Maybe now is the right time to turn the coin around to learn from another also from a procurement perspective. As an example, procurement teams could utilize customer relationship management tools such as Salesforce to manage actively internal and external stakeholders (Conga, 2020). This can lead to stronger business partnerships strengthening its position within the organization. Furthermore, it is paramount for supply management to further utilize data sharing within the value chain. In the Figure below, the relationship of the five prepositions developed is presented:

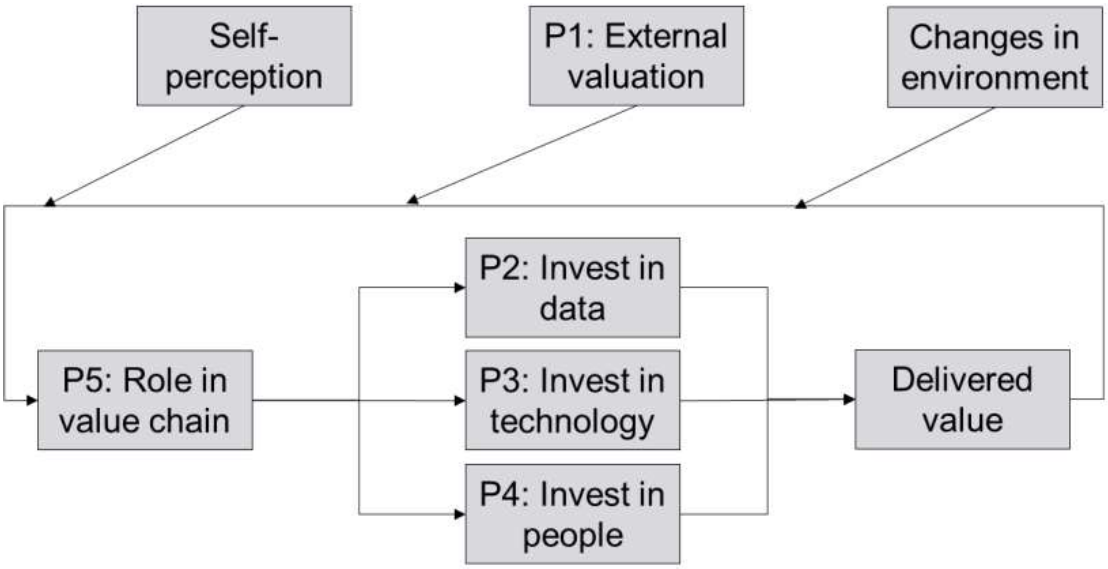


Figure 2: Combine the propositions into a feedback system (own illustration)

Now, how can we break out of this cycle? Procurement managers and scholars need to take risks to update outdated systems and try creative new ways – AI is a potential game-

changer for procurement, which requires abrupt changes in technology and trust in data-driven analysis and decisions. Buyers are generally skilled with analytical understanding and like to dig into the numbers in order to find new innovative approaches to be able to improve organizational processes across the value chain, reduce overall costs, and ensure supply in-time, in-quality. If this potential is fully utilized, scholars might be asking the reverse question "how did procurement suddenly become the analytical champion within the organization"? This process might start by looking inside at the role of procurement within the organization and across the organizational boundaries to convincedly communicate the need to invest in data, technology, and people – or it might be due to the reconsideration of organizational priorities, e.g., due to supply chain challenges - or due to changes in the organizational environment, e.g., by adapting to the technological advances of our negotiation partners in sales and marketing functions. In closing, to briefly summarize the five recommendations to further drive AI research and application in procurement derived from the developed propositions in this work:

- Consider closely the value that procurement delivers to the organization when evaluating where to invest in data, technology, and skill.
- Gather data with a consistent strategy aligned with the overall strategy where especially data sharing within the value chain is an interesting way to obtain better information.
- AI adoption should be seen as a long-term process of constructing an ecosystem whereby choosing the right technology partners is key to future success where in particular utilizing tools such as Salesforce could be a leapfrog for procurement.
- Set up organizational structures and processes to effectively combine human skills and artificial intelligence to achieve maximum efficiency with human-AI collaboration.
- Develop the skills, technology, and data in procurement functions to provide more value to the organization.

There is a need for further research on internal integration and the purchasing-marketing interface, not just for AI but also for AI and broadly analytics. Procurement scholars and managers must speed up data and analytical development, especially since our negotiation partners are benefiting from the rapid development of AI technology. A prominent example is automated negotiation is likely to play an important role in future

buyer-supplier relationships changing the types, design, and frequencies of interactions between organizations (Schulze-Horn et al., 2020). In addition, startups develop interesting solutions such as riskmethods to anticipate purchasing risk (Enthoven, 2020) or Scoutbee to identify potential new suppliers (Scoutbee, 2021). The examples of Celonis, XiaoE and Fitow, Suplari, Coupa, Zycus, Synertrade, Siley, SAP, Jaggaer, and Ideapoke further showcase the potential of artificial intelligence in procurement functions. Thus, we believe that the research fits well with the Hamburg International Conference of Logistics and would be glad to discuss this ongoing research with you!

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AI-based recognition of dangerous goods labels and metric package features

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Purpose: *Dangerous goods shipments require special labeling, which has to be checked manually every time a shipment is handed over in the supply chain. We describe an AI-based detection methodology to automate the recognition of dangerous goods labels and other shipment features (such as single piece volume detection).*

Methodology: *We use five industry RGB cameras and three AZURE RGBD cameras to generate images from shipments passing through a gate. The images are processed based on the YOLO detector to identify and separate dangerous goods labels and barcodes. We trained YOLO for our particular problem with about 1.000 manually labeled and 50.000 artificial generated images.*

Findings: *While dangerous goods labels detection was successfully validated in a laboratory environment and a warehouse, volume detection for single pieces consolidated on a pallet could be conceptualized. The system shows a high detection rate combined with fast processing, where the addition of computer-generated training images significantly improves the recognition rate for complex backgrounds.*

Originality: *Parallel detection of multiple package features (volume, barcode, dangerous goods labels) of multiple pieces consolidated on a pallet is not available yet. Our solution processes a shipment faster and more accurately than existing single-piece solutions without restrictions to the material flow.*

First received: 28. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Transportation planning and handling are based on information about the packages shipped. As the various modes of transport or warehouses have limitations related to weight and volume, these parameters are of high interest to optimize consolidation and transport efficiency. Unfortunately, in practice, data provided by the shipper is not very accurate. Therefore, in many industries measuring weight and volume at a logistics service provider location has become standard. The corresponding processes are time-consuming and require special equipment to measure the dimensions of a shipment. While shipments in courier, express, and parcel logistics are processed as individual pieces in automated handling and sorting systems, skid-based handling takes place in general cargo logistics. As a shipment consisting of multiple individual packages (pieces) is handled with one or more skids, the dimensions of those skids are measured instead of the dimensions of the individual pieces. The results are higher total volumes than the actual volume. Especially for modes of transport where volume is a significant limitation, e.g., in air transport, this leads to inefficient transport planning as transport volume could remain unused because the planning algorithm and its solution were based on exaggerated shipment volumes. Transforming the handling processes from skid-based handling to piece-level handling would cause inefficiencies in the handling processes (as the reason behind the invention and use of loading devices like skids was the idea of increased efficiency based on consolidated handling of multiple pieces). Therefore, solutions for measuring single-piece dimensions are required.

Special handling requirements further impact transport planning and handling. One of the most critical aspects is information about dangerous goods. In case of an accident or other emergency, these goods pose a safety risk as they could explode, ignite, intensify a fire or cause harm to nature. The various types of dangerous goods are classified into several classes (Nations, 2019). These items have to be handled with care. To limit the risks in terms of the impact (and not of the probability) of an incident, the quantities that could be stored or transported together are limited and related to other requirements, such as additional fire protection equipment. There are also co-loading restrictions which means that only limited quantities of certain dangerous goods could be stored or

transported together. To ensure correct handling and thereby reduce the probability of an incident, pieces containing dangerous goods must be clearly labeled and thoroughly checked at acceptance and when leaving a warehouse or other handling facility. The checking procedures are typically initiated by the accompanying information flow or paperwork. The checking of procedures consists of checking the correct labeling of the relevant pieces, more thorough checking of damages to the package and outgoing shipments, the clear visibility of those labels (to simplify identifying critical pieces in case of emergency). The checks and the transport require special training and cannot be done by every logistics employee. Shipments could remain undetected even if they are correctly labeled if the corresponding shipping documents do not indicate dangerous goods. To further minimize the risks and accelerate the check-in and check-out processes of dangerous goods, assisting technology should be assessed.

In this work, we present a fully automated approach for detecting and analyzing various characteristics of multi-piece shipments on a skid or pallet. Our aim is to identify and decode barcodes and dangerous goods labels (DG labels) without interfering with the material flow. Additionally, we describe an approach to measure the volume of those pieces while being stacked on the skid. We first describe the relevant related work. Then, we present our pipeline to detect and decode barcodes and DG labels in the method section. In the same section, we present the approach for the automatic generation of training data sets for volume measurement. Subsequently, we discuss the results that we have achieved with our approaches. Finally, we give a short conclusion and discuss possible future work.

2 Literature Review

In this section, we provide a brief overview of relevant and recent publications. We first review the relevant publications on the camera-based acquisition of 2D package information, such as barcodes and DG labels recognition. Second, we discuss the current situation and related work on package volume estimation.

2.1 Barcodes and DG labels recognition

A large number of publications about barcode localization and decoding exist. The classical methods mostly use low-level image features as gradient analysis, build of saliency maps, Hough space analysis, or probabilistic methods (Gallo and Manduchi, 2011; Sörös and Flörkemeier, 2013; Creusot and Munawar, 2015; Namane and Arezki, 2017). Some of these approaches have further geometric restrictions, e.g., that the barcode must be horizontally aligned (Gallo and Manduchi, 2011) so that the algorithm is not suitable for detecting barcodes on real, freely arranged goods. Other approaches are unable to deal with blurred or poorly lit images (Creusot and Munawar, 2015; Namane and Arezki, 2017). However, all of them have a high computational effort in common, which, combined with the high resolution of today's cameras, makes them not real-time capable. For over a decade now, neural networks have been successfully used for barcode localization (Zamberletti, Gallo and Albertini, 2013; Hansen et al., 2017; Zhang et al., 2018). In Zamberletti (Gallo and Albertini, 2013), the authors use a Hough transform and a simple Multi-Layer-Perceptron to achieve good results if the barcode is very present in the image. Hansen et al. (2017) detect barcodes utilizing the YOLO Detector (Redmon et al., 2015). This approach shows good detection performance, but it does not accomplish accurate segmentation of the barcodes. Zhang et al. (2018) presented another localization approach based on deep learning but used special acquisition hardware to keep the input images well illuminated and nearly noise-free. Recently Brylka (Schwanecke and Bierwirth, 2020) presented an approach that covers the localization and decoding of barcodes under challenging circumstances. Their solution is explicitly aimed at the industrial capture of barcode information and focuses on correcting poorly conditioned images (poor illumination, meager barcode resolution, blurring). Our approach for barcode detection strongly relies on this approach and complements it with the DG labels detection methodology.

Many publications are primarily concerned with the detection and recognition of DG labels. For example, Pozo et al. (2013) showed two approaches based on edge detection and saliency maps. However, both methods only work if the label shows enough contrast to the background and has sharp contour. Also, the final categorization of the label is not fulfilled with these approaches. Mohamed (Tünnermann and Mertsching, 2018)

presented an approach based on spectral residual saliency (Lienhart, Kuranov and Pisarevsky, 2003) and a Scale Invariant Feature Transform (SIFT (Lowe, 2004)). Building the saliency map over the input image, they first localize the DG label and then search for the best label match in a SIFT descriptor database built from a training set of DG labels. This approach shows good results, at least if the label background is sufficiently different, but it is very slow. Also, many techniques based on Deep Learning have been presented in the field of DG label recognition (Edlinger, Zauner and Zauner, 2019; Sharifi, Zibaei and Rezaei, 2020; Tijtgat, Volckaert and Turck, 2017).

In particular, the YOLO detection system was often utilized. For example, Tijtgat (Volckaert and Turck, 2017) used YOLO to detect dangerous objects in images from a drone's camera. Using the positioning of the drone and the localization of the detected object in the camera image, they were able to approximate the GPS localization of the dangerous object. However, the authors focus on the overall system and limit the detection of DG labels only to one specific label selected for their purpose. Edlinger (Zauner and Zauner, 2019) used the YOLO detector for detecting multiple DG labels. However, the dataset used by the authors shows labels always on the same background and at a large distance from each other. This leads to limitations in the real scenarios, with different backgrounds and multiple labels at the same tiny package. The approach of Sharifi (Zibaei and Rezaei, 2020) is another application of YOLO as a detector of DG labels. The dataset used in this application contains images taken with different backgrounds, sometimes with poor lighting conditions and overlap. However, the DG labels are very present in the images. They lack the typical noise and motion blur in images of moving objects, so they are very different from real-world images for a logistic transportation scenario. We also utilize YOLO for detecting and decoding DG labels. However, we put the most significant weight on the easy adoption of the system to new situations, as the expansion of the DG labels set or the change of the working space. Therefore, one of our main focuses is the development of a training data generator.

2.2 Volume estimation

There are various approaches to determine the volume of an object represented by a point cloud. One method is to calculate the convex hull for the point cloud (Preparata

and Hong, 1977). However, this approach has several disadvantages. First, most objects are not convex, so the calculated volume will be significantly larger. Second, if the requested object is not fully represented, the volume will be much smaller. Furthermore, a typical load consists of several packages, which makes the assignment of the volume to each individual package challenging. Another approach is to approximate the sought object by primitives, such as boxes, cylinders, or spheres. However, methods that follow this approach (Goron et al., 2012; Figueiredo et al., 2019) only work well if the objects to be detected (single pieces) lie on a homogeneous, planar surface. A condition that cannot be guaranteed in a warehouse environment with forklifts, trucks, and people in motion.

In practice, there exist three different processes to measure volume. One is that the pieces are separated and measured piece by piece. This is typically done in the CEP (Courier, Express, Parcel)-Industry with the help of automated material handling and sorting systems. Here, the typical restrictions in weight and volume of pieces apply (e.g., Max. 36 kg) – so measuring a skid-sized box is not possible. The second option, which is more common in general logistics, is measuring the maximum dimensions of the shipment on the skid or pallet by creating a box that contains the full point cloud. A prerequisite of this approach is that one pallet carries only one shipment. The existing systems require user interaction for the identification of the shipment, typically by scanning the barcode. Based on this information, the measured volume is then saved in the warehouse management system. Therefore, measuring the volume is an extra process step that disrupts the material flow and takes extra warehouse space and labor time. The third option is to measure shipments manually, which is done for oversized cargo or if only a small percentage of all shipments are measured (Borstell, 2018).

For quite some time now, machine learning has also found its way into processing and information extraction from point clouds. Especially in autonomous driving, where point clouds generated by a LIDAR system are processed by deep learning methods to locate other road users, such as other cars, motorcyclists, bicyclists, or pedestrians (Fang et al., 2021; Lang et al., 2019; Shi, Wang and Li, 2019). However, for the autonomous vehicle, only the situation in the ‘plane’ of the surrounding roads is relevant. Therefore, in most approaches, a bird's eye view is chosen, and the problem is reduced to 2D localization. In the street situation, where road users are usually not on top of each other, this does not

lead to problems. However, if one wants to localize individual packages lying on top of each other, the lack of altitude leads to difficulties. However, some approaches deal with the localization and segmentation of objects away from the road. The S3DIS and ScanNet datasets (Armeni et al., 2016; Dai et al., 2017), for example, provide large-scale scans of office building interiors. These datasets are used to test the localization and segmentation of individual objects such as tables, chairs, walls, etc. (Pham et al., 2019; Yang et al., 2019). Most deep learning approaches realize supervised learning. In this case, a large number of annotated datasets is used for training deep neural networks. Since, to the best of our knowledge, there is no dataset that represents the annotated packages in a logistics process, in this project, we present an approach for creating such a dataset with minimal manual effort. With this dataset, we can test the transferability of existing approaches to our particular domain and validate new approaches more quickly.

2.3 Dangerous goods regulation

Transport and handling of dangerous goods are regulated based on global standards of the UN (Nations, 2019). There are different guidelines for the various modes of transport as the potential impact of an incident varies. For specific infrastructure an elevated regulations apply – for example, additional limitations have to be considered if a road transport passes certain tunnels. The strongest requirements apply in air cargo as any incident in the cargo compartment while in the air leads to a total loss of the airplane and all persons and the cargo on board. Several incidents related to lithium batteries led to additional restrictions and a new lithium battery mark (section 5.2.1.9 of the UN model regulation).

In general, the regulation defines nine different classes of dangerous goods. For those classes, requirements for packaging, labeling, handling, storage, and transport apply. Additionally, all personnel involved in the transport and handling process needs specific training to ensure compliance.

Special focus in the transport chain is, of course, on the handover of dangerous goods shipments. For incoming and outgoing shipments correct labeling (for all labels, see section 5.2.2.2.2 of the UN model regulation) and integrity must be checked thoroughly (Part 5 and Part 7 of the UN model regulation).

Correct labeling ensures that the critical pieces could be identified immediately in case of an incident, and the response from the emergency services could be adapted accordingly. Ellis (2010) showed that up to 7% of wrong labeling was discovered by authorities in maritime shipping.

3 Method

In this section, we discuss the hardware configuration of our camera system, which was developed specifically for this purpose. The description of our software system can be divided into two main aspects: the detection and decoding of 2D information and the 3D volume determination of the load. In the following, we will discuss these three topics separately.

3.1 Camera setup

The main challenges in capturing the visual characteristics of air cargo shipments are:

- the large scanning area of about 2.5 x 2.5 x 2.5 meters
- insufficient light conditions
- high speed at which the cargo can be transported with a forklift

To meet this challenge from a technical point of view, we developed a camera setup whose schematic structure can be seen in Figure 1. Our camera system consists of five high-resolution industrial RGB cameras and three Azure Kinect RGB-D cameras. All cameras are hardware synchronized and are connected to a central computer.

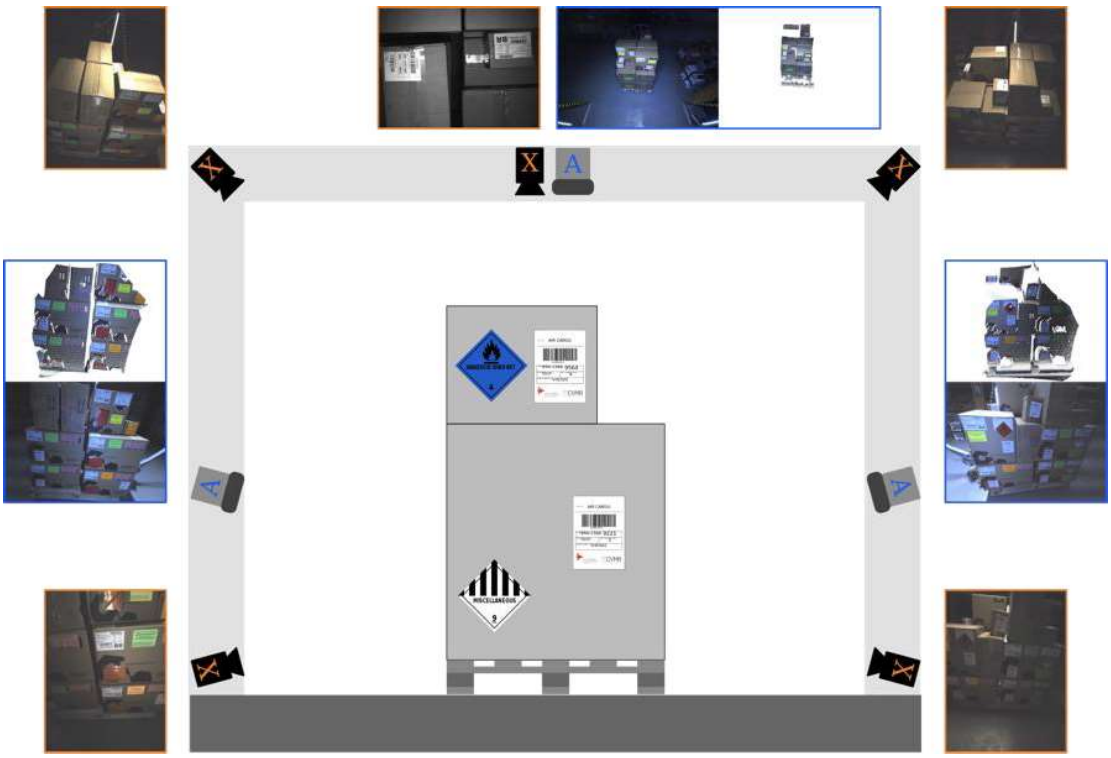


Figure 1: Shipment handling camera setup

Our system consists of five high-resolution cameras (marked with orange X) and three Azure 3D scanners (marked with blue A) and enables extensive coverage of the five (visible) sides of the cargo.

The industrial cameras all have a resolution of 12.4 MP, are equipped with a global shutter, and can acquire images in RAW format. These features make these cameras primarily used for capturing and decoding barcodes and DG labels.

The Azure 3D scanners work with the so-called Time-of-Flight method, enabling the creation of depth maps that we use to measure the volume of packages. In addition to depth measurement, any Azure device has a 12.4 MP color camera sensor. These cameras are equipped with rolling shutters and provide the captured images with JPEG compression, limiting their use to detect barcodes or DG labels.

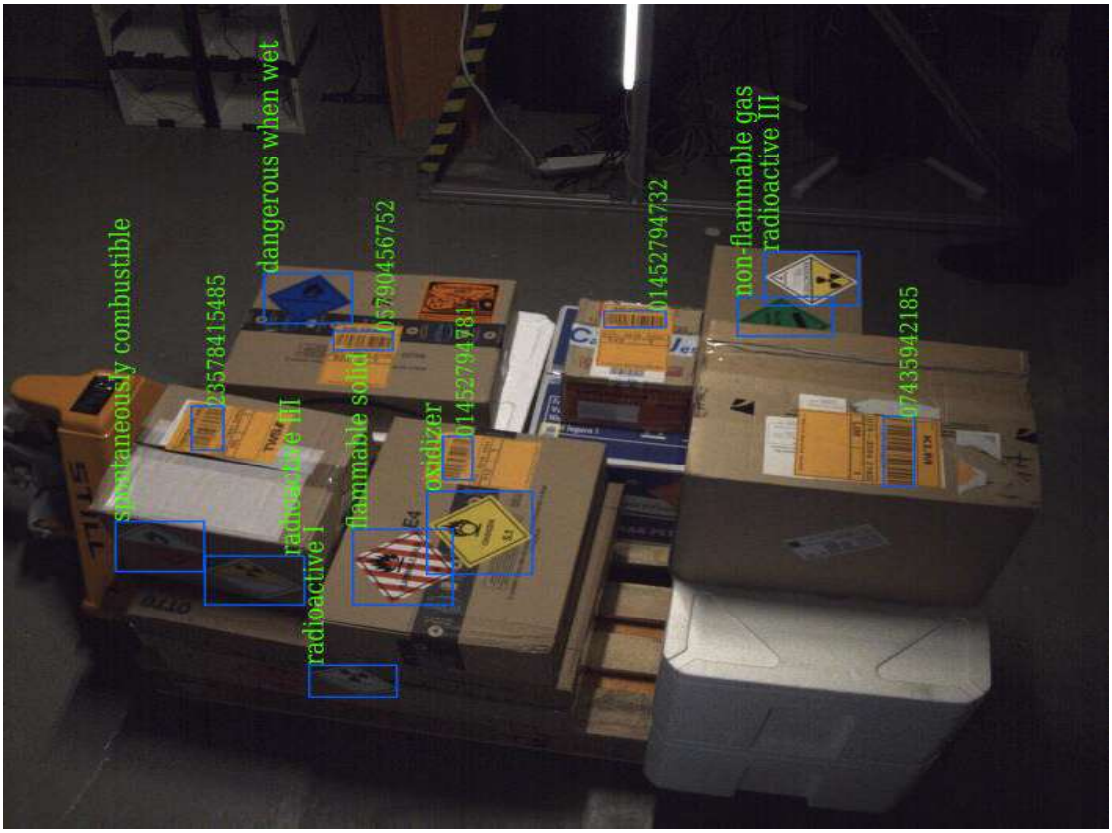


Figure 2: Exemplary presentation of the barcodes and DG labels detection and decoding

3.2 Barcodes and DG labels

The 2D detection of our system focuses on the barcodes and DG labels. As shown in Figure 2, we like to detect and decode all the existing relevant barcodes and DG labels for each individual input image.

We limit the selection of relevant barcodes to those provided on the Air Way Bill (AWB) labels. A template of an AWB is shown in Figure 3 left. The design, in the form of a rectangle with a dominant barcode and additional information, is specified by a standard. We limited the selection of DG labels to seventeen pieces for our test scenario, which are essential in air cargo (see Figure 3 right).



Figure 3: 2D information labels. Left: AWB template in white, right: selection of seventeen DG labels used in our scenario

Barcodes: As indicated in related work, we have followed the work of Brylka (Schwanecke and Bierwirth, 2020) to detect and recognize the barcode information. Figure 4 show the main steps of the barcode detection and decoding pipeline:

- coarse localization of the barcode
- limiting the barcode area to be considered based on this localization
- refinement of the localization by segmentation of the barcode's stripes
- determination of the orientation and narrowing the area to a quadrilateral
- horizontal alignment and mapping to a rectangle
- deblurring of the barcode and subsequent decoding

First, bounding boxes of the barcodes are determined using the real-time detection system YOLO (Redmon et al., 2015). Based on this localization, a more refined segmentation of the barcode bars and the determination of their contours is performed. This step is performed with an additional neural network U-Net (Ronneberger, Fischer and Brox, 2015). In this case, the segmented foreground represents the barcode stripes and classifies all the surroundings as a background. Relying on this segmentation, the orientation of the barcode is determined, and the final square contour is determined (see cyan contour, with a solid line representing the barcode base in Figure 4). With the specified orientation, we can align the barcode horizontally, or with the square contour, we can rectify the barcode to a square. A nearly horizontal orientation of the barcodes is a precondition for decoding the barcodes with a standard barcode decoding library. In our case, we use the freely available image processing library ZXing (David Gilbert and Huy Cuong Nguyen, 2021). Since the images are generally very noisy and very dark, and blurred due to insufficient lighting, decoding of the barcodes very often fails at this point. This is where the strength of the algorithm (Brylka, Schwanecke and Bierwirth, 2020) comes into play. With the help of an additional U-Net network, the noisy, blurred barcode

bars are reconstructed into sharp ones. Subsequent decoding is performed using the ZXing library. The use of the standard barcode library takes over the position of the validation tool. Thus, the checksum verification finally determines whether the considered image section represented a barcode.

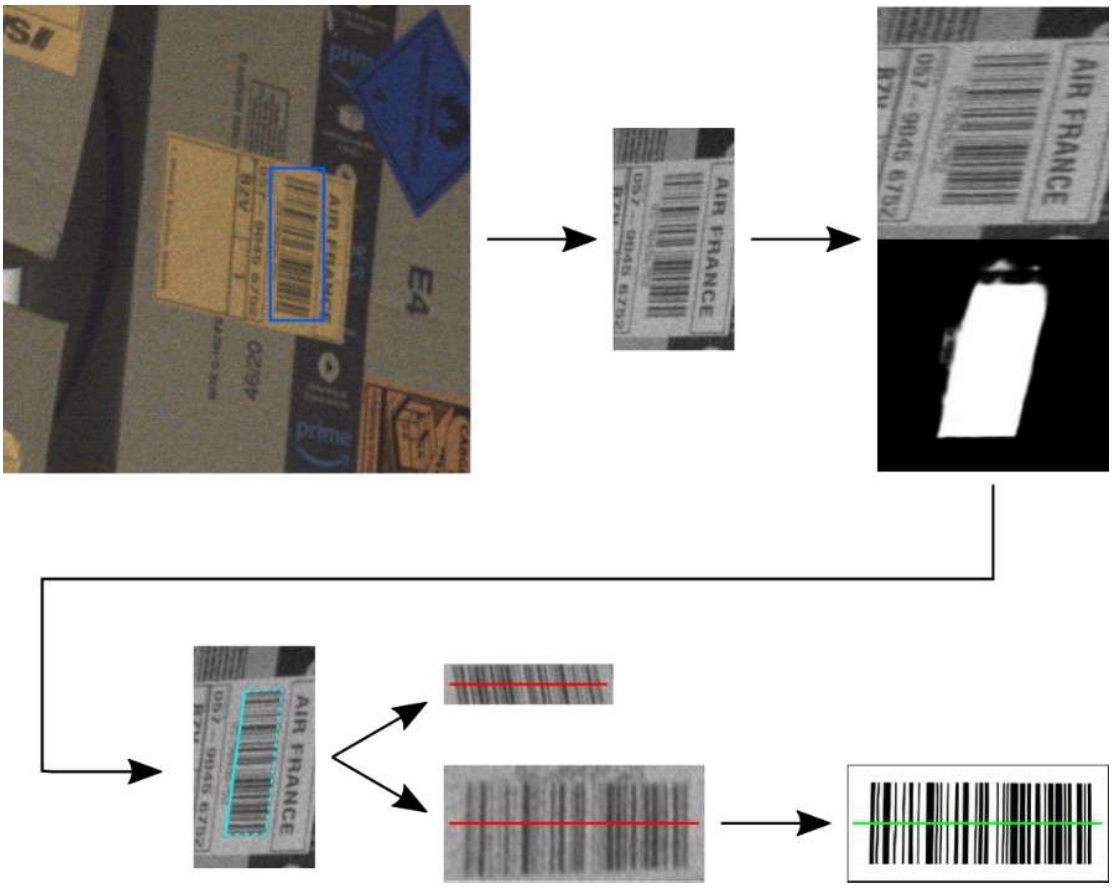


Figure 4: Main steps of the barcode detection and decoding pipeline

Following the path: coarse localization of the barcode, restriction to the relevant area, barcode bars segmentation, orientation and quadrilateral area estimation, horizontal alignment and rectangle mapping, deblurring, and decoding.

DG labels: Our detection and decoding of DG labels are mainly based on the YOLO detector. The detection with YOLO only leads to good results if there is a lot of labeled data in the training phase that covers all eventualities. If there is a significant deviation in the images in the test phase compared to the training data set, the results are likely to

be significantly worse. Adapting the system to the new conditions can be easily accomplished with additional training data reflecting the new situation. However, the manual labeling of the data is very dull, time-consuming, and often error-prone. For this reason, an essential part of the software component in the part of the DG labels detection was dedicated to the development of a training data generator.

Before meeting the requirements for the generator tool, we analyzed several records of real transports. In doing so, we found inconsistencies in the appearance of individual DG labels. The selection of DG labels we chose for our test scenario (see Figure 3) shows black lettering consistently. However, it is quite common for white lettering to be used as well. Like, for example, the label *liquid gas* in the reference Figure 5 on the left. Another observation shows the problem in the means of transport medium itself. As seen in Figure 5, center and right, forklifts can be labeled with many information stickers. These high-contrast labels, which are often very similar in shape and color to the real DG labels, can be distracting if they were not present in the training set. The goods themselves can also vary greatly, whether they are a wooden crate or pure cardboard, for example. Finally, the background itself can also vary. So, whether it is a truck loading area or if the camera system stands in the hall and the background is a random warehouse environment.



Figure 5: Challenging situations when recognizing DG labels

On the left: deviation from the standard white lettering, center and right: warning and information labels, which can lead to falsification of the result due to their similarity.

Finally, we implemented the following requirements in our generator tool:

- freely selectable background images (track bed, warehouse, etc.)
- free definition of the load (cartons, plastic boxes, wooden boxes, etc.)
- easy extension of the existing DG labels (color of the label, generally more characters, etc.)
- possibility of adding 'structured noise' (such as high-contrast labels, etc.)

Figure 6 shows some examples from the training dataset generated with our tool. For example, various product presentations can be seen, such as black plastic containers, fabric tarpaulins, or cardboard boxes. In addition, several DG labels and contrasting clutter objects can be seen on the load.



Figure 6: Example of training data created with our generator tool

To see are several DG labels projected on different goods. Also, to see are the disruptive elements in the form of high-contrast labels.

Volume estimation: As mentioned in the related work section, most of the current methods for detecting objects in 3D point clouds are based on machine learning. Thereby, supervised learning is used, which always requires labeled training datasets. We will present a method, which creates the annotation for the training datasets in a fully automatic way. As explained in the camera setup section, the Azure 3D scanners used in our setup provide a 3D point cloud and a color 4K image of the reconstructed scene. In our approach, we first localize the packages in the colored 2D image and then transfer the mapping to the reconstructed 3D point cloud.

One of the common ways to localize an object in an image is the use of fiducial markers. A fiducial marker is a separate element that is attached to the object to be identified. A widespread form of fiducial markers is the ArUco marker (Garrido-Jurado et al., 2015; Romero-Ramirez, Muñoz-Salinas and Medina-Carnicer, 2018). An ArUco marker is a plain 2D imprint composed of black and white rectangles (see Figure 7 left). With the freely available ArUco library, such markers can be easily localized in an image. Given the size of the marker and the calibration of the camera, the 3D pose (position and orientation) of the marker relative to the camera can be determined (Garrido-Jurado et al., 2015; Romero-Ramirez, Muñoz-Salinas and Medina-Carnicer, 2018).

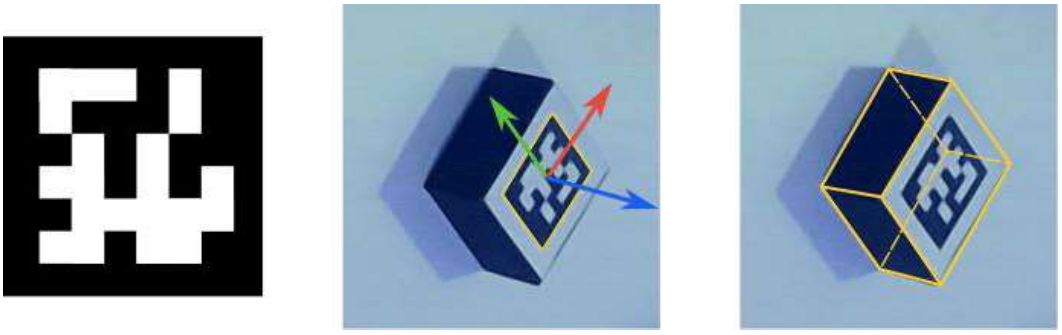


Figure 7: Fiducial markers; left: template example of an ArUco marker; middle: localization of the marker, right: bounding box for the detected object (yellow)

In our case, we use the 3D pose of the marker to determine the 3D contour of the relevant package and thus simultaneously mark the relevant points in the point cloud. For this purpose, we provide a selection of cardboard boxes with the ArUco markers on them. Figure 8 (left) shows an example of our prepared package. The three separate views are given by the three Azure cameras in our setup. As can be seen, each of our packing boxes has a total of 6 markers applied to the six possible surfaces. With this number of markers per box, it can be assured that detection from different view angles (cameras) is possible. Furthermore, the problem of overlapping by other packages can be reduced. As illustrated in Figure 8 (middle), we bring the three partial point clouds together. Therefore, we use the stereo calibration procedure (Zhang, 1999), which computes the position and orientation of the sensors to each other. As a result, we get a jointed point

cloud and the estimated bounding boxes registered to each other (cyan-colored boxes). Performing a Principal Component Analysis (PCA) over the collection of the bounding boxes, we estimate the final average bounding box, which represents the best enclosure box (Figure 8 right).

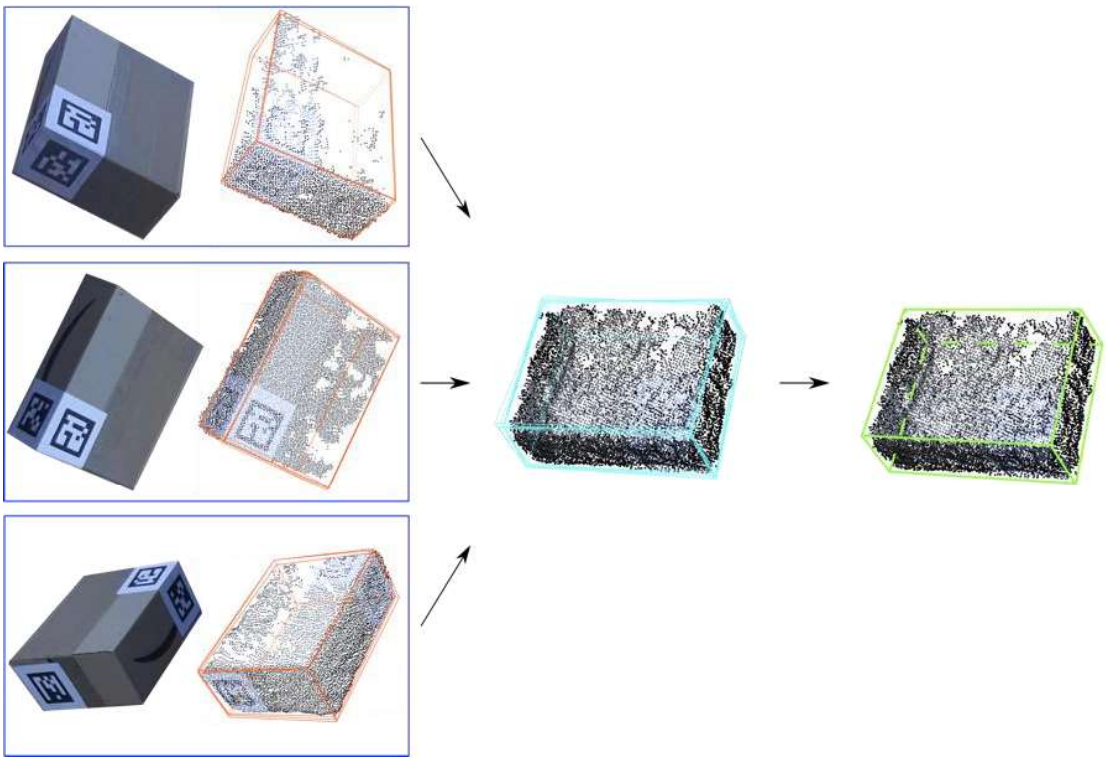


Figure 8: Automatic piece annotation

From left to right: three unregistered inputs (image and point cloud) from the Azure devices, registered point clouds, and registered bounding boxes given by ArUco library, last row: PCA resulting bounding box and final enclosed box point cloud.

With this method, a set of training datasets can be generated easily and used in deep learning approaches for object segmentation and detection in point clouds. Figure 9 shows an example of our dataset, with the registered point clouds from the three 3D scanners, the average enclosing boxes, and the annotation denoted by different colors (white marks whole irrelevant region).

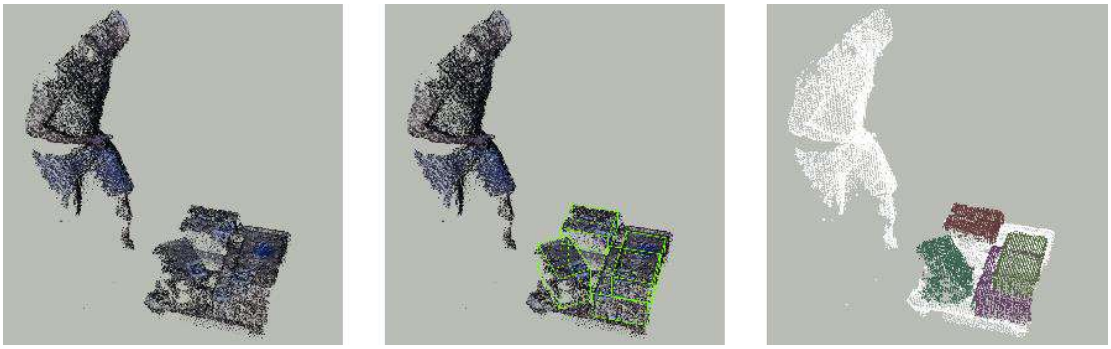


Figure 9: Preparation of real dataset: input point cloud, automatically detected enclosing boxes, annotation colorized according to different instances

4 Results

In this section, we present the results obtained by our approach. First, we discuss the results for the detection and decoding of 2D information. Second, we show the results of our approach for 3D volume segmentation using our automatic annotated dataset.

4.1 Barcodes and DG labels

In our barcodes and DG labels detection pipeline, a total number of three networks are used. The two U-Net networks, used for barcode contour segmentation and barcode deblurring, are trained with the exact settings as in the initial publication. For more details, please refer to Brylka (Schwanecke and Bierwirth, 2020). We tailored the YOLO detector to our scenario. In addition to the localization of barcodes, it also localizes the 17 different DG labels. We use a mixture of about 1.000 manually annotated data and 50.000 artificially generated data as a training set. The training set contains about 60.000 barcodes and about 9.500 of each DG label, distributed over all images. Because it has an enormous performance increase with a small loss in detection rate, we used the current YOLOv4-tiny version. We set the input size of the network to be 640 x 480, which is around one-sixth of the original image size (all cameras deliver images in 12.4 MP). This input size is a compromise between the performance and accuracy of the network and was

determined experimentally. We trained our model with batch size 64 with an initial learning rate of 0.001. After 50 epochs, there was no significant oscillation of the loss, which is also our stopping criterion.

Barcodes: We have evaluated the performance of our pipeline related to the localization and decoding of barcodes on the challenging dataset of Brylka (Schwanecke and Bierwirth, 2020). This dataset shows the transportation of cargo shipment under real conditions. This dataset has the ground truth annotation for a total number of 840 AWB's distributed over 400 images. There are no DG labels in this dataset. We achieved a 5% higher Recall than Brylka (Schwanecke and Bierwirth, 2020)on this dataset. This is mainly because our network input size of 640x480 is significantly larger than the original input size of 416x416. We also use real, manually labeled images in the training set. The mixture of real and artificial training data seems to perform better than just using artificial images. Finally, we used the latest, fourth YOLO architecture.

DG labels: We have created a new validation dataset for the evaluation of the detection of DG labels. This dataset consists of eight sequences showing the loading process of the cargo. We manually create ground truth annotations for the total number of 2.216 images and 5.820 DG labels. As described in the method section, the detection of DG labels is only based on the YOLO detector. Thus, the balance between the detection rate and the error rate can only be tweaked by the score threshold of the YOLO detector, i.e., at what score a detection is considered valid. In general, the higher the threshold, the fewer false detections. However, this also means that some of the DG labels can be overlooked.

Since the goods are screened several times as they pass under the camera arch, the detection rate is defined in practice as the number of recognized labels within a sequence. This means that the recognition rate is 100% if all DG labels are correctly recognized at least once in a sequence. Of course, to increase the reliability, the system should decode as much as possible of all existing labels per image. At the same time, however, the number of incorrect assignments should be kept small. We tested our system considering these aspects by using different values of the score threshold. Table 1 shows the obtained results with the Recall, Precision, and Detection Rate per Sequence metrics. The Recall is defined as the quotient between the correctly detected and all given DG labels. The system quality is measure by Precision which is defined as

the quotient between the number of correctly decoded candidates and all candidates suggested by the system for a given label. The Detection Rate per Sequence is defined as described above; a unique occurrence of a DG label in a sequence needs to be correct decoded at least once to get the full score. Table 1 summarizes the results over all seventeen DG labels and sequences.

As can be seen, our system can operate at the highest threshold setting without a single false detection. It achieves a Detection rate per Sequence of almost 80 %. The Recall is at a moderate 20 %. The low recognition rate per frame can be explained by the fact that the imaging of the DG labels varies significantly during the sequence. Therefore, at the entrance and exit of the scan area, the DG labels are very small (due to the angle of view of the cameras). So, it can be expected that only the DG labels in focus will get a high score, and thus positively affect the Detection rate per Sequence.

Table 1: Results of the DG labels detection over the validation dataset

YOLO Score Threshold	Recall	Precision	Detection rate per Sequence
99	0.197	**1.000**	0.795
95	0.286	0.995	0.885
90	0.325	0.990	0.885
85	0.351	0.987	0.923
80	0.368	0.982	0.949
75	0.385	0.976	**0.962**
70	0.395	0.971	0.962

YOLO Score Threshold	Recall	Precision	Detection rate per Sequence
65	0.407	0.968	0.962
60	0.418	0.961	0.962
55	0.427	0.955	0.962
50	**0.439**	0.951	0.962

When the threshold decreases, a positive trend in Recall and Detection rate per Sequence can be seen as well as a degradation in Precision. For a threshold value lower than 75 %, there is no change in the Detection rate per Sequence. This is because some of the DG labels are covered by other packets to such an extent that they do not contain enough information for the system. Based on these observations, we have determined the threshold value of 75 % as the optimum for the system. Further analysis revealed that many misclassifications fell into the classes 'flammable liquid' and 'flammable gas' as well as 'misleading' and 'c9a'. This can be explained by the fact that the labels of each of the two classes are very similar.

4.2 Volume estimation

We tested our approach to automatically generate training sets for point cloud segmentation on BoNet (Yang et al., 2019). The output of BoNet is a semantic segmentation, i.e., the assignment of points to a specific category as well as an instance segmentation. In instance segmentation, the points with the same semantics are assigned to individual instances. Initially, BoNet was tested on ScanNet and S3DIS (Dai et al., 2017; Armeni et al., 2016). These two datasets show the facilities of a typical office environment as well as large conference rooms. As described in the method section, our automatic annotation method splits the point cloud into two classes: packets and the rest. Each of the annotated packets is mapped to one particular instance.

As training data for BoNet, we automatically annotate packages on 150 pallets, which are always brown boxes with ten different dimensions (see Figure 9). For training BoNet, we used the default settings, a learning rate of 0.0005, and a batch size of 4. As a termination criterion, we restricted the maximum number of learning epochs to 300. To validate the results, we collected another dataset containing packages without the ArUco annotation and differentiating in size and color from the scheme of the training set. Figure 10 shows the results for part of the validation set. The first column shows the pallet arrangements. In the second column, we see the registered point cloud acquired with the three Azure scanners, which is the input to BoNet. The third column shows the semantic segmentation results, with cyan marking the points that belong to the package and white marking the background. The last column shows the instance segmentation results. The background is again marked in white. The different instances of the packages are marked with different colors. As can be seen, the semantic segmentation between the package instances and the background is very good.

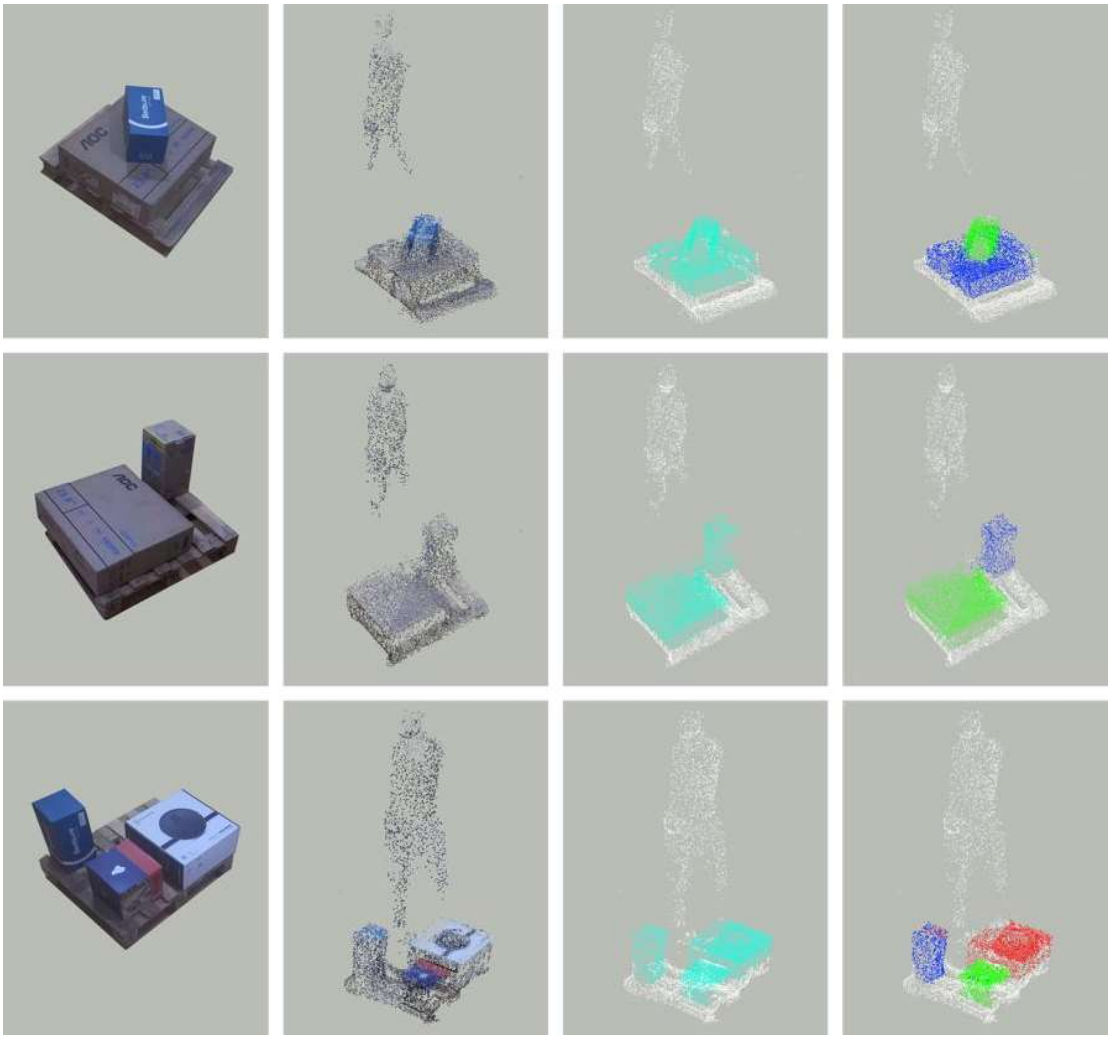


Figure 10: Visualization of the semantic and instance segmentation results

From left to right: Image of the scene, colored point cloud, segmentation of package and background, segmentation of individual packages and background.

Therefore, it is possible to isolate the packages and separate them from the background. The instance segmentation results show slightly more noise and imprecision. Nevertheless, points belonging to a specific package can be separated very easily. Subsequently, we can determine the smallest enclosing box for each separated point cloud. And thus, we can approximate the volume of a single package.

5 Discussion and outlook

The presented fully automated process enables significantly faster and safer handling of dangerous goods. Correct labeling could be automatically verified by matching against the corresponding information flow or paperwork. So far, only the integrity check would remain manual. Besides the handling of known and booked dangerous goods shipments, unidentified shipments (because the information and/or paperwork does not indicate dangerous goods contents, no explicit checking and handling would occur) would be identified and handled correctly. Additional to the faster checking and higher quality, the camera system would directly provide pictures to document deficiencies (e.g., damages, wrong labels).

The AI-training generator allows for a fast and easy-to-implement adaption to identify more and other special handling labels (e.g., 'Do not stack'). With a limited number of real pictures and a vast number of generated images, good results could be achieved. This is especially important as labeling, and the respective handling requirements can change rapidly, as the example of lithium batteries has shown.

Single-piece volume detection without having to manually separate the piece helps to improve transport planning, volume-based billing, and load planning. The integration of the measurement process in the material flow without interruption and reliable near-real-time results saves time and space in the warehouse.

The detection and identification of the 2D package information were proven to be very reliable. The precision of DG label detection could be further increased by examining the detected label areas concerning text existence. For example, an attempt could be made to read the class of the label from the given caption. Furthermore, extending the system with additional cameras could make more regions of the cargo accessible and thus increase the detection rate.

Our approach to automatically generate 3D package annotations was successfully tested with a common point cloud segmentation system (BoNet). Further testing is needed to determine the reliability of the overall system. In particular, scenarios with densely

packed pallets need to be investigated. Thereby, the required training sets can be generated with little effort using the presented approach.

Acknowledgements

The authors would like to thank our project partners T Word Service GmbH and Air Cargo Community Frankfurt e.V. for the fruitful collaboration.

Financial Disclosure

This project (HA project no.: 862/20-19) was funded by the State of Hesse and HOLM funding as part of the initiative “Innovationen im Bereich der Logistik und Mobilität” of the Hessian Ministry of Economics, Energy, Transport and Housing.

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Design of a DLT-based Document Management System in Road Transport

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Purpose: *While the transportation sector enters a new phase of digital transformation, Distributed Ledger Technologies brought a new paradigm in the design of IS with numerous pilot-cases in logistics. Despite the various benefits (e.g., security, availability) little is empirically known about the development of such solutions. Where practitioners face numerous design decisions, we complement research by deriving six design principles for the construction of an applicable artifact in road transport.*

Methodology: *We follow design-science-research to generate design knowledge based on a literature review, a morphological analysis, and case studies on DLT-driven applications for document management. We refine the results and demonstrate practicability via an instantiation based on expert interviews to provide generalizability in terms of actionable guidelines.*

Findings: *We extend theory showing that DLT is an effective solution for cross-border information exchange. The design principles address the data architecture, access and storage across multiple stakeholders, and the way how data is exchanged. The results may further accelerate the adoption of DLT-based applications in logistics.*

Originality: *We bridge the gap between technology and practical utilization by evaluating existing cross-industry use cases combining elements from the business, legal, and information technology perspective. Additionally, the instantiation of an applicable solution is further the result of an inter-organizational development process involving feedback of various practitioners (e.g., carrier, authorities).*

First received: 10. Apr 2021 Revised: 18. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The digitalization of business processes has been a main driver for new operational efficiencies in the transport industry (e.g., real-time tracking, digital freight marketplaces). While the awareness for the digital transformation has grown, relatively few companies have unlocked the full potential of successfully introducing new information systems (IS) to transform associated processes for even higher efficiency, safety, and sustainability standards (Min et al., 2019). Following the idea of a digital supply chain to improve the global movement of goods, the digitization of key documents in international trade has not received the required attention so far. Accordingly, document exchange between sender, forwarder, and recipient is still handled manually, printed on paper, and, thereby, a prevailing source for inefficiencies. Due to its susceptibility to errors and counterfeiting, associated processes show huge room for improvement (Naerland et al., 2017). It is estimated that 99% of cross-border transport operations in the European Union involves paper-based documents in at least one process stage (European Commission, 2018). One of these physical documents for the transport across national borders is the contract for the international carriage of goods by road, in short CMR (UNECE, 1956). The United Nations took note and agreed on a standardized protocol for a digitized consignment note, the so-called e-CMR, to be fully ratified in Europe soon (UNECE, 2021).

In comparison to established IS, we assume that the logistics industry may rely on a more secure, efficient, and trustworthy alternative for its implementation. Blockchain (BC) and Distributed Ledger Technology (DLT) enable decentralized IS that show potential to improve the information exchange across company boundaries and to increase transparency in supply chains (Wang et al., 2019). Electronic transport documents based on a shared ledger are verified in real-time and decrease administrative costs considerably (Belu, 2019). Transport information is stored in a tamper-proof database making it impossible to modify the documents without leaving traces. Hence, decentralized IS may eliminate intermediary intervention, reduce costs, provide integrity, and consistently streamline information across all participants (Juma et al., 2019). Despite the benefits and practicality of BC- and DLT-based document

management systems, it is still unclear how to design such solutions against the backdrop of relevant requirements and features (Wieninger et al., 2019). Although DLT is often used synonymously with BC, a shared ledger approach is not always dependent on a chain of blocks. Recent research shows plenty of distributed database solutions that store an increasing amount of transaction records (Collomb and Sok, 2016). By focusing on DLT as the applicable level of abstraction, practitioners must identify relevant trade-offs to successfully introduce such applications (e.g., public or restricted view of transactions). While solutions for electronic document handling in logistics exist (e.g., bill of lading in sea freight), there has been no contribution for an applicable artifact in road transport so far (Naerland et al., 2017). To support organizations in the decision-making process, we address the following research question: *What are design principles for developing a DLT-based document management system in road transport?*

Based on design-science-research we define the problem area, specify objectives for development, identify relevant features of DLT and design decisions through both literature reviews as wells as empirical data from expert interviews. Accordingly, a morphological box is introduced to instantiate a specific solution design to derive knowledge in terms of six design principles.

The remainder of the paper is as follows: The next section highlights the motivation for digitalization in road transport and the challenges of applying DLT. Where section 3 introduces the methodology, section 4 describes the iterative development and artefact instantiation. Before the paper closes in section five, the design principles and their evaluation is presented and discussed.

2 Theoretical Background

2.1 Digitalization in Road Transport

Recent developments in real-time monitoring of vehicles and cargo slowly improved the electronic interaction in the road transport industry (Koroleva et al., 2019). A consistent flow of information in international trade across companies and authorities should therefore become a rule and not the exception (DTLF, 2018). According to Civelek et al.

(2017) one important factor for the digitalization of information flows across multimodal supply chains is the integration of electronic documents. As a prerequisite, it allows to access relevant information in one shared interorganizational system.

One of the key documents in international trade is the CMR. In general, a CMR serves the purpose of proving that goods have been securely transferred and accepted during their transport. It is applied when sender and recipient are located in two different countries. The CMR serves as a contract between sender, carrier, and consignee and must be issued prior to the transport operation. A legally valid CMR must be directly available to be signed by the sender as well as by the carrier (DTLF, 2018). In 2008, the e-CMR protocol was issued by the UNECE, which requests that the CMR should be managed electronically. However, new IS systems that should replace existing paper-based processes via e-CMR are still not widely adopted within the industry. Companies still have concerns to fully digitize the processes. Sensitive data may be shared, where third party provider cannot ensure standards of security and integrity (Chen, 2019). Hasratyan et al. (2020) indicate the lack of data security and the importance to improve the protection of company information. Technical interoperability between stakeholder also poses problems for cross-border information exchange. The reason is the lack of cooperation and the insufficient support for standardization (Burinskiene, 2019). Finally, various legal requirements at an international level are leading to low acceptance and unclear responsibilities in front of authorities and courts (Koroleva et al., 2019).

2.2 DLT-based Application Design

The implementation of more reliable data sharing technologies may improve the current situation. DLT provides a shared database for decentralized applications and ensures secure data provenance. The distributed solution represents an opportunity for data authenticity to enhance the low standards of security and integrity in cross border data exchange (ITU-UN, 2019). Every party in the process operates its own node to store and update information between all network participants. A decentralized management of the shared ledger lies at the core of any DLT system that improves the availability of transactional data and eliminates a single point of failure (Kannengiesser et al., 2020).

Ultimately, organizations can increase data sovereignty through the built-in mechanisms of DLT and its cryptographic functions (Juma et al., 2019).

Existing research on DLT-based document applications show that health records are very often applied in such cases (e.g., Lee et al., 2019, Xiao et al., 2018). Other research investigates the applicability of DLT for commercial, financial, or legal documents (e.g., Chang et al., 2019, Chen et al., 2019). Despite the advantages of a DLT-based document solution in road transport, the application of an e-CMR has not yet been considered to the best of the author's knowledge. However, all these use cases highlight critical dependencies when choosing a specific type of DTL. The characteristic of the various technologies lead to trade-offs (e.g., flexibility and security). On the one hand a low number of participating nodes within a DLT network may increase flexibility. But on the other hand, a limited degree of decentralization may decrease the security of the system (Kannengiesser et al., 2020). Due to these trade-offs, there is no DLT design that fulfills every requirement of a specific application area. For practitioners, it is still challenging to select a suitable DLT framework and to identify the relevant design options. Comprehensive knowledge is needed to understand these dependencies.

3 Methodology

To generate new knowledge in terms of design principles for a DLT-based document management system in road transport, we apply design-science-research (DSR) to create an artifact that solves the identified organizational problem (Hevner et al., 2004). The iterative approach uses rigor and relevance cycles and is based on the guidelines of Peffers et al. (2008) highlighting five phases associated with problem identification and definition, development, demonstration, evaluation, and the communication of results.

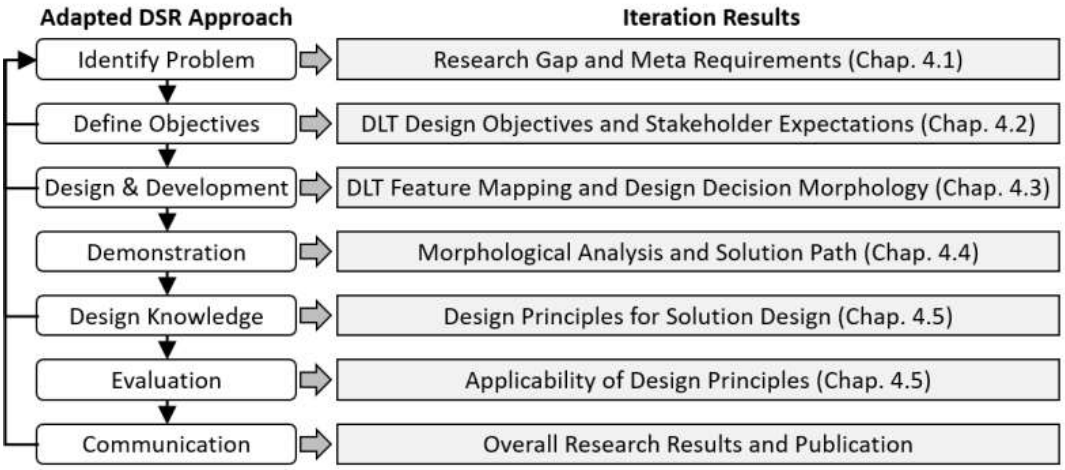


Figure 1: Design cycles and iterative results based on Peffers et al. (2008)

We adapted the approach in figure 1, where we identified problems in existing solutions at first. In the second cycle, we addressed opportunities of DLT-based systems through two interviews and a requirement workshop with seven practitioners. The goal of the third cycle was the identification of DLT-specific design features that map and fulfill the identified design objectives of our proposed system. Subsequently, we reviewed extant research to introduce a morphological box by addressing and refining relevant design decisions on the construction of an DLT-based application through existing cross-industry DLT use cases on document exchange. After we instantiated a solution path through secondary data and two expert reviews, the overall artifact in terms of the six design principles was finally evaluated by four experts according to the key criteria (e.g., applied effectiveness and efficiency) of Sonnenberg & Vom Brocke (2012). Beside secondary data gathered through extant literature following the guidelines of Webster &

Watson (2002) in common scientific databases (cf. EBSCOhost, AIS Library, Jstor), we collected primary data from 15 semi-structured interviews in total (Table 1). All participants were experts in their respective domain, where each interview lasted between 25 and 45 minutes according to the respective phase in the DSR cycle. We transcribed the interviews and analyzed them to identify the most important statements and outcomes (Ayres, 2008).

Table 1: Overview of interviewees

Interview Round	ID	Job Position	Company Information		Average Experience	
			Type	Size	DLT	Road Transport
1st Interview Round: Respective DSR Relevance Cylce	A1	Project Manager	Logistics Association	Medium	2 years	4 years
	A2	Economic Affairs	Logistics Association	Large	1 year	10 years
	U1	Researcher	University	Large	5 years	18 years
	A3	Head of Digital Policy	Technology Association	Small	4 years	8 years
	A4	Project Manager	Logistics Association	Medium	2 years	4 years
	P1	Consultant	IT Service Provider	Small	2 years	3 years
	P2	Managing Director	IT Service Provider	Small	1 year	13 years
	P3	Managing Director	IT Service Provider	Small	4 years	6 years
	P4	Business Development	IT Service Provider	Small	6 years	2 years
	C1	Software Developer	IT Consulting	Large	5 years	-
	U2	Researcher	University	Large	4 years	4 years
2nd Interview Round: Artifact Evaluation	C2	Senior Consultant	Technology Consulting	Large	3 years	-
	C3	Business Development	IT Consulting	Small	5 years	3 years
	P5	Business Development	IT Service Provider	Small	4 years	1 year
	C4	Senior Consultant	Technology Consulting	Large	4 years	3 years

4 Design and Development

4.1 Problem Statement

We address the research gap by identifying the relevance of data sharing solutions in the field of e-CMR documents through a systematic literature review, which indicated a lack of research for interorganizational information exchange in road transport. To further investigate the topic, we gained additional practical insights through expert interviews about the opportunities and challenges in applying a digital CMR (cf., e-CMR implementations). Where digitalization allows, for example, significant cost reductions, businesses may be concerned that electronic documents can easily be manipulated. There is a common understanding in practice to ensure a feasible design of the system. On that basis, we were able to define so-called meta-requirements of an e-CMR application in road transport. A DLT-based document management system must fulfill these criteria to increase the acceptance in the industry. The following three meta-requirements summarize this understanding and lay the basis for our research:

4. **Authenticity:** The risk of data manipulation must be very low so that no party involved can modify the e-CMR after its issuance without saving the modification in a neutral storage. There are many cases known where the CMR was modified after its issuance due to monetary benefits. Companies need a guarantee that the authenticity of the information is ensured and that they can fully trust the information (e.g., electronic signatures) (Interviewee: A1, A2, U1, A5, P1).
5. **Confidentiality:** The process of sharing information between businesses and authorities must be secure and confidential. The principles of data protection must be observed, and no personal data may be disclosed unintentionally (Interviewee: A1, A2; Engelenburg et al., 2019).
6. **Security:** A centralized data storage system for transport information entails a high threat for a cyber security issue and an incident could jeopardize the entire supply chain of a company (Interviewee: A2; Hasratyan et al., 2020).

4.2 Design Objectives

To fully address the meta requirements and to meet applicability in practice, we build upon the existing body of knowledge to specify design objectives (DO) based on the

capabilities of DLT. The goal is to identify stakeholders and their needs for analysis, communication, and subsequent implementation. The traditional technique includes the usage of questionnaires, interviews, and review of existing literature (Nuseibeh and Easterbrook, 2000). To capture the key objectives, we rely on previous literature and align applicability with DLT applications. The most important document is called Business Requirements Specification from the United Nations for trade facilitation and electronic business (UN, 2018). It describes essential business processes, transactions, and information entities for implementing the e-CMR. Complemented by research on associated DLT-publications (Naerland et al., 2017) and evaluated by selected experts, table 2 shows the ten evaluated key design aspects from a user perspective for a DLT-based solution in practice.

Table 2: Overview of DLT Design Objectives for an e-CMR Implementation

No.	Objective	Description from a User Perspective
D01	Creation	I want to simply create a new e-CMR, so that I can use the document electronically.
D02	Modification	I want to modify an e-CMR in a neutral database to maintain its integrity so that I can adapt it to the circumstances.
DO3	Attachments	I want to attach additional documents and photos to the e-CMR, so that I can report issues in the exchange process.
DO4	Archive	I want to archive and restore the e-CMR, so that I can access it in the event of a legal issue.
DO5	Authentication	I want to access the e-CMR based on authorized and authenticated users to control the distribution of the e-CMR.
D06	Signature	I want to sign the e-CMR with a reliable, unique digital signature (Qualified Electronic Signature) to identify involved stakeholders (cf. signatory ID, sole control, visible changes).

No.	Objective	Description from a User Perspective
D07	Neutral Infrastructure	I want to store my signature in neutral server infrastructure, so that I can guarantee its authenticity and non-repudiation.
DO8	Accessibility	I want to electronically exchange and share the e-CMR with the authorities (e.g., customs declaration, border control).
DO9	Data Structure	I want to see the event, its timestamp, and its unique event ID in the distributed ledger to track the exchange process.
DO10	Data Protection	I want to store my data in a secure environment, so that my data is protected from corruption and threats.

4.3 Design Decisions and Features

According to the derived DOs, we conducted a literature review to identify design features (DF) of different DLT frameworks (e.g., public or private DLTs) and to highlight respective design decisions and trade-offs in the context of DLT taxonomies. We used the presented scientific databases in November 2020 and defined the following search string for a title and abstract search (“Blockchain*” OR “Distributed Ledger”) AND (“Classification” OR “Taxonomy”). The search resulted in a set of 54 documents. We excluded irrelevant (e.g., not available in English, non-research papers) and duplicate publications, resulting in five documents to answer our research question. After an additional full text screening, we selected the morphology of Wieninger et al. (2019) as the most suitable to meet our DOs. Considering the criteria of completeness and degree of detail, it represents a synthesis of sixteen existing DLT morphologies, classifications, and taxonomies focusing on various characteristics. The features are described below:

Participation section

DF1 Authorization to view transactions: The feature authorization to view transactions is divided into a public and a restricted characteristic. Public transactions are visible for everyone (e.g., Ethereum). A restricted read authorization is used in hybrid and private networks (e.g., Hyperledger).

DF2 Right of proposal: Similar to the first feature, the ability to propose a transaction is characterized by a public and a restricted distinction. Different authorization levels regulate the right of proposal.

DF3 Validation of transactions: The consensus mechanism defines who can validate transactions. The validation can be done by anyone (e.g., Bitcoin blockchain), a restricted group (e.g., Hyperledger) or a central, predetermined authority.

DF4 Awareness of identities: Underlying regulatory requirements and other privacy reasons define whether the identities of the participants in a DLT networks must be revealed or remain concealed.

Application section

DF5 Token type: The ownership of a digital unit is represented by a token. It can represent different values or is the value itself. Wieninger et al. (2019) has classified this feature along five characteristics. A cryptocurrency which is used in a digital payment system, a utility token for accessing an application, an asset token representing the asset itself, (e.g., shares or rights), other usages or that no token is to be utilized within the system.

DF6 Incentive for validation: The validation of a transaction requires an incentive for the user to ensure a sustainable maintenance of the network. A distinction is made between a monetary incentive and a non-monetary incentive.

DF7 Location of the assets: In the DLT, information is stored in form of a transaction, which represents a transfer of information (e.g., documents) from one node to another. This document can either exist in the DLT itself or just its link is stored within the distributed network pointing to an external data storage (e.g., IPFS).

DF8 Possibility of change: The possibility of change does not refer to the extension of the distributed network with additional transactions or blocks. Instead, it specifies who can change functionality such as the selection of the notary nodes. If a central power can change the functionality of the network, it is defined as one entity. In all other cases, the possibility of change is distributed over the entire network.

DF9 Source code: The rules of the network are programmed into the source code. In a network where participants do not trust each other, confidence could arise from the fact

that the rules are transparent in the source code. When the source code is publicly available, the development of it can also happen through public users. In this context, the term open source is defined as the possibility to access the source code.

Technology section

DF10 Consensus mechanism: The consensus is a central element of the transaction process. The mechanism depends on its implementation and has a strong influence on the scalability and security of the system. If it requires a significant number of resources in terms of energy, storage, activity, or shares, it is described as resource-based consensus (e.g., proof-of-work algorithm). Non-resource-based mechanisms work without users having to provide a substantial contribution. Consensus can already be reached through a unique signature.

Feature 2 Turing completeness: The term Turing complete describes the possibility of a programming language to perform all the calculations a Turing machine is able to make. In a Turing-complete programming language like Solidity, complex conditions can be written, which is essential for smart contracts.

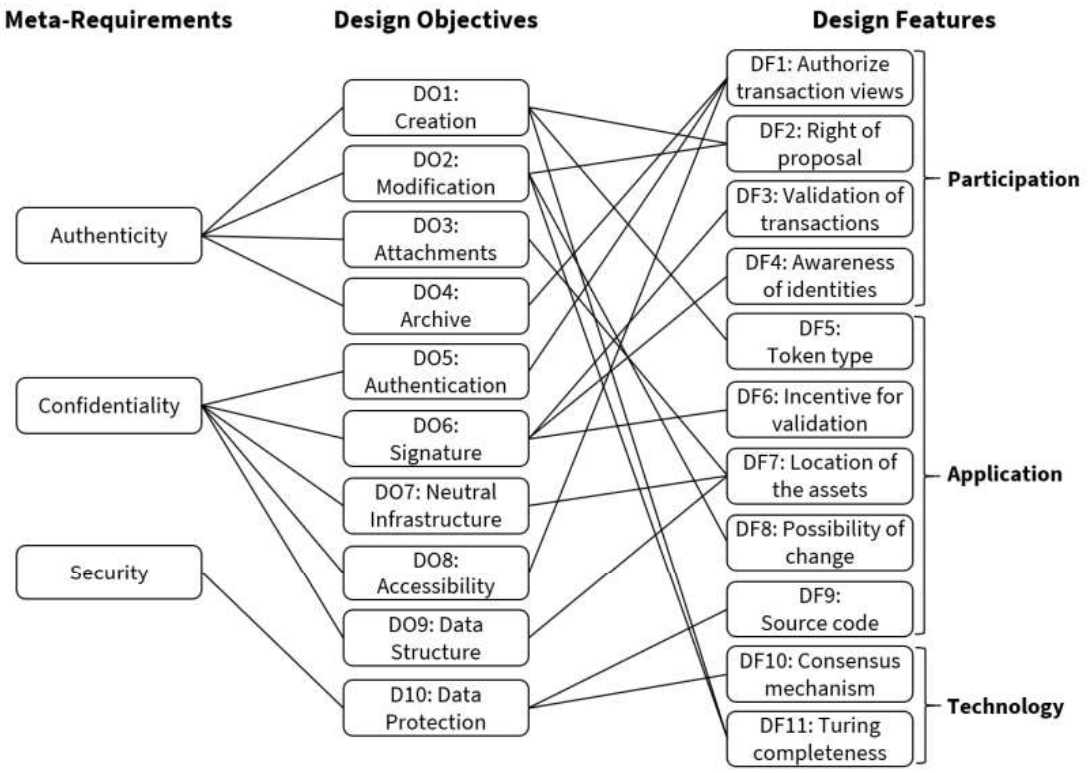


Figure 2: Mapping of Meta-Requirements, Design Objectives and Features

To visualize the coverage between challenges, objectives, and features for establishing a DLT-based document management solution in road transport, we mapped the presented DFs and DOs as well as the meta-requirements in Figure 2. The interdependencies are based on the premises that DLT is a feasible solution to cope with the identified challenges. For example, the meta-requirement *authenticity* (e.g., authenticity of the documents in the event of changes) is the basis for the design objective *modification*. The design objective *modification* can be fulfilled by the design features *right of proposal* (e.g., restricted), *possibility of change* (e.g., not one authority) and *Turing completeness* (e.g., yes, Turing-complete).

4.4 Solution Design

After selection and description of relevant features and their respective design decisions in terms of the morphological box by Wieninger et al. (2019), we extended the existing

knowledgebase for a subsequent solution design on basis of existing cross-industry use cases. For the literature analysis on DLT/BC based document applications, the common databases were used. We identified a set of eight publications ranging from health records to legal document solutions and assessed their applicability for a DLT-based document management system in road transport shown in figure 3 (cf. scope, coverage design feature area). As a result, we identified three publications (c.f. Aswin et al. (2020), Chen et al. (2019), Truong et al. (2019)) that mostly cover the relevant DF areas to extend our understanding and specify our solution design.

Use Case / Reference	Scope		Coverage Design Feature Area		
	Focus Road Transport	Practical Contribution	Participation	Application	Technology
Health Record Documents (Lee et al., 2019)	○	◕	●	●	●
Health Record Documents (Xiao et al., 2018)	○	●	●	●	●
Health Record Documents (Aswin et al., 2020)	◔	●	●	●	●
Supply Chain Documents (Chang et al., 2019)	◕	○	●	◑	◑
Trade Documents (Chen et al., 2019)	◑	◕	●	●	●
Finance Documents (Singhal, 2020)	○	○	●	◔	○
Real Estate Documents (Kopylash, 2020)	○	●	●	●	●
Law Documents (Truong et al., 2019)	◔	◕	●	●	●

○ No Coverage ◔ Low Coverage ◑ Medium Coverage ◕ High Coverage ● Full Coverage

Figure 3: Comparison of selected Document sharing Use-cases

The three selected use-cases provide a very good foundation for the application in road transport, where we were able to instantiate a path for each use-case in the morphological box (Figure 4). The first case deals with health documents, where the patients have full control over their records and determine who can access their history, by surpassing the trust issue through tamperproof data via DLT. Existing asymmetric

cryptography is used, requiring the users private key for sharing personal data. Accordingly, the architecture consists of four main components, an API module, the platform interface, the IPFS network using Hyperledger. The second case describes an end-to-end cross-border trade solution to share generic documents between multiple stakeholders across the entire supply chain, such as businesses and governments. An attribute-based encryption (ABE) for access connected to a private key for each user is proposed. The encrypted document is stored separately off-chain, where only a hash is kept for validation on the blockchain. The identity and data authenticity verification are done by smart contracts which are also implemented in Hyperledger's chaincode. The last case proposes a law document exchange platform, where a role-based authorization mechanism decides who can read, write, modify, and delete data. The data is distributed and stored over multiple places. A consensus mechanism protects the data from centralized modifications, including three main components (cf., Node JS web application, distributed file storage, and a private DLT system based on Hyperledger).

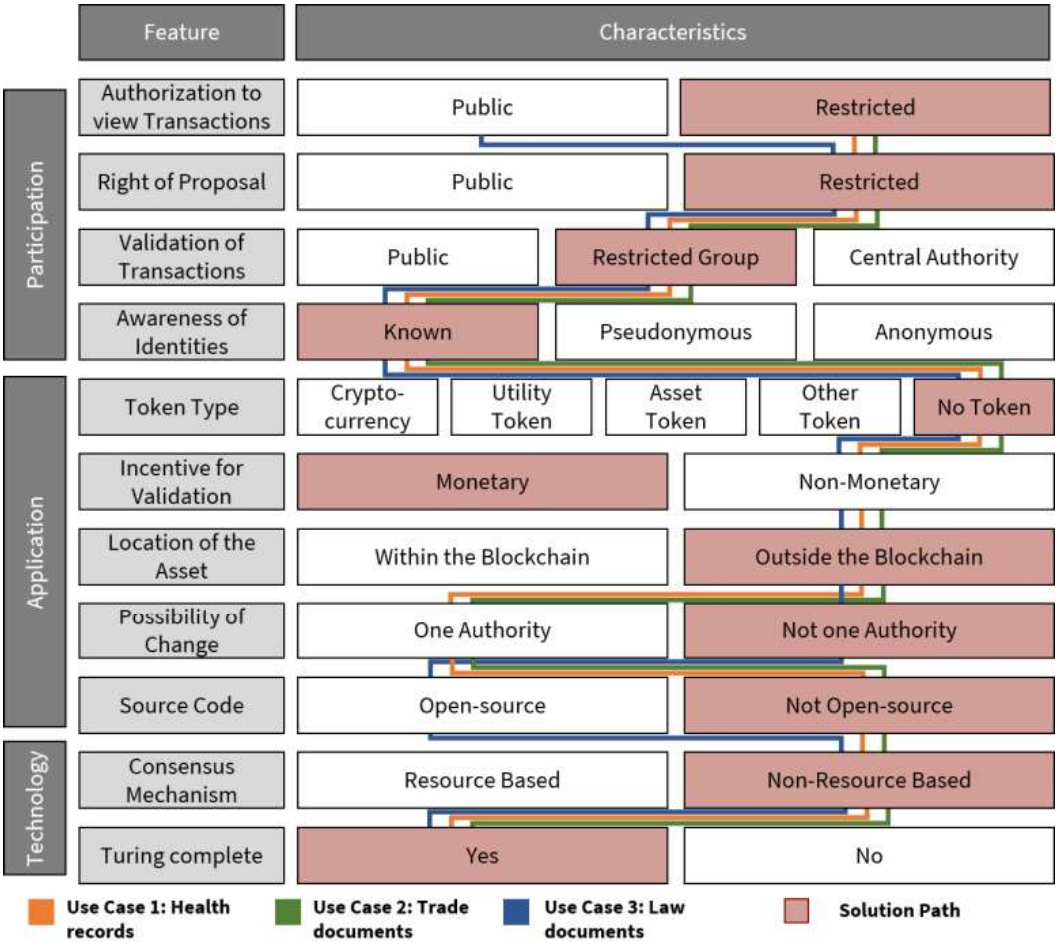


Figure 4: DLT design decision from literature use cases and solution path based on Wieninger et al. (2019)

Before a final solution design can be drawn, we evaluated these insights with two experts from the DLT and road transport domain. The final task was to select one specific design decision for each feature from our morphological box to identify the overall solution path and derive design principles. Beside a restricted authorization and validation of transport transactions by a selected group, a monetary incentive for operating the infrastructure was chosen, mostly driven by cost efficiencies and interoperability. According to "on-chain" data storage limitations, all relevant files (e.g., e-CMR, Pictures), except the identifier should be stored outside the shared ledger. The possibility to change the protocol should be initiated democratically by the group of stakeholders. Because of

restricted properties within the network, the source code should not be publicly accessible. To ensure scalability of the network, the consensus mechanism needs to be non-resource based. Turing completeness is the last characteristic chosen by the experts. Overall, great potential for the application was identified. The main advantage lies in one global source of information to be accessed from various actors. Additional value may also come from supplementary functions (e.g., goods insurance or in-transit financing).

4.5 Instantiation and Evaluation of Design Principles

This work aims at an artifact represented by an instantiation that proposes six nascent design principles to be applied in developing a DLT-based document solution in road transport. Design principles are a way of communicating design knowledge within design theories, where the output can be further differentiated according to their maturity and generalizability (Gregor and Hevner, 2013). On the most applicable level, an implemented artifact can be represented by a software product applied in a specific situation. In comparison, design principles and design architectures represent operational knowledge and are more abstract and generic. Based on our solution path, the identified features, and the collected design objectives, we gather first evidence for nascent design principles shown in Table-3.

Table 3: Nascent Design Principles

Design Principles	Description
Data protection mechanism	A DLT document sharing application in supply chain management must be protected by a gatekeeper that restricts access to the private network. Businesses want to avoid liabilities and do not trust each other. They want to keep all information confidential and decide who can participate in their private network.

Design Principles	Description
Application of participation roles	Different participation roles are required to guarantee that predefined tasks are performed exclusively by the relevant owner. Sender, carrier, and consignee run full nodes and are able to read, write, and validate transactions. Their identity is known and are considered to be the main parties in the DLT network. Other parties (e.g., authorities, service provider) operate a lightweight node that allows them to perform basic tasks. Public authorities are only authorized to view documents. This read-only access is important, as it lays the basis for faster processing. The validation is done once the cargo is handed over. The Carrier of the package proposes a transaction while the receiver authorizes it. A monetary incentive is not required, as an agreement defines the handover process.
Tamper-proof data storage	All required documents and attachments are stored via the DLT-system to reduce tampering and ensure transparency in case of modifications. DLT does not efficiently handle big data files. An off-chain storage is applied, where only content-address hashes are stored as transactions and distributed across the network (e.g., IFPS). This combination creates a performant and resilient file storage system. However, it must comply with a restricted group access for sharing the meta-data in case of sensible information.
Neutrality Principle	The owner of a DLT document sharing solution must respect the principle of neutrality. The IT provider can either have the rights to modify the application or pass on some rights to the customers. What is important is that each participant must have confidence in the software provider. This trust can only be achieved if the software provider is not involved in the core business of its customers.

Design Principles	Description
Automated data exchange	Smart contracts are based on a Turing-complete language to be used as an enabler for efficient data exchange mechanisms and process automation. Once goods are handed over, the transfer of ownership and timestamp allows to initiate subsequent financial flows. Smart contract based automated workflows improve working capital management (e.g., days payables outstanding) and complete the transition to automated systems across the supply chain.
Cryptographic data protection	A DLT application in document sharing must provide a cryptographic layer to strengthen data protection. The application provides a single source of truth for several companies, making it vulnerable to cyberattacks. A cryptographic layer helps to protect the data in case of an incident. Privacy is key in data sharing.

The evaluation process in DSR is a crucial element, where the final artifact was reviewed by four experts with extent experience in the domain (Hevner et al., 2004). We applied the evaluation criteria by Sonnenberg and Vom Brocke (2012), namely effectiveness, efficiency, and impact from an environmental and user's perspective. A structured questionnaire was used by assessing the artifact on basis of a Likert scale of 1: fully disagree to 5: strongly agree. Each design principle has been analyzed on its own and is accepted if the experts at least partially agree on the effectiveness, efficiency, and impact. Table 4 summarizes the average of the four expert responses.

Table 4: Evaluation of the Artifact

Design Principles	Effectiveness	Efficiency	Impact
Data Protection Mechanism	4.50	4.50	4.50
Application of participation roles	5.00	4.25	4.25
Tamper-proof data storage	4.50	4.25	4.75

Design Principles	Effectiveness	Efficiency	Impact
Neutrality Principle	4.25	3.50	4.50
Automated data exchange	4.50	3.75	4.25
Cryptographic data protection	4.50	4.50	5.00

5 Conclusion, Limitations, and Outlook

5.1 Principal Findings

Our paper highlights the need for a DLT-based document management system in road transport mainly for three reasons: first, to prevent counterfeiting of e-CMR documents (due to financial tax benefits); second, to solve the trust problem between companies in the supply chain using enhanced data protection mechanisms (access rights) and participant roles (full nodes for sender, carrier, and consignee and lightweight node for authorities); third, to survive a single-point-of failure in case of a cybersecurity incident by using a cryptographic security layer.

The analyzed applications of DLT-based document management systems in different industries use similar design features. Thus, the choice of design features (e.g., validation of transactions) does not depend on the industry. However, DLT-based document management systems have not yet focused on further process automation through smart contracts. In the future, automated end-to-end workflows will add the greatest value through extended use-cases and additional services (e.g., goods insurance, in-transit financing).

5.2 Contributions

Our work has two contributions to practice. First, the evaluation of meta-requirements helps to understand the challenges that transport company face in digitizing their businesses (e.g., confidentiality of personal data). The design objectives may further specify the selection of DLT design features when applying document sharing processes.

Second, the identified design principles give practitioners a basis for decision making in choosing relevant design features for developing applications in other cross-industry use cases. This is very important due to the complexity and the number of DLT design decisions practitioners face when implementing a DLT system for document exchange.

Furthermore, this paper contributes to research by extending the existing literature on document sharing use-cases in logistics and by applying the morphological box of Wieninger et al. (2019) on basis of empirical data.

5.3 Limitations and Future Research

From a practical point of view, the paper is limited by the fact that the experts are mainly from the logistics industry and thus, the DLT design objectives are heavily influenced by their profound knowledge. Despite our efforts to provide a comprehensive literature review, we may not have found all use cases for document sharing. Nevertheless, the selected literature gives a good impression of the existing state of the art. Additionally, DLT is still an emerging technology, where the applied morphological box just represents the current state of research.

Future research should focus on a software implementation and the corresponding performance measurements. Afterwards, the document management system should be benchmarked against other implementations and integrated into a real-life environment. Only in this setting further transformational problems may (e.g., process reengineering) be identified and technical challenges may be improved.

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Decision-making in Multimodal Supply Chains using Machine Learning

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Purpose: *To strengthen efficiency and resilience of supply chains at the same time, shippers and logistics companies needs proactive transparency about their orders. Machine Learning (ML) offers huge potential for precise predictions of complex logistics processes. This paper shows the results of a perennial research for implementing a ML-based system, which predicts multimodal supply chains, detects upcoming disruptions and provides suitable actor-specific measures.*

Methodology: *For each process of the considered supply chain an individual prediction model is developed, using four years historical data, about 50 identified features and various ML methods. The developed cross-actor ETA was linked with preventive measures based on expert knowledge. Both was integrated into a web-based prototype of a self-learning decision support system.*

Findings: *Thanks to the development of different ML approaches, most reliable model configurations were identified for each process. Moreover, important insights were gained regarding the availability of required data as well as the potentials and challenges of using ML-based solutions for decision-making processes in logistics.*

Originality: *The potentials from the use of ML for predicting supply chains has only been carried out for particular processes. An integrated approach including different processes like rail transports and transshipment points as well as a linkage with prediction-based measures is still missing.*

First received: 23. Apr 2021 Revised: 18. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Increasing demands on the reliability, flexibility and efficiency of logistics services require companies to make fast and optimal decisions when planning and controlling their supply chains (SC) (Handfield, et al., 2013). In this context, logistics decision-makers are faced with complex problems. A large number of influencing factors are present, which are continuously changing. In addition, various objectives corresponding to the different logistics stakeholders have to be considered, which are partly in conflict with each other (Straube, 2004). Many of the decisions are conducted under uncertainty, since often not all information is accessible.

One essential process information for Supply Chain Management (SCM) is the Estimated Time of Arrival (ETA) of the respective goods at various points in order to synchronize the individual processes and to ensure a demand-oriented capacity planning with regard to material stocks, personnel and infrastructure (Walter, 2015). The dynamic and diverse influences on process execution do not yet allow reliable predictions of the respective SC progressions (Weinke, et al., 2018). The difficulty of estimating process or arrival times applies in particular to multi-stage SC, due to the complex interdependencies of their individual process stages, as in the case of multimodal transports. This lack of transparency means that, currently only reactive action can be taken in response to disruptive events that occur. The derived decisions to adapt the processes often do not represent an optimum with regard to the overall SC. This results in high economic and ecological disadvantages for global SC in the form of unpunctual deliveries, underutilized transports, cost-intensive exception processes, and unnecessary risk buffers, which are shown in Figure 1 (Poschmann, et al., 2019).

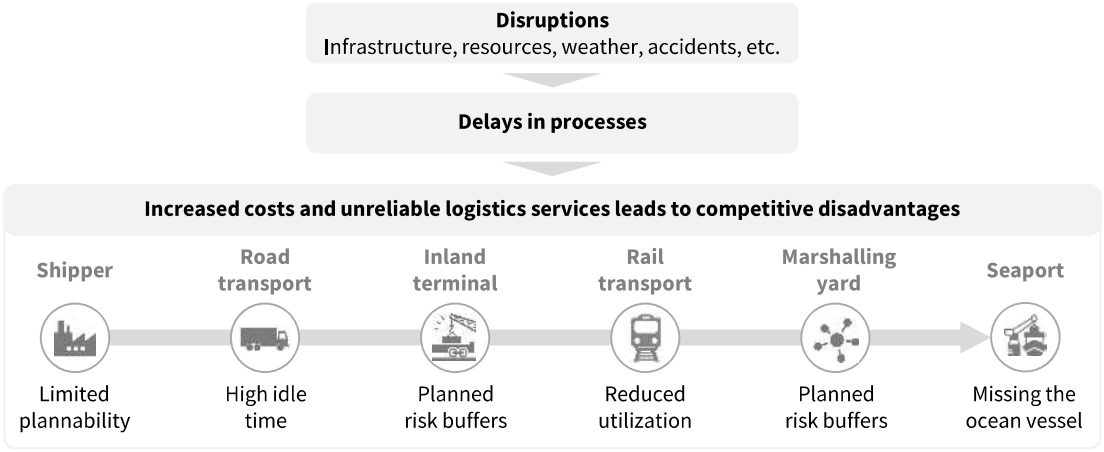


Figure 1: Effects of disruptions in multimodal supply chains

The use of Machine Learning (ML) to address this complexity in SC decision-making processes has high potential (BVL, 2018; Jordan and Mitchell, 2015; Straube, et al., 2020). With the help of self-learning IT-systems, problems can be solved more flexibly, with less effort, and with a higher accuracy of results. Moreover, it is the ability of systems to learn that enables autonomous execution of processes (Wahlster, 2017).

This paper investigates the feasibility of ML for predicting multimodal SC. Therefore, it shows the development of a prototypical IT-system, which for the first time uses ML for calculating ETA in this context and provides the involved actors with measures based on these predictions for a proactive avoidance of identified disruptions. In the following sections the procedure and main results of a three-year research process to develop this self-learning decision support system are presented. At the beginning, the framework of the project is discussed with a brief overview of the application area, the ML technology and previous approaches for predicting multimodal SC. Subsequently, the methodology of the development process is described. According to the individual steps, several results are presented, e.g. on the considered data and features as well as on the developed ML models for the ETA prediction and the corresponding expert-system for prediction-based measures. Afterwards, the implications for research and practice are critically reviewed. The last section provides a summary of the paper and an outlook for corresponding activities.

The paper addresses practitioners, such as logistics companies and shippers, as well as future research projects, which want to implement a ML-based decision support system in the context of process predictions. Information that may be used includes potentials of ETA for SCM, data availability, relevant features, suitable ML models for several SC processes and their reasonable integration, as well as the linkage of symbolic and sub-symbolic AI approaches.

2 Framework

2.1 Application area

The use-case of this paper is the combined transport (CT) of rail and road in the pre-carriage of the maritime SC. Therefore, real customer orders of sea freight containers from industrial shippers to the seaport were considered. In the corresponding door-to-port process chain, a container is picked up at the shipper and is first delivered by a truck to an inland terminal. Within this logistics node a potential short-term storage as well as a transshipment to a train is conducted. The according hinterland train is moving to a marshalling yard (MY), possibly with several stops for changing crews, traction units and wagons. In the MY, the respective wagon is partially again buffered for a short-time and transferred to a feeder train, which goes to the designated container terminal in the seaport. This considered process chain in the project is followed by a main leg with an ocean vessel and by a landside subsequent leg, which ends with the delivery of the container at the customer. This fragmentation of the process chain also leads to the involvement of various container-carrying and overarching actors, which are all potential owners of required data (Poschmann, et al., 2019). These include trucking companies, terminal operators in the inland and seaport, railway undertakings (RU) including marshalling companies, as well as infrastructure operators, CT operators, freight forwarders and shipping lines.

2.2 Machine Learning

ML is a subfield of Artificial Intelligence (AI) and combines several technical approaches, which can be broadly categorized into the three main types of supervised, unsupervised and reinforcement learning (Russell and Norvig, 2010). In contrast to a manual coding by rules or ontologies, which represent the knowledge of previous IT-systems for solving problems, in ML empirical relationships are determined independently by algorithms (Murphy, 2012). For this purpose, this sub-symbolic approach uses data on the respective domain as a basis for learning (Alpaydın, 2010). By evaluating the obtained results against a predefined performance metric, the ML approach allows for continuous improvement, i.e. a steadily more effective and efficient accomplishment of the considered task (Simon, 1983). This automatic acquisition of knowledge about the application area enables the recognition of complex correlations for problem-solving, which are not recognizable to humans or only with great effort. These patterns can be used for various operational tasks, including segmenting objects, deriving rules, determining future values in the form of predictions, and determining optimal solutions, including creating new content (Alpaydın, 2010; Döbel, et al., 2018).

2.3 Prediction of multimodal supply chains

For the evaluation of the state of research, an analysis of previous literature was conducted. Its results on existing prediction solutions of process or arrival times in multimodal SC are presented in this section. They were used for the initial evaluation of the suitability of prediction methods. Basically, a distinction can be made between model-based approaches, which are mostly based on simulation, and data-based approaches (Wen, et al., 2017). Approaches based on ML can be seen as a subset of data-based approaches, which were the focus of the literature review. Solutions for the entire SC as well as for the individual subprocesses were included.

The only representative for ML-based predictions of multimodal SC was identified as the paper by Servos, et al. (2020), in which an approach for ETA prediction for container transports over the maritime SC is developed. Randomized trees, adaptive boosting, and

support vector machines (SVM) are used. The approach only incorporates GPS data, but no other data, so operational factors influencing arrival time are not covered.

The availability of approaches for specific subprocesses depends heavily on the transport mode. For the main leg by ocean vessels, initial approaches to ETA prediction already exist. For example, in Lechtenberg, et al. (2019) an approach for the prediction of arrival times for ocean vessels in specific destination port regions is developed. For this purpose, different ML methods such as artificial neural networks (ANN), SVM, and gradient boosting are tested. For the road freight, hardly any scientific elaborations could be identified so far. Existing work focused on passenger traffic arrival time prediction, such as the paper of Fan and Gurmu (2015), which i.a. used ANN to predict travel times of buses. These are not directly transferable to freight transports. Only Li and Bai (2016) consider the development of an approach for road freight using gradient boosting, which includes only temporal characteristics. In case of rail, only data-based approaches exist for passenger transport. For example, Yaghini, et al. (2013) developed a prediction for passenger trains using ANN and decision trees. Markovic, et al. (2015) predict passenger train delay using ANN and SVM. Due to the different operational framework, these approaches are not directly transferable to freight transport. No paper on data-based approaches has yet been identified for relevant logistical nodes of inland terminals and marshalling yards.

In summary, there are currently hardly any reliable solutions for a data-based cross-process prediction of multimodal SC. This also applies to the individual subprocesses. Due to the high effort of mapping complex problems and the low scalability, model-based approaches have only established for individual subproblems, e.g. the modeling of subsequent delays in rail transport, but not for more complex multimodal systems. Instead, manual calculation methods based on subjective experiences of the process participants or extrapolations of current delay based on tracking information continue to dominate in this application area.

3 Methodology

To cover as wide a range of requirements and data, various companies were involved in the project, covering the individual actor roles in the considered SC, including shippers, terminal and infrastructure operators, land and sea carriers as well as CT operators and freight forwarders. The procedure was based on the industry-wide standard for planning of data-based projects in the form of the CRISP-DM. Based on an examination of the problem, this model provides an iterative procedure for the analysis and preparation of data as well as several steps for model development (Wirth and Hipp, 2000). According to the objectives, this procedure was adapted for the project (see Figure 2) and is described in this section according to several phases.

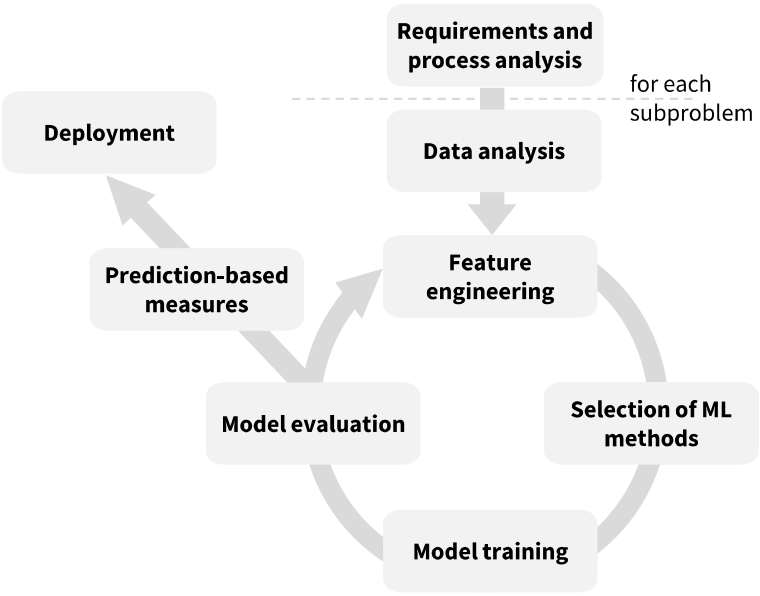


Figure 2: Structure of the research procedure

Requirements and process analysis: In order to realize a practice-oriented solution, the first step was to record and evaluate the requirements of the actors as well as the potential of the targeted solution. Together with the process-owners, important disruptions and their causes in multimodal SC were elaborated. Based on these activities, a specification of the application area for the development process was conducted, including the selection of suitable pilot relations and the segmentation into

different subprocesses based on data-side and operational requirements. Within these activities, 16 expert-interviews with a subsequent written survey were conducted.

Data analysis: The availability of historical data was an essential prerequisite for the targeted ML approach. Therefore, different measures were pursued to obtain appropriate data sources for each subprocess. The acquired data was processed and analyzed. This included both the consideration of process characteristics and the identification of possible factors, which are influencing process times. For this purpose, data visualization and methods for investigating correlations from the field of unsupervised learning were used.

Feature engineering: Based on the identified influencing factors and their causes, suitable input variables (features) were determined for all subproblems of the prediction. On the one hand, directly existing variables from the data sets were used as features. On the other hand, new variables were constructed by combining and transforming one or more existing variables.

Selection of ML methods: Based on these findings, potentially suitable ML methods from the field of supervised learning were selected for the specific problems. Among others., the type of target variable (classification or regression) and input variables, the statistical correlations between them, and the available training data and its quality were considered.

Model Training: The selected ML methods were finally trained for each subproblem with historical training data, whereby different model configurations were tested. Grid Search methods were used to determine the hyperparameters using a 10-fold cross validation for each subproblem.

Model evaluation: To determine the achievable prediction quality of the respective trained models, these were applied to an independent test data set. The MAE (Mean Absolute Error) and RMSE (Root Mean Squared Error) for regression problems and the accuracy for classification problems were used as quality measures. In addition, further problem-specific metrics were calculated for better external comprehension.

Prediction-based measures: Together with the actors, ETA-based use-cases and corresponding measures were investigated with regards to potential inefficiencies and

disruptions for the individual processes along the SC. These optimization opportunities were evaluated with regard to various criteria. Further six expert-interviews were conducted. Subsequently, selected results were transferred into a rule-based logic in the form of an expert-system. By this symbolic AI approach, knowledge and reasoning ability of human experts on a specific domain are emulated (Beierle and Kern-Isberner, 2019). In this case, the system should automatically detect disruptions and provide recommendations for optimizing action to the actors.

Deployment: The final step was the integration of the developed submodels into an overarching IT-solution. This included linking the individual prediction models to a prediction of customer orders across the entire SC (door-to-port ETA) as well as connecting this model to the expert-system. In addition, measures for the implementation of a future productive system were elaborated. In addition to a definition of data and interface requirements, a web-based prototype with a graphical user interface (GUI) for the visualization and interactive testing of the created solutions was developed.

The data activities as well as the development of the submodels and prototype were largely performed with R and SQL.

4 Results

4.1 Requirements and process analysis

During the analysis, several distinctions between the involved processes of the considered SC were identified, which have an influence on the development. This included the temporal determinacy of the processes by plan data, the causes for delays, the data availability, and the required reference points and objects for the ETA. Due to these differences, it was recognized that it is not useful to develop an overarching prediction model for the entire SC. Instead, the chain from the shipper to the seaport was divided into five subprocesses (see Figure 3). For each of them, at least one process-specific submodel has to be developed. Therefore, three representative pilot relations were defined: starting from the inland terminals Leipzig-Wahren, Munich-Riem and

Regensburg-Ost with their roadside pre-carriage transports via the MY in Maschen to the four container terminals in the seaport of Hamburg.

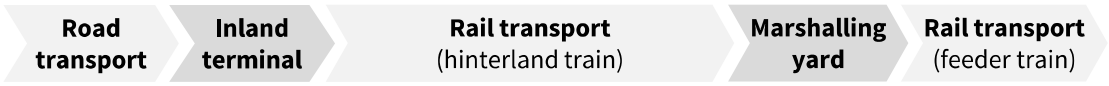


Figure 3: Considered subprocesses for the model development

4.2 Data analysis

4.2.1 Data acquisition

In total, during the project historical data for four years (2015 to 2018) from 16 different IT-systems of the participating companies was acquired. For the pilot relations, this included process data of 50,000 rail transports, 96,000 road transports, and 8.6 million container-related events. In addition, operational and external information on the individual processes was obtained, which depicts relevant influencing factors. This comprises personnel planning, vehicle characteristics, route and infrastructure information as well as construction sites, geo-data and weather conditions.

The highest data coverage was provided for rail transports. Firstly, detailed process data was available, since actual and planned times for the trains were recorded at discrete tracking points. Secondly, standardized disruption information for delays and many influencing factors were given. Usable data on marshalling processes in the terminals did not exist. For the road transport, actual departure and arrival times as well as start and destination points could be provided. In contrast to rail, no data was available on detailed routes, e.g. by GPS tracking. Also, disruptions were only recorded manually and not in a standardized way, so they were not considered. The data for the inland terminal and MY included the actual entry and exit times of the containers, wagons and trains. From this, i.a. the cumulative utilization could be determined. For the MY, planned times as well as information on the planned connecting trains of each container, respectively wagon were also available.

4.2.2 Data preparation

Due to the large number of involved IT-systems, merging them as well as ensuring a consistent database represented a major challenge. It was found that complete data coverage was not available for all customer orders, as some systems were only introduced at a later point in time (on certain routes) or data for older periods was deleted as part of the companies' data housekeeping. In addition to the completeness, a quality analysis was performed to identify anomalies. In particular, the extremes were considered, as these often indicate incorrectly recorded data. In addition, logical relations between the data were also reviewed, such as the fact that the departure must occur before the arrival. In many cases, implausibilities are due to manual data entry, e.g. the arrival time of trucks at inland terminals. Several measures were taken to ensure that all data sets could be used, despite the limitations in availability and quality. This included a transformation of syntactically incorrect data, a completion of missing values by predicting the most likely value based on other cases, and a selection of ML methods, which are explicitly suited for learning from incomplete training data sets.

4.2.3 Data analysis

After processing the data, various analyses were created to derive more operational information. By integrating the actor-specific systems, it was possible for the first time to derive statements about the total lead time of the containers along the SC, including actual times, planned times and delays, as well as about time-shares of the subprocesses. Figure 4 shows the distribution of the container-related total lead time for one of the considered relations from shipper to seaport for the years 2015 to 2017. For this relation, the median time is approx. 56 h. It shows a high variance with a strongly left-skewed distribution, which underlines the susceptibility to disruptions. In part, the long process times are also due to longer planned dwell and buffer times in the logistics nodes.

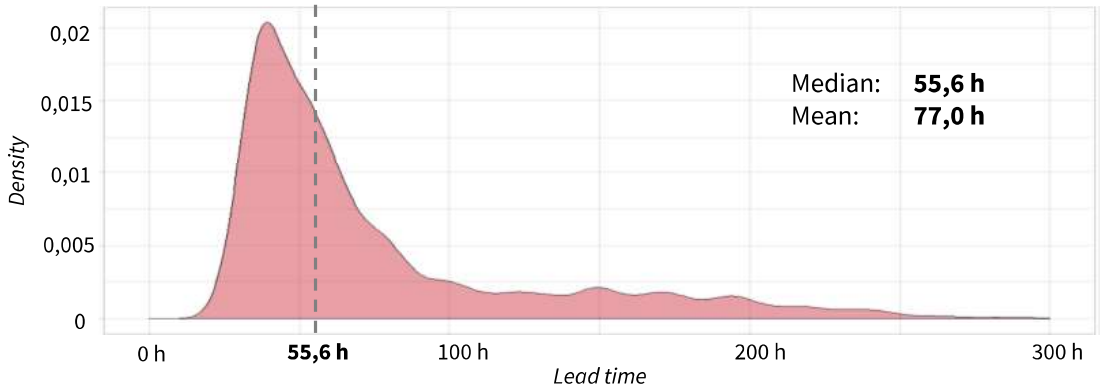


Figure 4: Distribution of total lead time

Figure 5 shows the lead time of this relation broken down into the individual subprocesses according to their time-share for the years 2015 to 2017 (arithmetic mean). A high proportion of around 70% is accounted by the logistics nodes. A major reason for this is the prevailing conservative planning of the SC, in which uncertainty about possible disruptions is to be compensated by additional planned dwell times in the nodes. The deliberate reduction of risk buffers through increased transparency represents a high potential for the ETA prediction. Rail transport between the inland terminal and MY takes up a share of about 20% of the total time. In contrast, road and rail transport between the MY and the seaport show low time-shares. Finally, it should be noted that the use of the arithmetic mean as an estimator for the average process duration and the existing skewness of the temporal distributions overestimate the dwell time in the nodes.

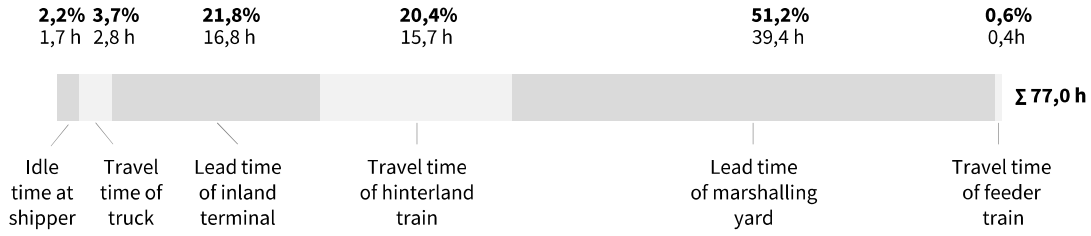


Figure 5: Lead time of subprocesses (absolute and ratio)

4.3 Model development

4.3.1 Prediction

To realize the ETA prediction for the SC, six process-specific prediction problems were derived, for which separate submodels were developed. In the first step, the travel time for the road delivery of the container between the shipper and the inland terminal is predicted. In the next step, a prediction of the achievable connecting train in the inland terminal is executed, considering the operating conditions. Afterwards, the arrival time of the train between the inland terminal and the MY is estimated, implicitly including the marshalling processes in the terminal. For the MY, the achievable connecting train to the corresponding destination terminal in the seaport is then determined. Finally, the rail transport to the port is predicted. The two sections of the rail transport in turn consist of further submodels for predicting the departure delay as well as the travel and stop times on the route, whereas each individual section between two tracking points or stations on the route is predicted individually. The overall prediction (door-to-port ETA) is composed of a logical connection of all individual submodels in the sense of a process chain prediction, in which the models successively build on each other: the output of a model serves as the basis for the subsequent partial prediction. As part of the iterative procedure for developing the submodels, the model configuration shown in Figure 6 was identified as the most suitable solution approach.

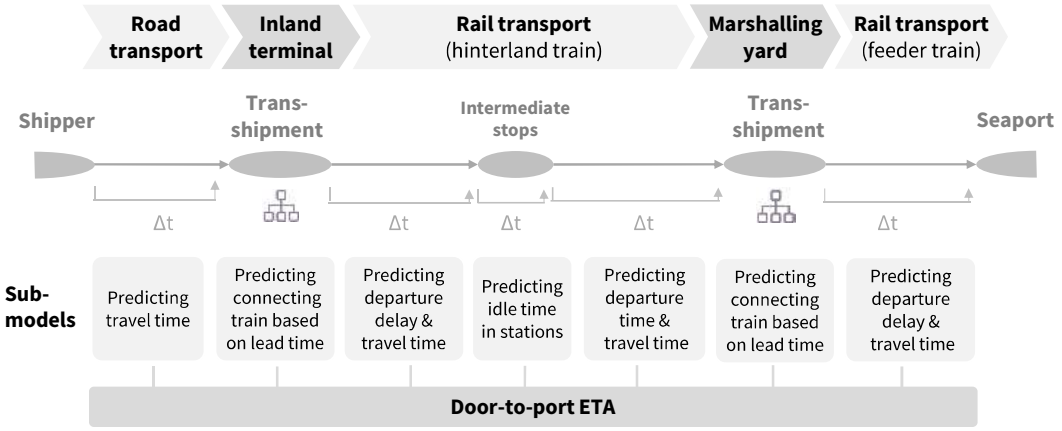


Figure 6: Process chain prediction approach for door-to-port ETA

During the model development, process-specific features were identified for each submodel and evaluated in terms of their importance as part of a feature selection process. A total of approx. 50 relevant features were identified for the submodels. Table 1 shows a sample of the considered features types, which map important operational influencing factors and disruptive events.

Table 1: Types of considered features (sample)

Feature type	Feature (generalized)
Infrastructure	Route information, construction sites, utilization, historical process times
Technical resources (especially vehicles)	Fleet planning, availability, vehicle characteristics, loading condition
Human resources	Shift planning
Freight information	Type, size, weight
Weather	Wind, precipitation, temperature
Time	Vacation, hour, weekday

The importance of two exemplary features for the subprocess of rail transport on one relation is shown by their correlation with travel time in Figure 7. A positive correlation is observed for the size of the train mass. Higher mass are associated with longer total train travel times. One of the causal reasons for this is the slower acceleration and braking behavior of trains with a high total mass. Furthermore, correlations were also found for the traction unit type. Causal reasons for this are different vehicle characteristics of each type, such as traction power and maximum running and braking speeds.

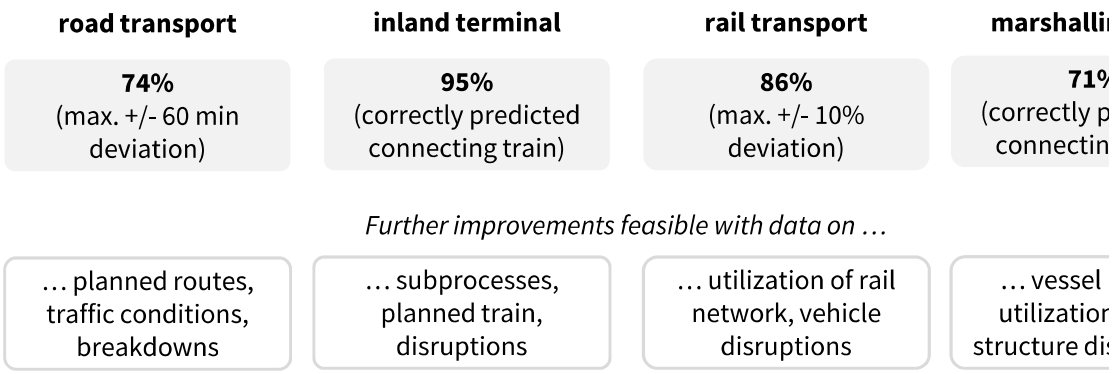


Figure 7: Correlation of train characteristics and travel time

Under consideration of the input variables according to the respective features and the target variables, the model configuration was performed. The output determined the type of prediction problem in the form of a regression or classification (Russell and Norvig, 2010). Transport processes were modeled as regressions since the output is a continuous variable. Classifications were used to predict the connecting transport at the inland terminal and MY. To identify the respective prediction algorithm, different ML methods were tested for each model. Overall, a combination of random forest, gradient boosting and linear regression trees was the most suitable approach. The suitability of the chosen ensemble learning methods can be explained by their specific properties. They can be trained well, even in the case of a high number of features (especially in terms of many binary variables due to a prior hot encoding of categorical variables) and small data sets. Another advantage is the automatic feature selection. Furthermore, these methods are well suited for learning from noise and incomplete data as well as they do not require extensive data preparation (Kuhn and Johnson, 2016).

By tuning the models, it was finally possible to achieve the prediction results shown in Figure 8 for the individual subprocesses of the SC. In this overview, the quality is measured on the basis of specific intervals, which the respective process participants have declared to be reasonable from an operational point of view. The prediction is always made before the respective process has executed, e.g. before a train departs. For the road process, 74% of the transports are predicted within a deviation interval of +/-60 min in relation to the actual time. In the inland terminal, the correct connecting train is

predicted in 95% of the cases. For rail transports, the arrival time of 86% of the trains is correctly predicted within a +/-10% deviation interval. A correct prediction of the connecting train in the MY is performed in 71% of the cases, with a no-information rate of 37%. Overall, the individual processes can be predicted with a high to very high accuracy by the selected model approaches. Following the composition of the individual submodels, very good results could also be achieved for the overall prediction of the considered SC (door-to-port ETA). According to this, the prediction deviations from the actual times for the transports from the shipper to the seaports, which often take several days, amount to a two-digit minute range for many orders.

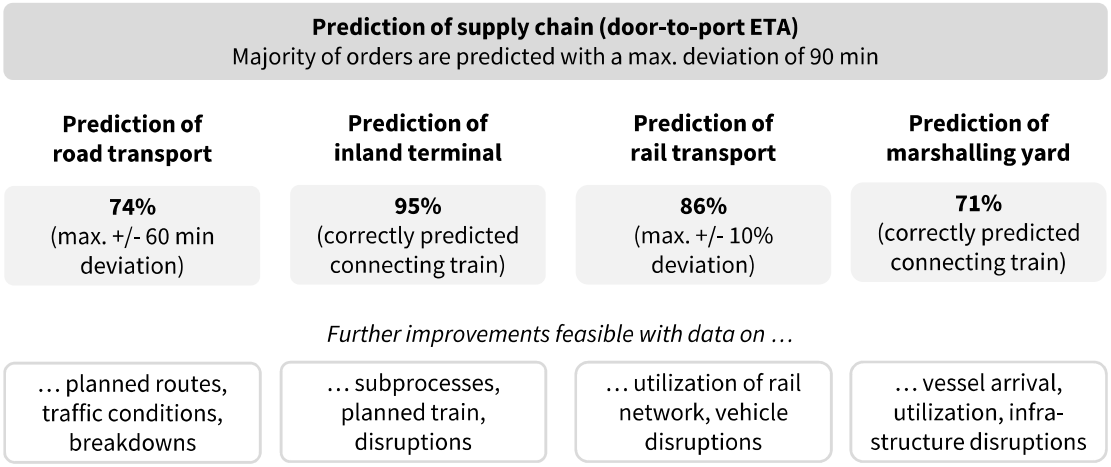


Figure 8: Prediction results and improvement potential

In the course of development, various levers for improving the prediction models were identified, which are also outlined in Figure 8. In general, high amount of training data and a coverage of relevant influencing factors by appropriate data are essential success factors. These requirements differ considerably in the individual processes. This explains, e.g. the better results for rail compared to road transport, where important information was missing like planned routes, breakdowns and stopovers. In the case of the inland terminal, this comprises data on the planned time of loading in order to consider planned storage times of the containers in the terminal. At the same time, data differences for the submodels with respect to the individual relations also become apparent. In the case of rail transport, the highest prediction quality was achieved on the

relation with the best data coverage, which has an average travel time of approx. 15 h (see Figure 9).

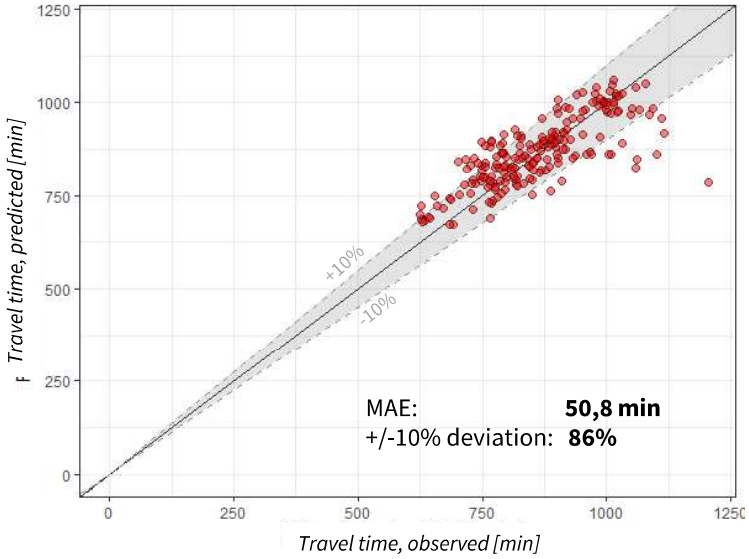


Figure 9: Prediction results of train transport

Across all processes, it can be stated that some influencing factors, such as technical disruptions to the infrastructure and to the used vehicle, as well as traffic-related influences and extraordinary disposition decisions, could not in principle be sufficiently considered in the prediction models on the basis of the available data. This also applies to large one-off disruptions that occur infrequently but have a high temporal impact, such as storms or strikes. Due to the pronounced individual character and the small amount of data available on these influences, the used ML algorithms cannot derive meaningful approximating relationships for the reliable prediction of new cases.

4.3.2 Prediction-based measures

Various use-cases for an ETA prediction were identified in the application area. These ranged from actor-specific optimization options, e.g. for shift planning in the logistics nodes, to timely synchronization of the entire SC. Latter option was linked with the highest potential for the envisaged solution, since reaching planned connection processes on time is of great importance in multimodal SC. In case of delays, even at the

beginning of the transport, this can lead to high conflicts with downstream processes. Especially, missing an ocean vessel at the seaport can induce delays at the destination lasting several days or even weeks. Based on missing the corresponding vessel closing, various operational situations (conflict cases) in the SC were identified that can lead to this scenario and that can simultaneously be detected in advance by the realized prediction. For that, suitable actor-specific measures were collected and evaluated with regard to their potentials, effects and feasibility. Some of them are listed in Table 2.

Table 2: Measures for preventing closing exceedance at the seaport (sample)

Actor	Measure
Freight forwarder	Register late-arrival at the seaport
CT operator	Transfer to earlier train from inland terminal
CT operator	Transfer to entire road transport to seaport
Inland terminal	Prioritized train disposition in inland terminal
Railway undertaking	Prioritized wagon disposition in MY
Railway undertaking	Prioritized train disposition in MY
Railway undertaking	Prioritized wagon disposition in seaport

The identified conflict cases and measures were transferred to an expert-system, whose general operating principle is shown in Figure 10. It starts with the generation of an order-specific transport plan for the entire SC, which contains planning information on processes, times, locations and resources. In addition, the door-to-port ETA prediction is executed. On this basis, a comparison is made between the plan and the prediction. In the case of a detected deviation, its impact is evaluated. Once there no negative impact

on the achievement of the vessel closing of a container, but it exceeds a defined threshold, a warning message is generated. Once the closing is exceeded, an automatic selection of suitable measures is triggered. The corresponding evaluation is based on logical decision rules. Firstly, this prioritizes measures that are most likely to prevent a missing closing. Secondly, measures that are associated with a high dispositive or financial effort are only proposed if alternative measures cannot be executed.

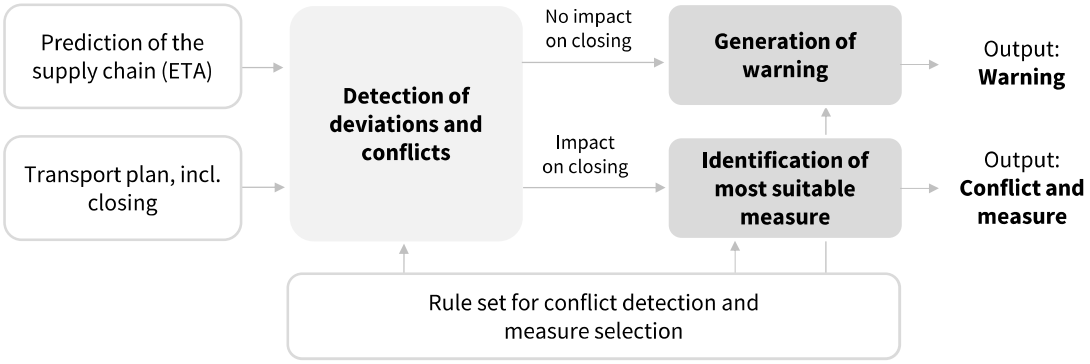


Figure 10: Operating principle of the expert-system

4.4 Deployment

The developed prediction models and the expert-system were transferred into an overarching prototypical IT-system (see Figure 11). This self-learning system consists of various subcomponents. It includes a module for training all submodels on the basis of the historical data from the 16 IT-systems, which also allows to check the quality and to retrain the model with new data. Another module applies the prediction results to new customer orders, detects deviations from the planned process sequence and performs the generation of measures. A web-based GUI was implemented for the prototype, allowing the retrieval of selected and anonymized orders. The system is publicly available on the website https://www.smecs-eta.de.



Figure 11: Web-based GUI of the prototypical IT-system

5 Potentials and limitations

By the developed self-learning decision support system, a contribution is made to the increasing need of transparency in logistics by providing reliable information on the arrival times of customer orders at important points along the SC, together with actor-specific recommendations for action. This information is already available at the beginning of the processes and considers effects on the entire SC. This enables companies to proactively select suitable decisions in the predicted event of a disruption, like a conscious prioritization of orders or an adjustment of capacities to achieve a higher adherence to schedules. At the same time, the efficiency and sustainability of processes can be improved by avoiding lower utilization and idle times of transports as well as cost-intensive exception processes, such as air or courier transports. This also includes the fact that deliberately planned risk buffers can be reduced, e.g. inventories in overseas plants or buffer times in logistics nods. Instead, the actual demand for required infrastructure, resources and transport capacity can be determined, which positively

influencing the utilization and thus the ecological footprint of processes. At the same time, the improvement in the decision-making basis reduces manual and time-consuming planning and coordination efforts for involved actors. With the help of these positive effects (see Figure 12), the obstacles of shippers and forwarders to use multimodal SC are counteracted by ensuring efficiency, flexibility and reliability comparable to other modes of transport.

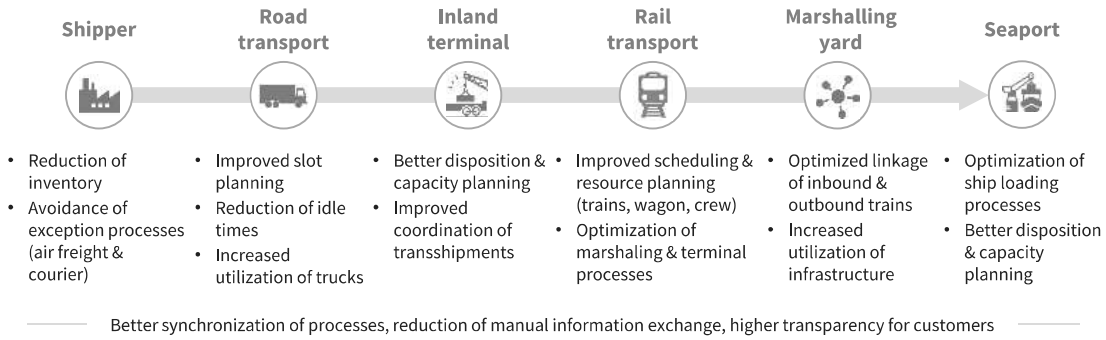


Figure 12: Potentials of the self-learning system

A main limitation of the research is the technical maturity of the developed IT-system. The prototype demonstrates the functionality for selected historical orders, but is not a productive system. The evaluation of the models was carried out under laboratory conditions using only historical data. Thus, no statements regarding the performance of the approach under real conditions can be provided. In future research, the system should be investigated under these conditions in the context of a field test. In addition to the prediction quality, other properties such as usability and acceptance must be evaluated in this context. Furthermore, the investigation has only been carried out for a specific process chain in terms of the maritime pre-carriage in combined transport on selected relations. A validation of the developed models on other transport modes and relations, including the transfer to the entire maritime SC, should be a subject of future research. Some important influencing factors are not considered in the solution due to the lack of data. In particular, the consequences of infrequent disruptions, which nevertheless have a high impact on the processes, could therefore not be predicted. Future research should examine how such disruptions can also be included.

6 Summary and outlook

The paper demonstrates the feasibility of a ML-based approach for the calculation of reliable predictions of multimodal SC. For the first time, a door-to-port ETA is provided, which allows a proactive intervention in terms of disruptions. The approach of implementing different ML submodels for several processes shows the best prediction results due to process-specific data and operational requirements. During the development of the models, it became apparent that the quality varies both in the individual processes and on the various relations. The achievable quality is strongly related to the available data, which show large differences along the SC. There is a lower coverage in road transport and inland terminals compared to the rail transport. Important factors influencing the process times are identified. Especially infrastructure disruptions, propagation of delays in the network and limited staff availability have a high significance. Frequent disruptions are well considered by the prediction, whereas unusual events require other approaches due to lack of data availability. After testing several ML algorithms and model configurations, ensemble learning approaches based on decision-trees show the best results for the most of the problems, since they are suitable for many variables with a small amount of training cases.

To support corresponding decision-making based on the prediction, the knowledge of involved actors was formalized within an expert-system. The identified measures show that there are different actor-specific possibilities for preventing upcoming disruptions. The used symbolic AI approach enables an objectively selection of suitable measures for an optimized planning and control of the SC. For the interaction of the prediction models and the expert-system a prototypical IT-system with a GUI was developed. This solution accelerates further research and the deployment of a productive system, since it provides insights in the model development and demonstrates the potentials of ML for SCM based on real customer orders.

The results of the research project are continued by DB Cargo AG in an internal project in order to provide a dynamic ETA prediction for its own transports at shipment level by a live operating system in the future. The authors apply the findings to other SC configurations. Together with shipping companies and terminal operators, they are

developing ML-based ETA predictions and corresponding optimization measures for national and international inland waterway freight transports within a further research project (IHATEC, 2020).

Acknowledgements

The authors thank all participants for their cooperation in the project as well as their confidence in providing comprehensive data and further company-related information. Special thanks applies to the employees of DB Cargo AG and the representatives of the other involved subsidiaries of Deutsche Bahn AG.

Financial Disclosure

The results of this paper are based on the research project SMECS (Smart Event Forecast for Seaports) funded by the German Federal Ministry of Transport and Digital Infrastructure (IHATEC, 2017).

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How Blockchain interrelates with trust in the supply chain context: insights from tracing sustainability in the metal industry

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Purpose: *Blockchain technology (BCT) is argued to deliver a trustless system where trust is driven by technology rather than individuals or organizations. This paper studies this claim using insights related to tracing sustainability features in the metal industry.*

Methodology: *The results of this study are based on multiple case studies of two supply chains (steel and copper) piloting a traceability solution for tracing metal sustainability throughout the supply chain. The data are collected and analyzed from multiple actors using sources such as interviews and secondary documents.*

Findings: *The study empirically supported that even if the BCT is applied, there will be a need for: benevolence, integrity, ability, and credibility dimensions of trust. Hence, a trustless system is still not yet applicable. Moreover, to remove the need for the trusted third party certificates, there are boundary conditions such as governance structures and standardizations that must be addressed first.*

Originality: *The concept of trust in the novel phenomena of the BCT was investigated from different point of views, such as the supplier and the buyer views. Moreover, different contexts were examined such as the commercial and the sustainability contexts. Therefore, this paper is among the first to handle the issue of trust from these regards.*

First received: 25. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

How Blockchain interrelates with trust in the supply chain context

1 Introduction

In today's business, inter-organizational interactions rely on unattached, multiple, and centralized systems across the supply chain (SC). That set-up requires much trust, harmony and coordination with participants to ensure unsafe, forged or fraud transactions do not occur anywhere in the network (Falcone et al., 2020). Therefore, many inter-organizational transactions are conducted through third parties or so called intermediaries, such as brokers or banks, who take on the potential risk of managing the transactions for an agreed price and sometimes a share in governance (Falcone et al., 2020; Lacity 2018).

Blockchain technology (BCT) is a distributed ledger in which all SC partners are given access in a peer-to-peer network to simultaneously exchange immutable records. This removes the need for central parties as it allows for a single trusted and visible source of information through the BCT (Francisco and Swanson, 2018; Wang et al., 2019). This could create a trustless system or a digital trust where trusting SC partners may be "not needed" given that the trust has been "programmed" into the BCT through its consensus mechanisms (Collier and Sarkis, 2021; Saberi et al., 2019). For example, in the metal industry, it is very difficult to trust other partners on the sustainability of their metals. This is because metals come from many different suppliers and countries and then they are melted, mixed and merged during the supply chain. However, with the help of the BCT, it became possible to have a trusted "eco-label" on metals to trace their sustainability features which facilitated the supply chain management (SCM) process (Svemin, 2019).

Saberi et al. (2019) speculated that BCT's trustless system can aid and support in solving many SCM problems related to environmental, economic and social aspects. Yet, great ambitions comes with great complexities. Indeed, there is a disagreement to wither the BCT is truly "trustless" as claimed by Saberi et al (2019), or a trustless system is a "myth" as described by Bratspies (2018). The problem lies in the nature of trust being a multidimensional, intangible concept that need to be operationalized into its underlying dimensions to be fully understood (Fawcett et al., 201). Now, trust became even more ambiguous due to the novelty of the BCT technology and the hypes surrounding it.

Therefore, some researchers suggested that trust will simply shift from intermediaries towards the technology itself and its governance process, but further research is needed to investigate such claims (De Filippi et al., 2020; Gucluturk 2018).

So the purpose of this paper is to explore the BCT and its trustless system in the SCM context. We endeavor to do this by exploring the current trust practices through close interactions with the individuals to capture their perceptions of trust as a concept. Insights from steel and copper supply chains are used to answer the following research questions:

- How is trust perceived with regards to SC partners and the BCT itself?
- To what extend the BCT's trustless system is applicable in the SCM?

2 Theoretical background

In this section, we follow a logical sequence to explain the BCT first. Then we explain the trust concept especially in the SCM literature. Finally, we link between trust and BCT to understand the "BCT based trust" in the context of SCM.

2.1 Blockchain technology

The BCT is defined as "a digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamperproof records" (Treiblmaier, 2018). The technology basically depends on unique features that defines it. These unique features are best described by Falcone et al. (2020) as: first being a distributed ledger technology (DLT) and second is the peer to peer network (P2P). Indeed, DLT and P2P are not new features to the information technology world, but what makes it truly unique is the novel combination of these two features with the utilization of advanced cryptography and consensus mechanisms to guard the whole process. (Falcone et al., 2020; Francisco and Swanson 2018; Kuhn et al. 2019).

The BCT has two types: permissionless (public) and permissioned (private) blockchains. In public blockchain, the digital ledger is completely decentralized and can be accessed

by any Internet user, which may put sensitive information at risk of exposure. On the other hand, private blockchain allows only a set of preselected participants to be authorized to use the ledger. In a fully private blockchain, entries are monitored by a central authority which can decide to accept new members into the network and determine their level of access (Treiblmaier, 2018). Moreover, an optional feature called the smart contract allows transactions to be triggered autonomously based on the trusted data of the distributed ledger. This has a great potential in terms of automation and artificial intelligence (Iansiti and Lakhani 2017).

2.2 Trust in the context of supply chain management

A highly cited definition of trust is "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (Mayer et al., 1995). In the literature, trust has been heavily discussed from different disciplines such as: psychology, sociology, economics, marketing, and SCM. This makes the topic of trust more complex rather than being simpler, since each discipline used its own lenses to explore it (McKnight and Chervany, 2001).

The SC literature defined trust in many ways. For example, Chan (2003) defined trust in SCM as the "reliability and consistency between different levels of the supply chain". Poppo et al., (2016) identified two main frameworks for trust, the first is calculative trust and the other is the relational trust. Indeed, Trust became even more complex in the context of SCM as it involves multiple inter-organizational relationships by nature (Arvidsson 2020 and Melander; McKnight and Chervany, 2001)

Batwa and Norrman (2021) argued that trust in SC partners can have dimensions like benevolence, credibility and openness of information sharing. These dimensions goes in line with some of the dimensions suggested by Fawcett *et al*. (2012; 2017) and Seppänen et al. (2007). Moreover, some other older and widely cited researches such as Mayer et al. (1995) have argued for alternative dimensions like integrity, ability and benevolence. Table 1 summarizes trust dimensions, its definitions and their references.

In this article, all the above dimensions are considered, whereas similar terminologies are grouped together. Indeed, the literature have many synonyms for trust dimensions, for example, Seppänen et al. (2007) mentioned more than 20 dimensions. But they can be grouped into few dimensions that depends on how broad or limited the definitions are. In this article, we focused on the most dominant dimensions in the SCM according to Fawcett et al. (2012; 2017), Seppänen et al. (2007) and Mayer et al. (1995).

Table 1: Dimensions of trust in SC partners

Trust dimensions	Definitions	References
Benevolence or goodwill	The mutual expectation between two parties that each will do good to the other	Fawcett et al. (2012; 2017); Seppänen et al. (2007) Mayer et al. (1995)
Openness	Transparency in sharing information and values	Seppänen et al. (2007)
Credibility	The confidence that each party in a relationship will perform as promised	Fawcett et al. (2012; 2017);
Ability or competence	The group of skills and competencies that enable a party to have influence	Mayer et al. (1995)
Integrity	The trustor's perception that the trustee adheres to a set of principles that the trustor finds acceptable.	Mayer et al. (1995)

2.3 Blockchain based trust

The BCT features that drives digital trust can be summarized in five points as mentioned by Lacity (2018) and cited by Falcone et al. (2020):

- "BCT allows participants to interact directly instead of through a third party
- BCT eliminates the need for reconciliation due to a shared, time-stamped, and immutable ledger of transactions,
- BCT instantly provides transparency and provenance of transaction's data
- BCT settles transactions faster and cheaper by automating the transaction and removing third parties
- BCT creates a data structure that is fault-tolerant, resilient, and persistently available to all participants in the network". (Falcone et al., 2020)

Batwa and Norrman (2021) proposed that trust is still needed for applying BCT. Therefore the influence between trust and BCT can have a reciprocal nature, i.e. trust can be both an antecedent for applying the BCT and a consequence. Moreover, trust can be seen with regards to two objects: trust in the SC partners and trust in the technology itself (Figure 1).

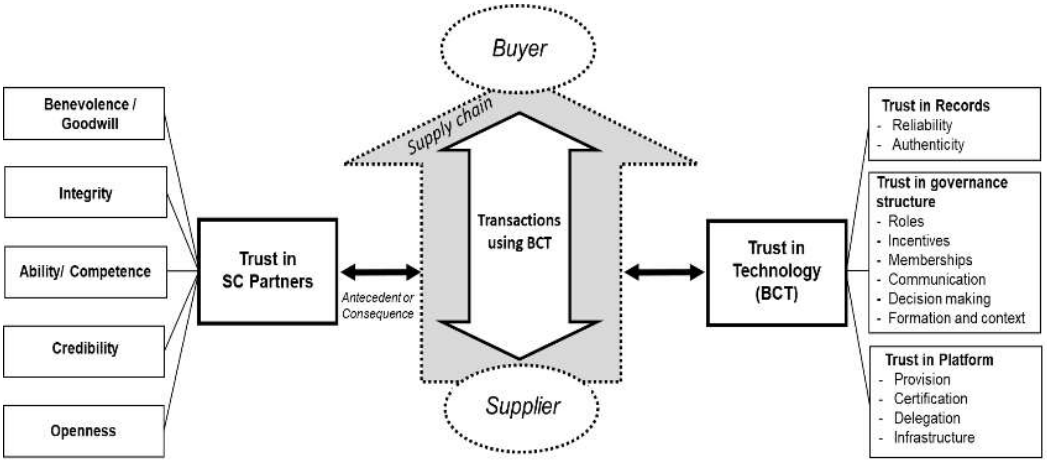


Figure 1: Framework for BCT based trust, adopted from Batwa and Norrman (2021)

After describing the dimensions of trust in SC partners, we now describe trust in the technology. Based on Lemieux (2016), Grandison and Sloman (2000), and Mak (2014), Batwa and Norrman (2021) proposed that this is perceived through two dimensions: trust in the records and trust in the platform. Other researchers such as Pelt et al (2021) and De Filippi et al. (2020) recently argued that confidence in the BCT depends fundamentally upon its underlying governance structure, this is also considered in this study (Table 2).

Table 2: Dimensions of trust in the technology (BCT)

Trust in BCT dimensions	Sub-dimension	Description
Trust in the records (Lemieux, 2016)	Reliability	The process of record creation: who creates the record and how they go about creating it
	Authenticity	Establishing and preserving the identity and the integrity of a record after its point of creation
Trust in the governance structure (Pelt, et al., 2021)	Roles	Describe observable hierarchical structures of participants
	Incentives	Motivational factors involved for the specified roles
	Memberships	The way participation are managed for the available roles.
	Communication	The formal and informal ways of communication between the stakeholders of the blockchain
	Decision making	How decisions are made, monitored and agreed upon
	Formation and context	The purpose of using a blockchain, and the type of the license used
Trust in the platform (Grandison and Sloman, 2000)	Provision	Trusts to let the trustee implement the service
	Certificate	A belief that the trustees' identity is claimed, based on certifications
	Delegation	To let trustee make decisions on the trustor's behalf,

Trust in BCT dimensions	Sub-dimension	Description
	Infrastructure	Trust in the related hardware and software to establish the BCT

3 Methodology

In this research, we are exploring the well-known trust concept but in the context of a novel phenomenon that is the BCT in the SCM. Since the context is intrinsic to the phenomenon, and since this phenomenon is complex and not yet fully understood, then it is very good match to use the qualitative research strategy (Golicic et al., 2005). This research depends on established trust concepts that can be used to approach the empirical context. The empirical data would lead into more insights to previous trust concepts in the novel context of BCT and therefore this research can be seen as a theory elaborating rather than theory generating research. (Ketokivi and Choi, 2014).

In terms of the research design, several researchers (e.g. da Mota Pedrosa et al., 2012; Voss et al., 2012; Yin, 2014) suggested that case research is an appropriate research method for exploring a phenomenon that we have limited understanding about. Furthermore, in this study we aim to capture trust aspects from close up interaction with the respondents to understand the underlying concepts of trust (Easton, 2007). Hence, case research was selected in this article as it fit the purpose of the study.

Multiple cases were used in terms of data collection. The reason for that is the nature of the supply chain context, for example, the settings for a dyadic relationships can be different than the relationship with a second or third tiers in the supply chain either upstream or downstream. The studied cases in this paper were copper and steel chain (Figure 2). In the steel supply chain, the blockchain pilot project involved a direct relation between the iron mines and their manufacturer of the steel. But in the copper chain, the blockchain project involved a second tier relationship between the copper mines, the copper wire manufacturer and the copper buyers that is a large electronic company. However, the manufacturer in the copper chain had a minor involvement in the

blockchain project and therefore it was not included in the interviews. The unit of analysis is trust in the context of different supply chains that applied at least a pilot blockchain project. One research institute has managed both cases where a pilot blockchain project has been applied separately for each case.

The main data collection method was a semi structured interviews to capture the related trust aspects (Easton, 2007). In total, 8 interviews were carried out. The interviews were done with key employees in each company who were involved in the blockchain pilot project including one interview with the project manager in the research institute who lead the two pilot blockchain projects. On average, the interview length was about one hour and 25 minutes per person. The median time is 75 minutes. All interviews were done through online meetings due to current Covid-19 restrictions. The interviews were recorded and transcribed using a transcription software with the author review and corrections, and with the permission of the respective interviewee. Additionally, we used published secondary documents by the research institute leading the two pilot blockchain projects.

Table 3 gives the details of the companies, the respondents, and the interviews. Due to confidentiality reasons, the companies and the respondents are given alias names. The letter S refer to “supplier” while the letter B refers to “buyer”. Moreover, the roles indicated two contexts: commercial context which is related to commercial activities such as sales or purchasing. And sustainability context that is covering environmental and social activities.

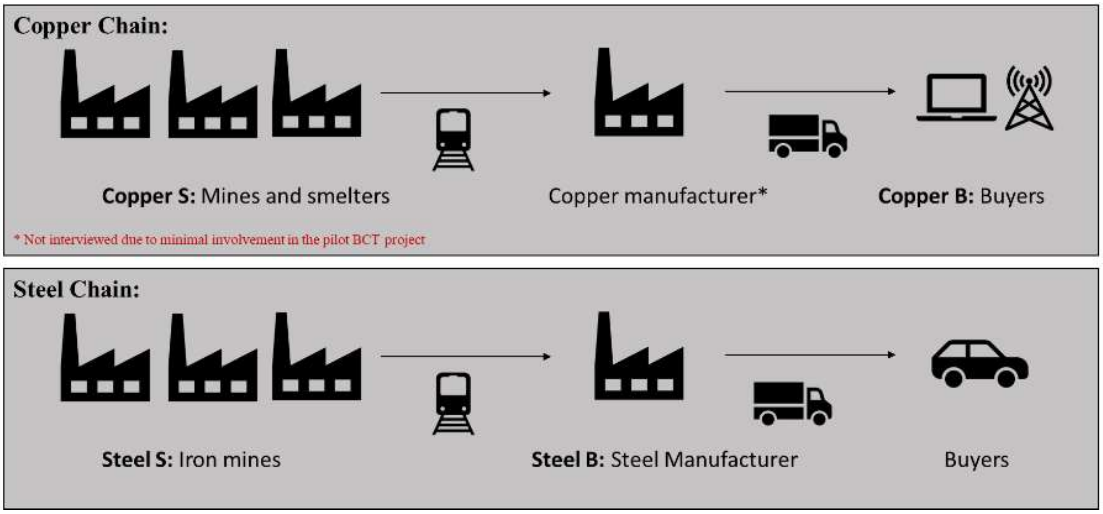


Figure 2: Copper and steel supply chains

Table 3: Respondents roles

Cases	Companies	Respondents	Respondent Alias	Interview length
Copper SC	Copper S	Sales director	Co-S-Sales	75 Min
		Sustainability advisor	Co-S-Sustainability	75 Min
	Copper B	Account manager (purchaser)	Co-B-Purchasing	120 Min
Steel SC	Steel S	Sales director	Stl-S-Sales	60 Min
		Purchaser	Stl-S-Purchasing	75 Min
		Sustainability director	Stl-S-Sustainability	75 Min

Cases	Companies	Respondents	Respondent Alias	Interview length
	Steel B	Sustainability director	Stl-B-Sustainability	120 Min
Projects leader	Research institute	Project leader	The project leader	90 Min

Following an abductive reasoning, we used iterative open and axial coding for the data analysis. In the open coding, the data from the different respondents was broken down to be analyzed, conceptualized, and categorized (Ellram, 1996; Yin, 2014). Then axial coding (pattern analysis) was used to make preliminary connections among the categories developed in open coding (Ellram, 1996). It is important to mention that analysis has been conducted in parallel with the data collection rather than a sequential process.

4 Cases introduction: the need for traceable sustainable metals

Due to the way metals has been traded in the global market, it was almost impossible to put an "eco-label" on metals to trace back its sustainability features. This is because metals are mixed and merged during the supply chain which puts the traceability of the chain of custody on the wish-list for decades, especially for mining companies with high environmental standards. However, in the last few years, things have started to change positively due to: legislation initiatives, development of new chain of custody (CoS) models and most recently the development of new technologies that allowed for real time traceability such as BCT (Svemin, 2019).

Indeed, "the need for sustainable metals and minerals will grow substantially as a result of a growing world population, increasing living standards and, not least, the transition to a climate neutral society. In this context, certification of metals and minerals could

contribute to meet sustainability challenges of increased resource use" (Svemin, 2019). According to Svemin (2019), Chain of custody models are different based on different needs. It could be for example:

- Identity preservation: in which the product can be traced back to the original source.
- Segregation: in which only products or materials from equivalent sources will be mixed in the production.
- Mass balance: in which the identity preservation and segregation are lost due to mixing of sustainable material with non-sustainable material.
- Certificate trading: in which sustainability claims are traded as certificates or credits. It is an approach to reward responsible production when it is difficult or impossible to trace products or material in the supply chain.

In the two studied cases of copper and steel chains, a mass balance approach was used. For each case, a pilot BCT project was applied using a private BCT system that was developed specifically to meet these two requirements for both cases:

- Implement an immutable and traceable mass balance chain of custody on a BCT database system
- Develop a certified declaration and tracking for mainly (1) carbon footprint and (2) recycled content of metals

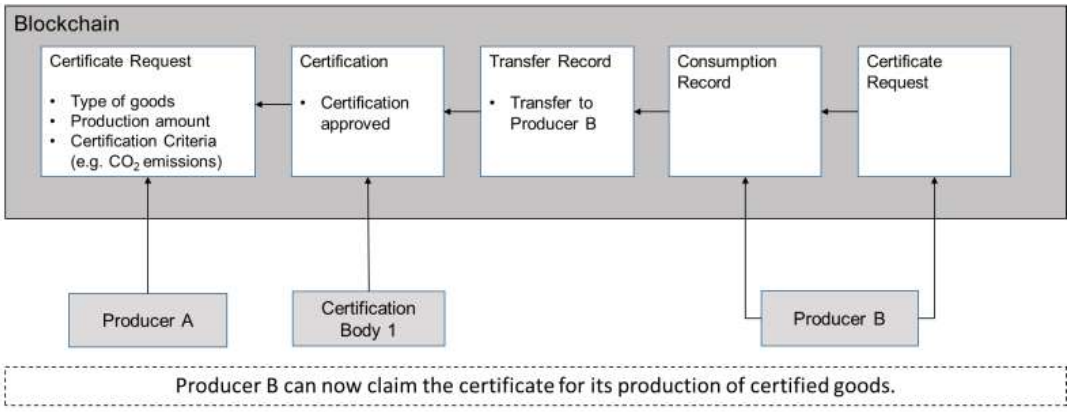


Figure 3: Explanation of how BCT certificates work

According to the project leader, it was useful to apply BCT in tracing the sustainable metals especially to meet the mentioned requirements. However, it came with some challenges related to the confidentiality, governance, correctness, and technical issues

such as energy consumption and node operations. A limitation is that the pilot projects were not implemented in full scale but only tested few times. Thus, the practicality and scalability of the BCT could not be deeply investigated. Furthermore, smart contract features were not used as it was not necessary needed to meet the two requirements.

5 Cases insights

For capturing how trust is perceived related to BCT, trust needed to be operationalized to its dimensions for developing a better understandings. Each trust dimension will now be explained based on the insights from the cases.

5.1 Trust in SC partners dimensions

Five dimensions were discussed through the interviews which are benevolence, integrity, ability, credibility and openness.

Benevolence or goodwill

All the respondents from the buyer and the supplier views said that no obvious opportunistic behavior with related to tracing CO2 emission and sustainable content materials. This indicates that maintaining a goodwill is a common practice in relation to sustainable context in the metal industry. However, Co-S-Sustainability from Copper S mentioned they face some altered information during the complex process of exchanging assays (i.e. quality documents for metal or ore). This practice make them benefit from reduced metal value which can be considered an opportunistic behavior that goes against benevolence. Despite this, benevolence is considered an important aspect of trust and it couldn't be replaced by the BCT as it goes beyond the opportunistic behavior into more productive collaboration as per Co-S-Sales S and Stl-S-Sales opinions.

Integrity

One example of integrity can be the adherence into the principles for reducing CO2 emissions among all the respondents. This can be justified as only a small number of actors were interviewed and sustainability issues was one of the main project aims.

However, integrity in other contexts is not as much agreed upon as reducing CO2 emissions. For example, Co-S-Sales stated that “the system without sanctioning capabilities basically doesn't provide any security for us“. If agreements must be “enforced” to be applied, this means a lack of trust in terms of integrity.

In terms of BCT and integrity, trust in other SC partner’s integrity is important for BCT to success and to avoid conflict on interests. Simply, the project leader indicated “it will be difficult to put many people in one room to implement a collaborative project if they don’t trust each other”. Hence, trust in other’s integrity remains important despite BCT implementation.

Ability or competence

In the two studied cases, a sort of consensus formed with regards to the ability dimension. All the respondents pointed out they generally trust their partners’ abilities. This is because they carefully picked them in the first place. Moreover, they cannot see how BCT would influence any partner’s power that is gained based on a specific ability or competence. Therefore, Trust in other’s abilities to fulfill the requirements is irreplaceable by BCT as it is embedded in the skills and competences of the core business.

Credibility

The respondents Co-S-Sustainability, Stl-S-Sustainability, and Stl-S-Sales from both sustainability and sales departments tied credibility with transparency. For example, Co-S-Sustainability stated “credibility to carry out the agreement is often related to what issues do they have at the production plant and if they are transparent with that, then it's easier for us to reach an understanding”. Stl-S-Sustainability stated that “if you have full transparency in the value chain, you will be able to monitor this (credibility) and you will see who is better than others”.

Yet, credibility is not all about transparency and visibility. Others pointed out that it can be developed over time such as the respondents Co-S-Sales, Co-B-Purchasing, and Stl-S-Sales. Besides that, all other respondents also pointed out that personal relationships are very important to develop confidence in an organization and they don’t see that a technology could replace experience or personal relationship aspects.

Openness or transparency

Many respondents perceive trust as a transparency in sharing information especially in the sustainability context. For example, Stl-S-Sustainability stated that ”my take on the term trust comes from a well, purely a sustainability perspective and to me, it equals transparency, which within sustainability is considered to be something that we strive for”. Stl-B-Sustainability stated that “Blockchain is all about the need for information sharing and a need to be transparent”. Co-S-Sustainability stated that “trust equals transparency: when we are transparent, we build trust”. Therefore, openness or transparency was the dominant perception among the dimensions of trust according to our interviews especially in the sustainability context.

However, to achieve transparency, many challenges come in the way. One major challenge is about setting up a standard way to calculate sustainability measurement criteria as it is not standardized among the SC partners neither in the copper nor in the steel case. Stl-B-Sustainability for example emphasized that “setting up standers is the most important challenge in the BCT implementation”. Others agree with him such as Stl-S-Purchasing and Co-B-Purchasing as well as the project leader.

Some cooperation was there between direct supplier-buyer relationships such as a project between both steel S and steel B as reported by both sustainability and sales respondents in both companies. This kind of cooperation was not visible in the copper chain since it has a multiple tiers relationship. Here, we quote from Co-B-Purchasing who stated that “I don't think blockchain will change the trust we have today towards the suppliers we work with directly, but it will increase the trust between the sub suppliers in the blockchain”

Other challenges related to openness is the confidentiality of sharing information. In terms of the sustainable context, CO2 emissions and sustainable materials content are not of course seen confidential. However, in the commercial context, many respondents find it difficult to share information like the origin and destination of the products, especially for the sales respondents due to reasons related to competitive advantages and negotiation of prices. This kind of issues has been technically discussed and it can be solved through DLT and P2P features of BCT at least on theory. So BCT based trust can

mainly replace the dimension of trust that is related to openness but some boundary conditions must be met first such as confidentiality and standards.

5.2 Trust in the technology dimensions

In this section, we will mainly discuss trust in the records as well as governance mechanisms. Since the two cases involved only pilot testing, it was difficult to draw conclusions related to trust in the platform and hence it would not be discussed.

Trust in the records

Trust in the records has two dimensions, first is the reliability and second is the authenticity. In terms of reliability, it relies on who created the records at the first place. Therefore, many respondents pointed out the need for a certified third party to validate the records before entering to the system. This finding comes from the suppliers' perspective as a competitive advantage to proof they are trustworthy. On the other hand, from the buyers' perspective, it is a condition prior to trusting the transactions. This can be interpreted into a lack of trust in the other SC partners, but also a common practice in the metal industry. In terms of authenticity, indeed all participants agreed upon the ability of BCT to provide a trusted data, which is related to maintain provenance records of the transactions. However, standardized process such as ISO are still required as suggested by some respondents.

To sum up the respondents opinion here: the records of BCT are trusted only if it is through a trusted third party specialized in providing such certificates. Once data entered into the BCT, it will be handled according to standardized methods and will be completely trusted. As an example: Co-B-Purchasing stated that ”If everybody will start to use some kind of certified method, then I believe, it is not so very difficult to get the trust between the actors within the blockchain. Because you can quite easily get that by forcing everybody to sign an NDA. If you sign a nondisclosure agreements for everybody, which is inside the certified blockchain, then you're forced to follow it, and then you're forced to trust the information you get”.

Trust in the governance structure

Governance structure has many dimensions and layers. However, as this was a pilot cases, it was difficult to capture all the dimensions with regards to BCT. However, respondents reflected mostly upon communication, roles, decision making and contextual factors for applying BCT.

Since the two cases are mainly related to sustainability context, free communication with agreed roles and decision making is not an issue at all, especially related to tracing CO2 emissions. However, some respondents speculated that if BCT is applied into other contexts, governance structures would be complex and would require a high cooperation to be agreed upon. For example, Co-S-Sales stated that "we are trying to figure out what is required to make it (BCT) a solution, which has a critical mass of governance structures, parameters and users" he also reflected on the contextual factors for applying the BCT since the current pilot was mainly to discover the potential benefits that might drive a competitive advantage for them, but the initiative was not based on an urgent need for solving a current problem within their business.

One way to remove the uncertainty and the mistrust regarding BCT governance structure is by relying on third party experts such as the technology providers or consultants to settle these issues. For example, Co-S-Sustainability stated that in terms of governance "I would rely on other experts to define if this is something we can trust or not. So I would rely on experts on the technology"

From the interviews, it can be seen that governance structures is a main source of uncertainty and it is not what companies needed at the moment. However, as many respondents pointed out especially in the steel SC, direct relationships helps in solving the boundary conditions but the true value of BCT comes with regards to trust in multi tiers partners. This also goes inline to what was said by Co-S-Sales.

6 Discussion and Conclusion

6.1 How is trust perceived with regards to SC partners and the BCT itself?

To answer the first research question, it has to be understood from two different perspectives. First is related to trusting other SC partners in the presence of BCT. In general, trust in the SC partner is perceived as openness in information sharing especially in the sustainability context. With this regards, BCT is perceived as a very promising technology. However, trust also perceived in other ways such as benevolence, integrity, ability and credibility. Indeed, in these aspects trust seems to be still needed even after applying the BCT, especially in the commercial context.

With regards to trusting the technology, the major perception is that there is a great trust in the records already tested in terms of authentication. For example the “eco labels” to trace the sustainability features of the products. However, there is less trust in the reliability or correctness of the data, i.e. garbage in garbage out problem. Therefore, the metal industry still relies heavily on third party certifications. Another important aspect of trust in the technology is related to trusting its governance structure and the different standards between the different companies. Indeed, one way to remove the uncertainty and the mistrust regarding governance structure and standardization is by relying on third party experts which contradicts a major goal of applying BCT and achieving a trustless system.

6.2 To what extend the BCT’s trustless system is applicable in the SCM?

With proper governance and standardization, we can say trust in a third party will be less needed. However, there will be a need for benevolence, integrity, ability, and credibility dimensions of trust. And hence, a trustless system is still not yet applicable in SCM. Table 4 summarizes the case insights that support this conclusion.

Table 4: Summarizing results and discussion

Trust objects	Trust dimension	BCT based trust	Context
Trust in SC partners	Benevolence	Required to avoid opportunistic behavior and for productive collaboration	Commercial contexts
	Integrity	Required to avoid conflict of interests	Commercial contexts
	Ability	Required to trust the ability that could be a core to the business even if the BCT is applied	Sustainability & commercial
	Credibility	It does not rely only on transparency, but time and personal relations as well, so it cannot be replaced by the BCT	Sustainability & commercial
	Openness	It can be replaced using the BCT if boundary conditions are met	Sustainability & commercial
Trust in technology	Trust in records	High trust in authenticity of the records, but not the reliability. The reliability would only be trusted if the records are entered through a trusted third party.	Sustainability & commercial
	Trust in governance	It could be trusted through technology provider or third party or if it is collaboratively developed	Sustainability & commercial

The above discussion is aligned with De Filippi et al. (2020) that suggested the BCT is not a trustless technology but rather a confidence machine, where confidence in the BCT depends upon its underlying governance structure. It also echoes Bratspies (2018) opinion that cryptography trustless is a myth.

7 Research contribution, limitation and future studies

This research helps in capturing the soft dimensions of trust in relation to the BCT, which contributes in appraising the potential benefits for this novel technology, despite the hype around it being a trustless system. In terms of the practical contributions, this research provided insights based on empirical data on the potential of applying the BCT to trace the sustainability of the metal industry. Indeed, the tractability of Co2 emissions and recycling contents in the metal industry can be achieved using the BCT although a complete trustless system is not yet achievable.

Future research is still needed for the BCT to seek solutions regarding the garbage in and garbage out problem. For example, using the BCT with internet of things (IOT) devices to capture inputs, and using smart contracts to trigger transactions. Indeed, the respondent Stl-S-Purchasing raised such questions but it remains for another research and another cases to study as it was not applicable in this paper. Moreover, this research could also be further studied using quantitative research strategies for generalizing its results and conclusions. The BCT indeed is a novel technology that is being considered by many businesses nowadays such as food chains and automotive industries. Therefore, the results of this study could be re-visited in the future with more cases other than the metal industry, and this would enrich the contribution and the value of this study.

The limitations of this study is that it only relied on a pilot project testing the BCT, and hence no conclusion could be driven on trusting the platform dimensions. Moreover, not all the companies in the supply chain were interviewed, mainly because of their minor contribution in the pilot projects, but yet this limits the conclusions for example with regards to the governance structure dimensions. However, interviewing employees from different contexts beside the projects leader helped in driving the conclusions of this paper.

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A roadmap for the effective implementation of blockchain technology

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Purpose: *This analysis aims to propose a reference model that could support companies in the implementation of a Blockchain-based initiative in their supply chain. This research identifies the sequential phases for the introduction of a Blockchain solution in an effective way. Furthermore, critical factors to consider in each stage are defined.*

Methodology: *A multiple case study approach was carried out. 22 interviews were conducted with different informants. Among them, companies that have implemented a Blockchain project for their supply chain, software providers, consultancy organisations that provided the Blockchain infrastructure or the support during the project, and a Blockchain expert.*

Findings: *The roadmap is a framework that encompasses stages, critical factors, and guidelines for implementing a Blockchain initiative in the supply chain. The roadmap is made up of four phases: (i) Approach Blockchain technology, (ii) Define Blockchain value for the business, (iii) Develop a proof of concept and pilot, (iv) Scale-up the solution. Regarding external dimensions to consider during the implementation, they include the technological development of Blockchain and the political and legal evolution.*

Originality: *The roadmap has been developed to foster the diffusion of Blockchain supporting the supply chain processes by showing the steps of adoption for its implementation.*

First received: 26. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The economic, legal, and political systems in the society are based on contracts, transactions, and records of them, that are essential elements in interaction between organisations but also individuals (Atzori, 2015). The Blockchain technology has an immense potential to change how parties interact (Mettler, 2016). Disintermediation could be imagined, as this technology records transactions in a secure, transparent, and decentralised manner (Mudliar et al., 2018). Thanks to its potential impact on the business environment, there is a lot of enthusiasm around this technology (Mougayar, 2016). Still, a lot of barriers need to fall and, as stated by Iansiti et al. (2017), "true Blockchain-led transformation of business and government, we believe, is still many years away. Blockchain is not a "disruptive" technology, which can attack a traditional business model with a lower-cost solution and overtake incumbent firms quickly (Dobrovnik et al., 2018). The Blockchain can potentially redefine the shape of society, but the process of adoption and integration is likely to be gradual (Wang et al., 2019).

Since this technology offers a decentralised approach to data management and sharing, supply chain management seems to be a promising field in which Blockchain could be applied (Queiroz and Wamba, 2019). The new way of recording transactions is likely to impact on current supply chain models (Schmidt and Wagner, 2019). The first implication regards the disintermediation effect that implies the removal of centralised positions (Schmitz, 2020). With the Blockchain, various players operating across the supply chain can exchange value without appealing to an intermediary to guarantee the transactions integrity (Cole at al., 2019). Furthermore, the Blockchain allows parties participating to the network to have a unique and shared view about the actual supply chain situation, improving supply chain visibility (Perboli et al., 2018). These concepts are becoming more and more crucial in a competitive environment that is always more complex and interconnected, if compared to the past (Perboli et al., 2018). Given these considerations, this work aims at exploring the connection between the Blockchain and the supply chain management.

Some gaps are still present in the literature on Blockchain application in the supply chain:

- existing contributions do not explain when the implementation of a Blockchain-based solution is valuable in the supply chain field. In this regard, a clear and unique definition of possible use cases is not present and the relationship between the Blockchain and existing technologies employed for the supply chain management is not defined;
- as the topic is quite new, critical factors for the implementation of a Blockchain project for the supply chain are not addressed by the existing literature;
- overall, no existing theory explains how to realise a Blockchain initiative in the supply chain context.

For these reasons, this study is developed on the following research questions:

- *Research question 1*: What are the stages of implementation for Blockchain projects in the supply chain and which are the guidelines that could be provided to companies willing to implement them?
- *Research question 2*: What are the critical factors for the implementation of a Blockchain project for the supply chain?
- *Research question 3*: What are the conditions in which the Blockchain application in the supply chain is valuable and what does this technology offer more than the existing technologies used in this context?

The paper is organised as follows: the literature review presents evidence from the extant knowledge, the methodology describes the adopted methodology, the findings section introduces the results, and conclusions and further development summarise the contribution and limitations of the model which can be addressed through future works.

2 Literature review

Even if Blockchain was born for the finance sector, projects outside the financial world have been mainly experimental, especially in the supply chain (Kshetri, 2018). There are a lot of reasons why this innovative technology may strongly fit supply chains (especially for the most complex ones that span over a multitude of production stages across many different geographical locations) (Kshetri, 2018). The principal ones are linked with the concept of transparency, accountability, and social responsibility, which according to Lee and Pilkington (2017), “are in high demand from consumers, thereby exacerbating both reputational risks and creating new opportunities for supply chain management”.

Moreover, companies are always more focused on developing collaborative initiatives in their global supply chains (Lee and Pilkington, 2017). Many enterprises are outsourcing whole noncore stages of their production, keeping core their competences in research, design, and development. This trend explains why real time data exchange and integration of financial, logistic and information flows between supply chain partners are urgencies that call for new solutions (Kshetri, 2018). Blockchain could be an enabler of a new decentralized information system that is no more trust based.

Moving from the lack of transparency and accountability in complex supply chain, Kshetri (2018) sustains that Blockchain may lead a higher supply chain visibility offering big gains to operations. Another important contribution to the Blockchain impacts on the supply chain is given by Lee and Pilkington (2017). The researchers introduce six principal use cases for Blockchain to improve the supply chain management. Even if Blockchain technology has a huge potential, according to Fiaidhi et al. (2018) it is crucial to keep in mind that it will have a bigger impact on their business and on their existing technologies, such as EDI. Indeed, since EDI alone cannot support the complex supply-chain processes of today, integrating a Distributed Ledger Technology (DLT) with the current system may be a feasible solution to benefit the whole ecosystem. Moreover, continuing to describe the relation between Blockchain and the more traditional technologies, O'Leary (2017) relates some proposed uses of Blockchain for transaction processing to other technologies, such as data warehouses and databases.

Wu et al. (2017) proposes a framework consisting of a set of dynamic and private sub-ledgers and a central public ledger. The sub-ledgers are order-based in the sense that they are created when an order is issued between certain trading partners and terminate when the order is satisfied. The sub-ledgers are private since only the partners involved in the execution of the order can participate to it. A similar Blockchain architecture based on a double chain is introduced by Leng et al. (2018), always to solve, at least in some extent, the trade-off between privacy and transparency mentioned before. A curious framework for traceability is presented in Toyoda et al. (2017). In this research is described a novel Product Ownership Management System for anti-counterfeiting purposes that tries to solve some limitations linked with the usage of RFID technology in the post supply chain.

Figorilli et al. (2018) suggest a tracing system within the wood supply chain that, based on RFID open-source technology and Azure Blockchain with a cloud deployment, integrates information related to the quality of the product with those linked with the traceability (logistics information). A different approach to study the Blockchain applied to supply chain is proposed in Gausdal et al. (2018). They aim to identify the main drivers and barriers of Blockchain adoption within the maritime industry. Specifically, the case studies examined are all related to the Norwegian offshore industry, and, for this reason, a limitation of this study could be a lack of generalization capability. Finally, a completely different use case of Blockchain application in supply chain management is presented in Mao et al. (2018). This innovative work assumes that information asymmetry is one of the most crucial issues that affect the food supply chain. Because of this, and due to the increasing supply chain complexity, as stated by the researchers "the credit risks of traders have increased rapidly". To overcome this dramatic issue, a Blockchain-based credit evaluation system is developed.

The main contributions that propose specific supply chain solutions to implement the Blockchain technology in different industries are presented in the Table 1.

Table 1*:* The usage of Blockchain in Supply Chain

Author	Application	Brief description
Wu et al. (2017)	Traceability	It is an online shipment tracking framework that complements current enterprise-based SC management solutions. The proposed framework consists of a set of private distributed ledgers and a single Blockchain public ledger.
Toyoda et al. (2017)	Product Ownership Management System (POMS)	It is a novel POMS of RFID-attached products for anti-counterfeit that can be used in the post supply chain.

Author	Application	Brief description
Lu and Xu (2017)	Traceability	OriginChain provides transparent tamper-proof traceability data, enhances the data availability and automates regulatory-compliance checking.
Kennedy et al. (2017)	Traceability	An anti-counterfeiting method: linking unique chemical signature data to Blockchain databases is used to limit the threat of counterfeiting of additive manufacturing parts across the supply chain.
Kim and Laskowski (2018)	Traceability	A traceability ontology and translation of its representations to smart contracts that execute a provenance trace and enforce traceability constraints on an Ethereum Blockchain platform.
Gausdal et al. (2018)	Data and document management	After identifying the main drivers and barriers for Blockchain adoption in the maritime industry, a Blockchain process framework is developed.
Leng et al. (2018)	Matching supply and demand	A double chain structure Blockchain application in agricultural supply chain to match demand and supply of resources.
Mao et al. (2018)	Credit Evaluation	A Blockchain-based credit evaluation system to strengthen the effectiveness of supervision and management in the food supply chain.
Figorilli et al. (2018)	Traceability	A distributed ledger that keeps records of digital transactions in such a way that makes them accessible and visible to multiple participants in a network while keeping them secure without the need of a centralized certification organism.

3 Methodology

The literature review on Blockchain confirmed that the Blockchain is a new technology, for which there is limited academic theory (especially for its application in the supply chain context). For these reasons, it was clear from the beginning that there were insufficient data to perform quantitative analyses. The conclusion reached was that the approach to investigate the Blockchain applied in the supply chain context should have fit for an exploration in a quite unknown field. A case study approach was chosen as the most appropriate methodology to carry out the whole research. A case study, according to Yin (1984) is “an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used”. This kind of research method typically addresses questions that investigate how and why a phenomenon occurs, in unexplored areas such as the one analysed in this study. The deliberate purpose has been to develop new theory, not to test it. The fundamental principle of this approach was to exploit case studies, as the basis from which to inductively build theory.

Multiple academic researchers have focused their efforts in developing the case study methodology as a qualitative research method Yin (1984). One of the first work in this direction was the one by Glaser and Strauss (1967). These scholars developed their method to build grounded theory based on an incremental approach that relies on a continuous comparison between data and theory.

Case studies are used to create theoretical constructs, propositions that are based on the empirical evidence (Glaser and Strauss, 1967). The case study is particularly relevant as it represents a vivid empirical picture of certain instances of a phenomenon Yin (1984). This research methodology can involve a single case study or multiple case studies (Eisenhardt and Graebner, 2007). For this work, a multiple case studies approach was chosen. The theoretical reasons behind the selection of multiple cases were driven by the need for replication (even contrary replication), enlargement of theory and removal of alternative explanations. Since the purpose of this study is to develop theory and not to test it, a theoretical sampling was considered appropriate. This kind of sampling implied

that cases were selected because they were particularly suitable for supporting the development of a theoretical framework, revealing, or adding relationships among constructs.

The unit of analysis identified is the “Blockchain project in the supply chain”. The cases were then selected using the following three main theoretical reasons.

- Replication: convergent evidence from various cases was sought to investigate analogies between them. Similar Blockchain projects were examined.
- Contrary replication: cases representative of different pattern of behaviours were chosen. Various cases regarding different industries and different project size were selected specifically to highlight the differences among them.
- Extreme cases: some cases of clearly successful implementation and other characterized by an unsuccessful deployment were picked.

Multiple data collection methods were used with the purpose of triangulate different data sources regarding the same case to provide stronger and better-grounded constructs. The data sources used were interviews, a workshop discussion, internal and public companies’ documents, and websites. Interviews were the principal source of information for developing the model since these represented a rich and effective way of gather data about a specific Blockchain project. However, there is a crucial issue regarding this data collection method: the personal biases generated from the informant. Despite he tries to be as much impartial as possible, it has its own view of the project. Therefore, to mitigate this risk, highly knowledgeable informants belonging to different companies (typically an interviewee was performed with the technological provider and the other with the company implementing the project) were interviewed, with the purpose of collecting different perspectives about the same project.

The target organizations and informants identified as relevant for conducting an interview, were split in the following categories.

- "Demand" companies: companies that have implemented a Blockchain project for their supply chain.
- "Supply" companies: software providers and consultancy organizations that have provided the specific Blockchain infrastructure and support for the development of the project.
- Blockchain experts: specialists and researchers that are studying Blockchain technology and its applications in the supply chain field.

A total of 22 interviews were conducted. One interview was performed with a Blockchain expert, and it was used to investigate the overall phenomenon of Blockchain for the supply chain. In the following table, it is shown how the remaining 21 interviews were used for creating case studies. It must be mentioned that some interviews were exploited twice, thus creating more than one case study with a single interview. In some situations, it was possible but also necessary to deepen some aspects for the specific case. Therefore, more than one interview was dedicated to certain case studies. Given these considerations, the 21 interviews contributed to the creation of the model, through 15 cases studies. A table showing the list of informants interviewed per case study is provided (see Table 2).

Table 2: List of informants interviewed per case study

ID	Case study	Number of interviews	Role of informants (# of interviews)	Length
1	Shipping company and provider	2	Blockchain Solution Leader at logistics company (1) Senior Consultant, Blockchain Local Practice Leader at provider (1)	60'

ID	Case study	Number of interviews	Role of informants (# of interviews)	Length
2	Provider	1	VP, Head of Governance, Risk and Compliance, Asia Pacific & Japan, and Greater China at provider (1)	45’
3	Provider	1	Chief Operation Officer at provider (1)	35’
4	Provider	1	Chief Financial Officer at provider (1)	30’
5	Provider	1	Logistics & Technology Lead at provider (1)	30’
6	Agri-food company and provider	2	Blockchain Solution Leader at agri-food company (1) Senior Consultant, Blockchain Local Practice Leader at provider (1)	65’
7	Agri-food company and provider	3	Consultant at agri-food company (1) Founder & Director and Co-founder at agri-food company (1) Co-founder at provider (1)	70’
8	Agri-food company and provider	2	Senior Manager, Blockchain HUB MED Leader at agri-food company (1)	40’

ID	Case study	Number of interviews	Role of informants (# of interviews)	Length
			Senior Consultant Digital and Innovation and Director at provider (1)	
9	Agri-food company and provider	2	Senior Manager, Blockchain HUB MED Leader at agri-food company (1) Export Director at provider (1)	45’
10	Provider	1	Partner, Head of FSI Tech & Fintech, EMEA co-leader at provider (1)	30
11	Utility company	1	Director at textile company	35’
12	Provider	1	Senior VP, Head of Advisory services at provider (1)	35’
13	Shipping company	1	Senior VP, Global Director M&A and Digital Transformation at insurance company (1)	30’
14	Shipping company	1	ICT Business Development Executive Manager at insurance company (1)	30’
15	Utility company	1	Power Trader & Blockchain Manager at energy company (1)	40’

Contextually with the interviews, all the data collected also from other sources were examined and a lot of observations and first impressions were taken about what was emerging from the research, in the form of notes. The continuous overlap between data collection and data examination "allows researchers to take advantage of flexible data collection" as stated by Eisenhardt (1989). Thanks to this flexibility, this process of theory building from case studies also gave the opportunity to change the line of thought when new significant themes emerged from some cases, with the purpose of improving the resultant theory.

To analyse the interviews, the first step was the transcription of them in a textual format. After this necessary passage, the software *Nvivo* was used to investigate and classify the content, through the coding process. Coding is a process that consists in examining data line by line, looking for concepts, events, feelings and so on. Thanks to *Nvivo*, the interviews transcriptions were analysed with the purpose of labelling emerging themes. The starting point was choosing the nodes. A node can be thought as a logical container that groups together conceptually similar events, actions, and interactions. Thanks to this process, the data collected from the interviews and from other sources were organized in a precise structure. This process facilitated the identification of patterns, relations, and theory by means of within-case and cross-case analysis. The list of nodes chosen, in line with research questions, can be seen below:

- Stages of implementation.
- Critical factors.
- External dimensions to consider during the implementation.

After this part, an important stage is the iteratively comparison, in a systematic way, of the emergent model with the evidence from each case, to assess how well or poorly it fits with case data. (Eisenhardt, 1989) The main purpose of this continuous checking process is creating an empirically valid theory. During this step, the main constructs such as stages of implementation and critical factors characterising the model, were subjected to a continuous sharping process: the accumulation of evidence from diverse sources to confirm or change the elements of the model, was fundamental to converge, at the end, on a single and well-defined structure. The relationships between constructs were examined by looking for evidence through the different cases. Using replication logic,

cases have been used to confirm emergent relationships, such as the chronological order of different guidelines or the relationship between a certain critical factor and the correspondent stage of implementation.

In a multiple case studies approach, a number between 4 and 10 cases is usually considered to work well (Eisenhardt, 1989). The maximum of ten cases is usually set to avoid the risk of getting lost in a huge amount of data coming from different sources. As regards the conclusion of the iterative process, this process ends when the theoretical saturation is reached. The theoretical saturation is defined by Glaser et al. (1967) as "simply the point at which incremental learning is minimal because the researchers are observing phenomena seen before". It can be asserted that the degree of saturation reached was satisfactory.

4 Findings

The final framework is now illustrated. This phase mainly consisted in formalisation of concepts emerged during the methodology process. The proposed model is structured as a broad and not prescriptive roadmap that guides during the implementation of Blockchain projects in the context of a supply chain. The ambitious goal of this framework consists in highlighting all elements and criticalities to consider in the implementation of such projects. The roadmap focuses on the earlier stages of projects realisation. The decision to deepen these phases is guided by the empirical evidence: many Blockchain projects for supply chain have been announced or they are starting to be realised, few are operatives.

The roadmap is divided into four phases, as shown in the next figure. Each phase includes:

- a phase outline, containing a brief description of the identified phase and explaining why this phase should be taken into account;
- critical factors that represent those essential elements for a successful implementation of the Blockchain in the supply chain context;
- guidelines as a useful step-by-step tool for guiding in the realisation of such projects.

A roadmap for the effective implementation of blockchain technology

Transversely to these phases, the model encompasses two external dimensions to consider during the implementation of these projects. Critical factors and guidelines will not be presented in the executive summary for sake of conciseness since they require an in-depth explanation. The roadmap is represented in the following figure (see Figure 3 below).

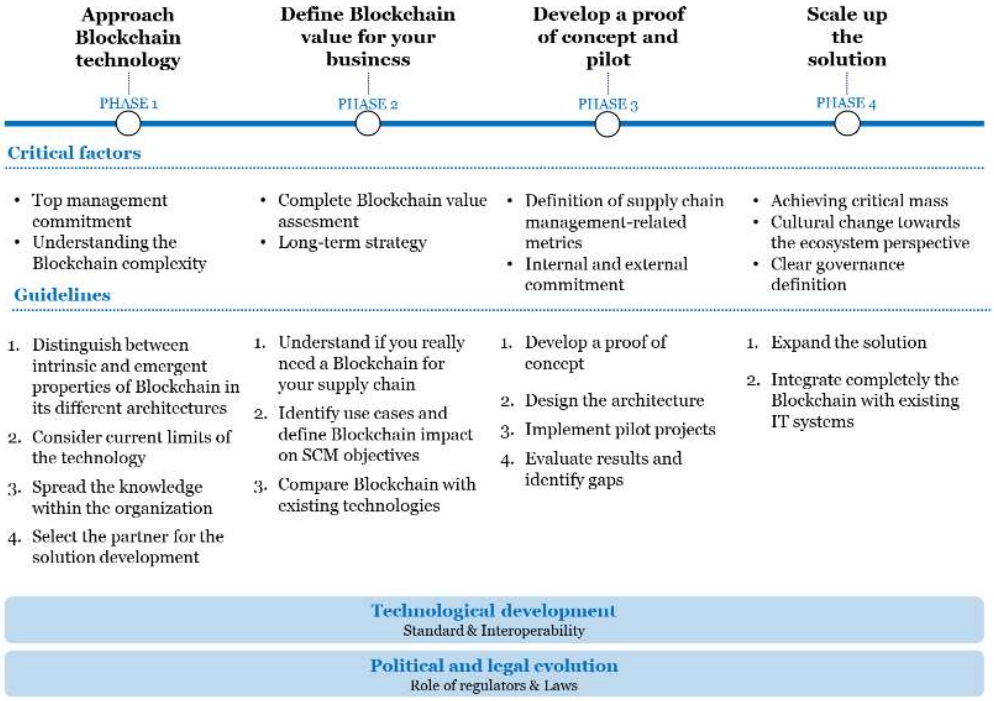


Figure 1: Final research framework

The roadmap encompasses the following phases:

1. Approach Blockchain technology. The first phase in the implementation of a Blockchain project is represented by initial steps a company should take to understand what this innovative technology is. This phase begins with the analysis of the main Blockchain properties, key concepts, and limitations.
2. Define Blockchain value for your business. This second phase is particularly important for companies willing to implement a Blockchain solutions in the supply chain. During this phase, the company defines whether the Blockchain is valuable for its business. Having described this phase, a visual framework is presented to properly answer the third research question. It represents both a theoretical and practical tool that resumes this phase of Blockchain value definition (illustrated in chapter 4). It encompasses a checklist that can be

used to identify whether the Blockchain can be the right solution. Having confirmed this, the relationship between the Blockchain and existing technologies employed in the supply chain is analysed. This step is essential since the Blockchain is not a stand-alone entity. In the light of these considerations, it can be understood how the Blockchain can be leveraged and the value deriving from its introduction in the supply chain.

3. Develop a proof of concept and pilot. This phase is related to the moment in which the company starts to develop an experimentation to concretely verify the validity of the thought solution. This stage can encompass the development of a proof of concept and, in a successive phase, pilot projects.
4. Scale up the solution. In the fourth phase, involved companies try to expand the solution in terms of new actors and/or functionalities. During this phase, a governance model is necessary to be clearly defined.

As regards external dimensions to consider during the implementation, they include:

- the technological development of Blockchain. It should be considered due to the low maturity level and diffusion of Blockchain. In particular, the lack of a standard and the need for interoperability between different Blockchains are two elements that should be constantly evaluated by companies;
- the political and legal evolution. It encompasses the role played by governments (and other authorities) in the diffusion of the technology and the introduction of laws related to the Blockchain.

The roadmap is a framework that encompasses stages, critical factors, and guidelines for the implementation of a Blockchain initiative in the supply chain. Each case study differs from others for certain aspects. For example, the sector, the type of use case, the role of the company, but also the direction taken for the development of the solution can distinguish one case from the other. By mapping case studies through phases identified in the roadmap, it was possible to create behavioural clusters that explain different development paths. In each phase, differences but also similarities emerged. Clusters were created starting from the sector the Blockchain initiative belongs to. The sector turned out to be relevant for differentiating case studies. The result is the identification of six paths, belonging to three different sectors: international shipping, agri-food and utility ones. Here below, a brief explanation of different paths is provided.

4.1 International shipping sector

In this sect, path A called “An international shipping ecosystem” and path B, “A Blockchain-based solution for the international trade” were identified. In both paths, it is a major player in the international shipping sector that approaches the technology. In path A, the Blockchain provider is represented by a big tech company while, in path B, the technological provider is a smaller company. These paths share the same use case (i.e., data and document management) and the same supply chain management objectives are impacted (i.e., cost, time, and risk reduction). The biggest difference regards the ambition and the consequent direction taken whether in path A the aspiration is to create a market solution for the global shipping industry, in path B projects are set on a smaller scale. In both cases, the scale up is complex since there is the need to involve many different players in this sector.

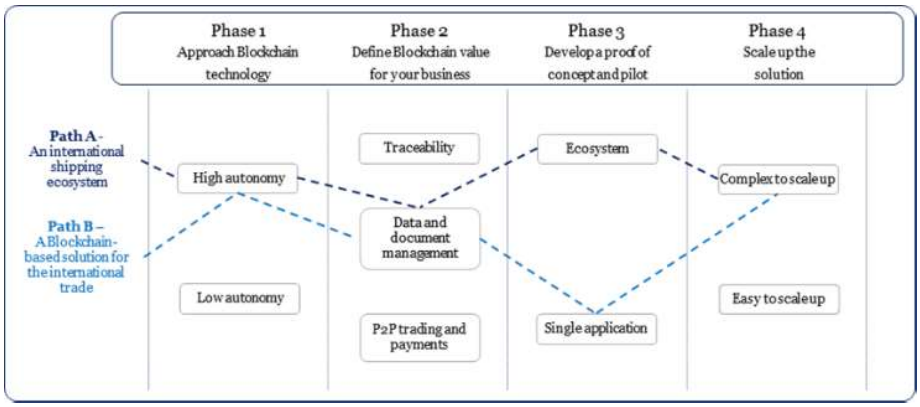


Figure 2*:* Blockchain development paths in the international shipping sector

4.2 Agri-food sector

Three different development paths were observed: path C called “An ecosystem for food trust”, path D called “Traceability for the single supply chain” and path E, “Blockchain for certification companies”. The main differences between path C and path D consist in the different ambition and the role of the company promoting the project: in path C a leading company in its market aspires to create an ecosystem, including different parties from various agri-food supply chains; in path D, instead, promoting companies (usually smaller firms that are less autonomous in approaching the technology) want to offer

higher quality products to customers by strengthening their traceability process. Thus, the focus is solely on their supply chain. The identified use case, in both paths, is traceability. The path E regards a different type of company, a certification body, that develops a Blockchain solution with the objective of strengthening its role in the supply chain.

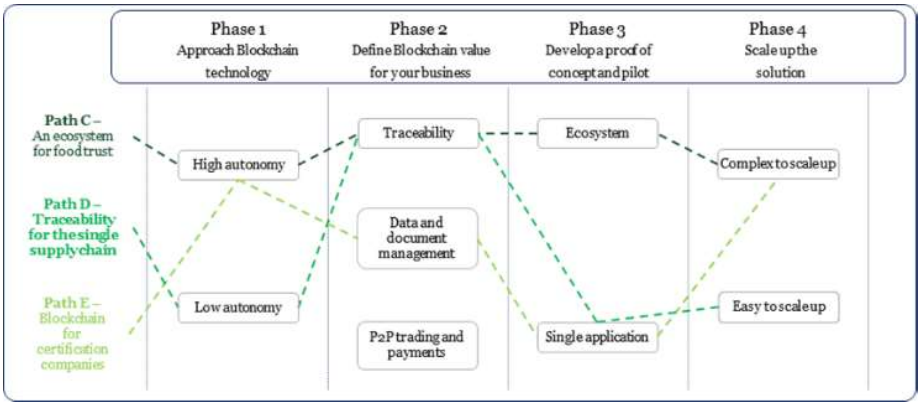


Figure 3. Blockchain development paths in the agri-food sector

4.3 Utility sector

The last path belongs to the utility sector, specifically the energy one. The path F is called "A peer-to-peer marketplace for energy trading" and it mainly differs from others for the implemented use case (i.e., peer-to-peer trading). The identified path consists in the creation of a peer-to-peer marketplace based on Blockchain. This marketplace includes many companies of this sector, and it allows to eliminate the need for intermediaries in trading. The governance is in the hands of a consortium formed by participant companies, with the objective of including interests of all parties.

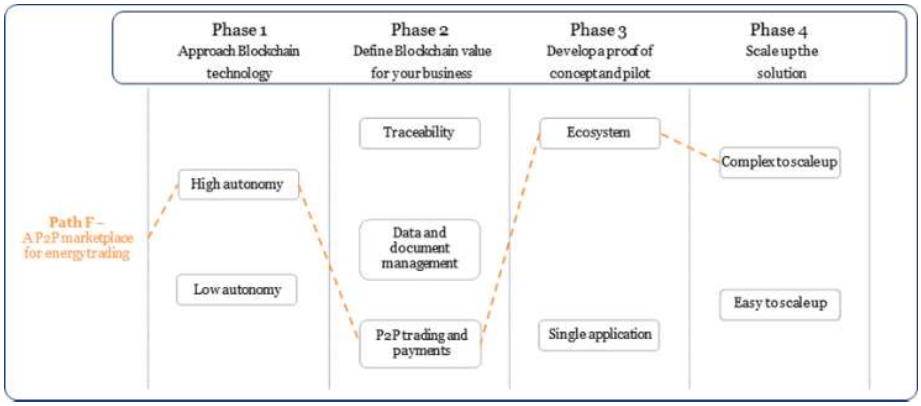


Figure 4: Blockchain development path in the utility sector

5 Conclusions and further development

This paper has the main aim to provide an effective practical tool for managers to understand the possible usage of Blockchain in the supply chain. The visual framework that explains when a Blockchain implementation is valuable in the supply chain is the first theoretical contribution provided by this work. The result of this analysis consists in the identification of how the Blockchain can be leveraged for defined use cases, explaining the Blockchain relationship with existing technologies and highlighting what this technology offers more than existing ones.

A significant contribution regards the identification of critical factors for a Blockchain implementation in the supply chain field. No existing literature identifies the most critical factors to consider for a successful implementation of the Blockchain technology. Moreover, the recognition of four sequential phases characterising the implementation of a Blockchain solution for the supply chain can be valuable from a theoretical viewpoint. Both critical factors and phases indicated in the final model have been validated through a multiple case study approach, thanks to the various interviews performed.

Finally, the results obtained from the case studies can give a theoretical contribution for the research. Indeed, they can be used as valuable sources to study more in detail the diffusion of Blockchain in many industries, with a specific focus on supply chains. The

case studies can also support researchers interested in investigating the evolution of the phenomenon in the next years.

From a managerial point of view, the roadmap proposed can support companies' managers to face in an efficient way a Blockchain implementation for a supply chain use case. Indeed, the research team behind this work firmly believe that achieved results can be useful, under various perspective, in the decision-making process of companies willing to adopt a Blockchain solution for their supply chain. The guidelines identified in each different phase of implementation aim at helping companies' managers in the whole implementation process, supporting them in considering all relevant elements that, if ignored, could potentially transform the initiative into a not desired outcome. This roadmap is thought to be useful in the specific situation in which companies nowadays operate. Considering the current level of technology maturity and deployment in the supply chain context, it becomes so valuable to understand the necessary steps for the implementation of the technology. This kind of framework could help in achieving a higher diffusion and experimentation of Blockchain for different use cases in the supply chain. At the same time, the model has been defined to offer a "safe approach": Blockchain is not the panacea for all supply chain pain points and, considering the existing complexity in defining realistic returns on investments, its deployment must be cautiously evaluated. A relevant part of this framework is dedicated to the understanding of how the Blockchain could create value in the context of a supply chain. In this sense, the framework is valuable as it presents conditions in which it makes sense to apply the Blockchain, the potential use cases and the relationship between the Blockchain and existing technologies for such use cases. In this regard, it is also shown how the Blockchain could be leveraged for supply chain and what makes it unique, if compared to existing technologies. Another part of the model with significant managerial implications regards the last phase of implementation. Since few Blockchain projects have already passed through this phase, the current knowledge about it is generally low. For this reason, it is particularly valuable for a company to be aware since the beginning of the project that, for instance, the Blockchain solution can scale up only by shifting the traditional mentality towards a new ecosystem perspective. This concept is crucial in every Blockchain implementation, especially in the supply chain field. If a company does

not change its mentality, it will be impossible to define a clear and shared governance within the ecosystem. Consequently, it will be unfeasible to obtain the expected value-added from the solution, by considering the various interests of parties involved.

Additionally, the paths of development have the specific purpose of offering a concrete tool to companies willing to implement a Blockchain solution. By assessing similar paths, a company could use this instrument as reference for moving the next steps toward an effective Blockchain implementation.

Besides the results achieved, the research presents some limitations. The qualitative methodology chosen implies some limitations in terms of generalisability. The risk of resulting in narrow and idiosyncratic theory is present. The selection of cases in specific sectors and the selection of interviewed informants can decrease the generalisation capability of the model. Future studies should be carried out to include in the research other case studies from different sectors, possibly involving a broader set of informants. This future research could verify the generalisability of the proposed framework, eventually enhancing results of this investigation. As soon as the Blockchain diffusion in the supply chain context will be sufficiently wider, the interpretative methodology could be combined and enriched with quantitative research methods. Another research limitation regards guidelines and critical factors included in the model. The intent of the roadmap is to be broad and not prescriptive. In this sense, some guidelines and critical factors deserve to be further deepened by future research.

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Machine Learning in Supply Chain Management: A Scoping Review

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Purpose: *Especially in supply chain management (SCM), data has become essential to the success of companies. Traditional analytical methods are being augmented by machine learning (ML), which is considered the foremost relevant branch of artificial intelligence. This article maps various ML use-cases and assigns them to the appropriate SCM tasks.*

Methodology: *We applied a scoping review and checked scientific databases for relevant literature. Subsequently, the articles were assigned to different categories to map the research area. In the categorization, we considered, amongst others, the ML tasks and algorithms, data source and type, and the field of application.*

Findings: *The results show that there are numerous ML use cases in SCM. These range from predictive demand forecasting and intelligent partner selection to the use of assistance systems for resource management. Various data sources, such as internal company data and publicly available data, are used for these applications.*

Originality: *By mapping ML use cases in SCM, this complex and multifaceted field of research is presented in a transparent and structured way. Science and practice can deploy the results to improve existing ML use cases in SCM on the one hand and to identify promising areas of application on the other.*

First received: 21. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1. Introduction

A particularly important and ongoing topic in supply chain management (SCM) is the need to make complex decisions. Furthermore, supply chains are plagued by uncertainty and information asymmetry. In other words, on the one hand, decision-making processes in SCM depend on diverse, non-influenceable factors that are currently often influenced by information barriers (Ni, Xiao, and Lim, 2020, p. 1463). On the other hand, the volume and variety of data are constantly increasing, and there is more data available than ever before. Analyzing this data with the use of traditional methods is inefficient, or even impossible, in most cases. For this reason, new methods and applications are emerging from the field of advanced data analytics (ADA). One of these methods is machine learning (ML), which deals with the development and application of self-learning algorithms (Marsland, 2014, pp. 6-9; Wenzel, Smit, and Sardesai, 2019).

ML has proven to be particularly capable of coping with large amounts of data and detecting patterns in the data. This property enables ML to make reliable decisions that humans are not capable of. Moreover, ML algorithms enable users to deal with rapidly changing conditions and discontinuous information. Thus, ML is a significant asset for SCM (Ni, Xiao, and Lim, 2020, p. 1463). Kersten et al. (2020) confirm this assumption and show the potential of ADA, and, thus, also ML, in SCM. Companies can particularly benefit from ML in the areas of planning, procurement, and delivery (Kersten et al., 2020).

However, how is ML applied in SCM to make complex decisions related to uncertainties? The research goal of this article is to answer the following question:

> *"What is the current state of research on the use of machine learning in supply chain management?"*

The remainder of this article is organized as follows. Chapter 2 describes the methodological approach and distinguishes this article from the current state of research. Chapter 3 includes the classification of the identified literature in terms of publication type, SCM task, industry focus, related data sources and types, and applied ML algorithms. Chapter 4 answers the underlying research question and identifies further research needs. Finally, Chapter 5 summarizes the results.

2. Methodological Approach

Systematic literature reviews (SLR) are used in a wide range of research areas (Arksey and O'Malley, 2005). SLRs originated in the field of medicine. Later, Tranfield, Denyer, and Smart (2003) adapted SLRs to the needs and characteristics of management research and Durach, Kembro, and Wieland (2017) to those of SCM research. These adaptations are necessary because each research area has different requirements and characteristics (Durach, Kembro, and Wieland, 2017, p. 68). Currently, scoping reviews, which also follow a systematic approach, are becoming increasingly important for the aim of a synthesis (Munn et al., 2018). However, SLRs and scoping reviews have different objectives. Therefore, researchers should carefully determine which of the two procedures is appropriate to achieve their individual research objectives (Arksey and O'Malley, 2005). If, on the one hand, the research objective is to analyze the feasibility, appropriateness, usefulness, or effectiveness of specific practices, then an SLR is particularly well-suited to achieve the research objective. If, on the other hand, the research goal is to identify specific concepts and to present, report, or discuss those concepts, a scoping approach should be used (Munn et al., 2018, p. 144). Since the research objective of this article is to address the current state of research on the application of ML in SCM, the scoping review approaches of Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010) were chosen as the methodological foundation of this article.

The following section describes the search and selection process for the scoping review to ensure that the research process is transparent. Furthermore, a differentiation of this research from the current state of research is presented to emphasize the unique research insights of this review.

2.1 Search and Selection Process

According to Arksey and O'Malley (2005), scoping reviews assist in rapidly capturing the key concepts of a research area, especially when the area is complex or has not yet been analyzed. In addition, research gaps and designs can be identified and analyzed, or the macroscopic view can lay the groundwork for a further SLR (Munn et al., 2018, p. 144). Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010) described five

steps for conducting a scoping review. Figure 1 shows the step-by-step process of the conducted scoping review.

1) Identify the research question – The underlying research question for this paper is "What is the current state of research on the use of machine learning in supply chain management?" It was formulated by the authors to achieve the research objective of this paper.

2) Identify relevant studies – To identify relevant articles, the online databases Scopus, Web of Science, ScienceDirect and IEEE Xplore were selected. Specific search terms were determined, divided into two distinct word groups, and meaningfully related using Boolean operators for the targeted search for the relevant articles. The first word group included "machine learning" and the second word group "supply chain" or appropriate synonyms. The literature search was performed on January 1, 2021, with a search for a combination of the two word groups in the title, abstract, and keywords of the articles. Thus, an initial literature set of 1,878 articles were identified.

3) Study selection – The selection of relevant studies from the initial literature set included duplicate screening, abstract screening, and full text screening. Since the literature was retrieved from multiple databases, some articles were found to be duplicates, and these were removed during the duplicate screening process. Thus, the initial literature set was reduced from 1,878 to 1,145 articles. The abstracts of the articles were evaluated according to previously determined inclusion criteria, according to ten Hompel and Hellingrath (2007) and ten Hompel, et al. (2013). In addition, the ML method used in the article must involve one or more ML algorithms, according to Marsland (2014). Thus, the relevant articles could be further narrowed down, from 1,145 to 497. In the next step, full text screening was done. The previously mentioned inclusion criteria were used, but the full text of the articles was screened for relevance. After the full text screening, 183 articles were classified as relevant. In a further step, a search for additional literature was undertaken with Wohlin's (2014) snowballing approach. For this purpose, 14 literature reviews previously identified during the study selection process were examined to identify additional relevant literature. With consideration of the same inclusion criteria, 79 articles were added to the literature set. Finally, 262 articles that address ML algorithms in the SCM context were identified.

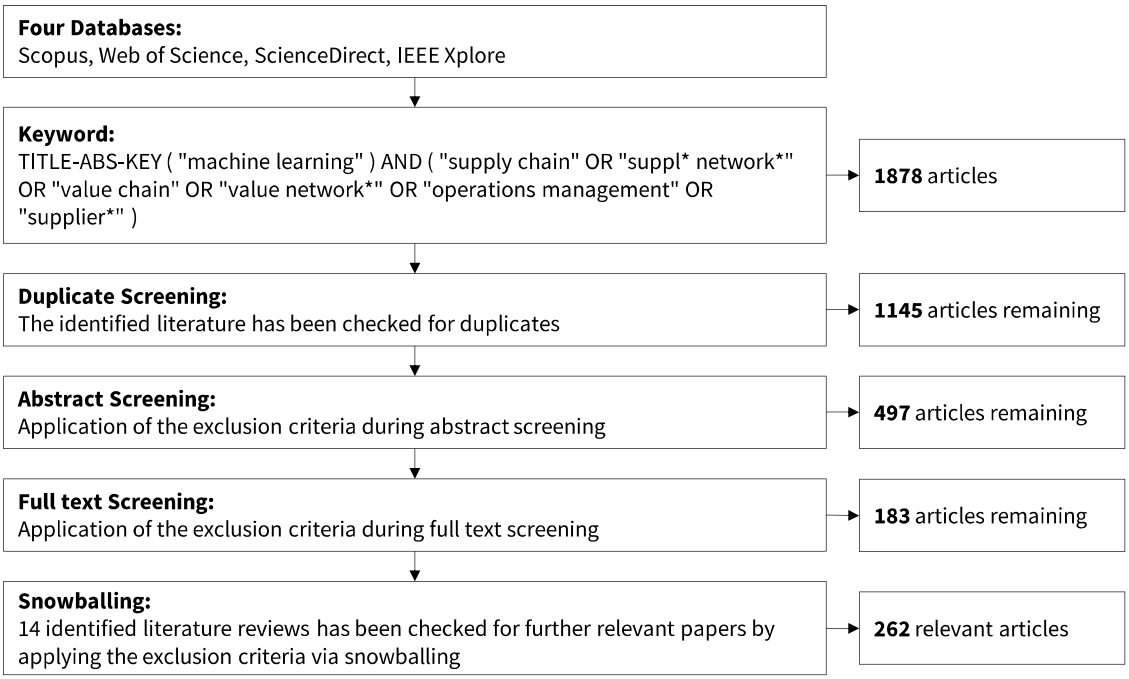


Figure 1: Methodological approach for the scoping review, following Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010).

The next steps, according to Levac, Colquhoun, and O'Brien (2010), are 4) charting the data and 5) collating, summarizing, and reporting results. charting the data means classifying the data according to previously determined classes. The resulting classification is then analyzed, and the results presented descriptively. Collating, summarizing, and reporting results are done to provide an overview of the scope of the literature, but not in the form of a synthesis. Instead, a numerical analysis is done, presenting, for example, the scope and nature of the studies with the use of tables and charts. The scoping review is concluded with a thematic analysis. Steps 4 and 5, following Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010), are conducted in detail later in the article.

2.2 Related Studies

As mentioned above, 14 literature reviews that had an objective comparable to that of this article were identified during the search and selection process. All 14 identified

articles focus on the applications of ML or artificial intelligence in the logistics or SCM context. The main differences are in terms of the time periods considered, the research methods applied, the consulted databases, and the search terms used. The primary difference of this article, aside from its topicality, is the research method. The identified articles were all literature reviews, but not all were SLRs. However, none of the reviews followed the approach of a scoping review and the accompanying systematic quantitative analysis and interpretation of the research findings. Table 1 shows the 14 identified literature reviews and their respective focus topics.

Table 1: Identified literature reviews

No.	Authors	Focus of literature reviews
01	Bousqaoui, Achchab, and Tikito (2017)	Supply Chain Management
02	Burggraf, Wagner, and Koke (2018)	Production Management
03	Cadavid, Lamouri, and Grabot (2018)	Demand & Sales Forecasting
04	Hachimi, Oubrich, and Souissi (2018)	Reverse Logistics
05	Nguyen et al. (2018)	Supply Chain Management
06	Baryannis et al. (2019)	Supply Chain Risk Management
07	Calatayud, Mangan, and Christopher (2019)	Supply Chain Management
08	Diez-Olivan et al. (2019)	Industrial Applications
09	Ni, Xiao, and Lim (2020)	Supply Chain Management
10	Wenzel, Smit, and Sardesai (2019)	Supply Chain Management
11	Hosseini and Ivanov (2020)	Supply Chain Risk Management

No.	Authors	Focus of literature reviews
12	Kumar et al. (2020)	Distribution Planning
13	Seyedan and Mafakheri (2020)	Demand Forecasting
14	Aamer, Yani, and Priyatna (2020)	Demand Forecasting

3. Classification of Articles

In the following section, the 262 identified articles are classified in terms of year of publication, publication type, SCM task, industry focus, related data sources and types, and ML algorithm applied to provide a comprehensive picture of the current state of research into ML in SCM.

3.1 Year and Type of Publication

If we examine the number of publications over time, as depicted in Figure 2, it is notable that there is a sharp increase. The first noticeable increase was in 2005, when six articles on the topic of ML in SCM were published. By 2015, with the exception of some fluctuation, the number of publications per year had more than doubled, from six to 17. The most interesting development in terms of the absolute number of publications is evident during the period from 2015 to 2020. After a decrease from 17 publications in 2016 to 11 in 2017, there was rapid increase during the following two years. During 2019, 60 papers were published. ML in SCM seems to have gained importance, which can be related to the increasing amount and importance of data in research and in practice (Kersten et al., 2020). The decrease in the number of publications in 2020 and 2021 can be explained by the fact that, as described in Subchapter 2.1, the literature search was conducted on January 1, 2021, and not all submitted and published articles had yet been entered into the databases.

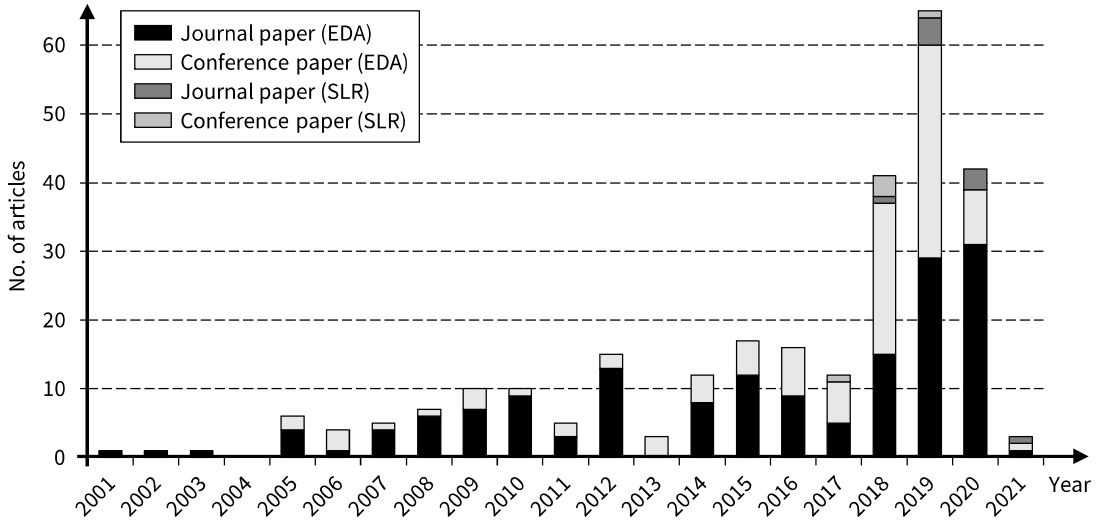


Figure 2: Classification in relation to the year of publication

In addition to the number of publications, it is worth investigating the types of publications and research methods used over time. First, we distinguished between journal and conference papers that applied exploratory data analysis (EDA) related to ML to evaluate historical-empirical data. In the early 2000s, authors mostly published in journals, which illustrates the strong connection between this topic and academia. In 2005, the ratio of journal articles to conference papers was four to two, and the number of journal articles continued to increase through 2012, when there was a ratio of 13 to two. These numbers reinforce the scientific importance of ML in SCM. As of 2014, there was a change in terms of publication type. The ratio of journal to conference papers changed from 13 to two in 2012 to 29 to 31 in 2019. This change in the publication ratio can be partially attributed to the fact that the requirements are less stringent and the publication timeframe shorter for conference papers compared to journal articles. Authors working on the topic of ML in SCM seem to want to publish their new findings and results as soon as possible in the scientific communities. As previously mentioned, the literature was retrieved from scientific databases on January 1, 2021, and, therefore, presents a distorted view of the publication ratio for 2020 and 2021.

There was an additional finding relating to publication types and research methods. In 2017, the first article that used an SLR as a research method, in which Bousqaoui, Achchab, and Tikito (2017) investigated how ML is applied in SCM, was published. Over the following years, more journal and conference papers that conducted SLRs were added. Since then, the number of publications has steadily increased. SLRs help to identify research gaps (Munn et al., 2018). In addition to the emergence of a research method, there is another observation worth highlighting in this context; compared to papers that applied EDA, SLRs were initially presented at conferences rather than published in journals. The first journal papers that involved an SLR methodology were published in 2018. This is one year after the first conference paper was presented. Due to this fact, the scientific relevance of ML in SCM can be emphasized again, as it is well known in the scientific environment that SLRs tend to be more difficult to publish in journals than papers involving other research methods, but, nevertheless, the number of SLRs in journals is steadily increasing.

Especially in recent years, scientists tend to present their results at conferences and, thus, through a rapid publication channel. In addition to EDA, SLR has become an effective and scientifically accepted research method.

3.2 Supply Chain Management Tasks

The following subsection analyzes the SCM tasks in which ML is applied. The investigation is based on the SCM task model by ten Hompel et al. (2013). Figure 3 shows the distribution of the 262 identified articles in relation to the SCM tasks. A detailed assignment of the articles to the individual SCM tasks can be found in the online appendix[1] of this article. Specific criteria for the classification and assignment of the articles were derived from an evaluation of the SCM tasks described by ten Hompel et al. (2013) and ten Hompel and Hellingrath (2007). It should be noted that individual items can be assigned to multiple SCM tasks. In their SCM task model, ten Hompel et al. (2013) distinguish between the SCM tasks supply chain design (SCD), supply chain planning (SCP), supply chain execution (SCE), collaborative tasks, and complementary tasks on

[1]Online appendix: https://www.researchgate.net/profile/Martin-Brylowski-2/research

the macroscopic level. In some cases, these higher-level SCM tasks are broken down into further SCM subtasks. The complementary tasks are not considered further in this article, as none of the identified items could be assigned to this SCM task.

The task of SCD involves long-term planning regarding the logistical strategy, partner selection, and location issues (ten Hompel et al., 2013, p. 148). A total of 70 of the 248 identified articles could be assigned to SCD. These included the SCM subtasks, with seven articles assigned to supply chain strategy, 54 to partner selection, one to facility selection, three to sourcing process design, and seven articles were assigned to design of communication and information processes. It became clear from this analysis that, from a scientific point of view, partner selection especially benefits from ML. ML algorithms are applied to find potential partners (Handfield, Sun, and Rothenberg, 2020), evaluate them (Sasaki and Sakata, 2020), and, subsequently, selects the appropriate partners (Wu et al., 2020).

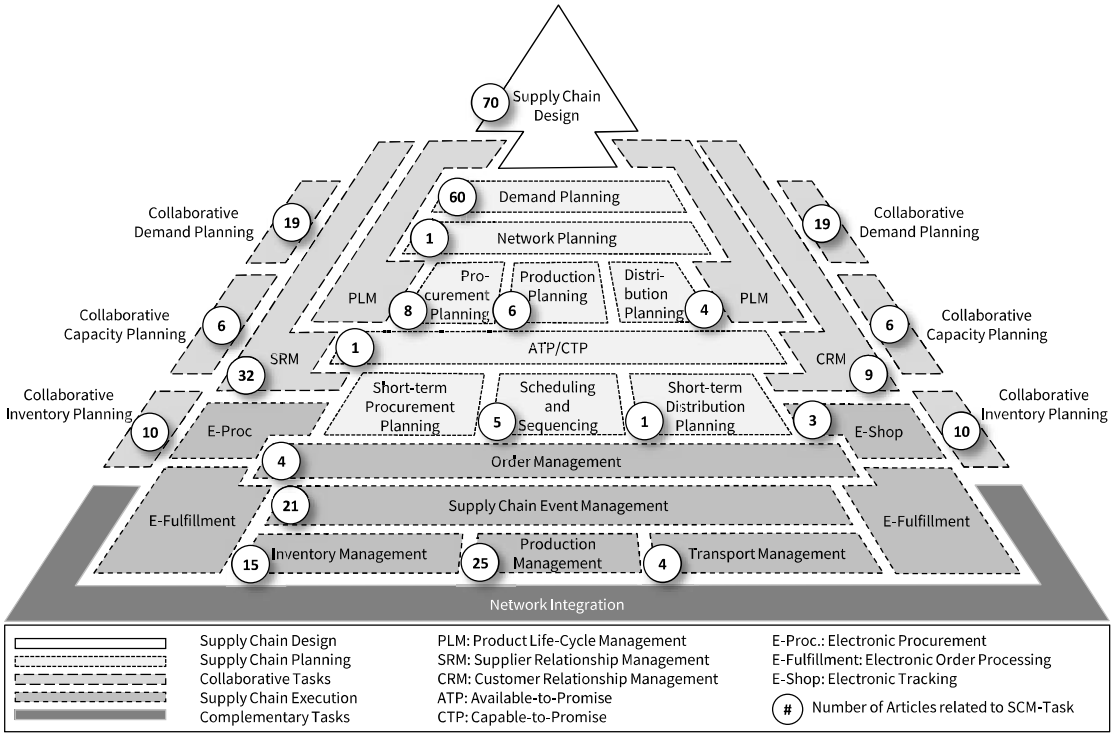


Figure 3: Classification in relation to SCM tasks,
based on Ten Hompel et al. (2013) and Ten Hompel and Hellingrath (2007)

The term SCP includes all medium-term planning tasks of a company, as well as deriving customer requirements (ten Hompel et al., 2013, p. 149). A total of 81 of the 248 items could be assigned to SCP. Of these, 60 were assigned to demand planning, one to network planning, eight to procurement planning, six to production planning, four to distribution planning, one to available-to-promise/capable-to-promise, five to scheduling and sequencing, and one to short-term distribution planning. One SCM subtask in the planning task area is particularly dominant compared to the others. ML is used far more in demand planning and support, for example, for the prediction of future customer requirements and supply chain performance (Feizabadi, 2020) or the timely provision of spare parts for customers (Babajanivalashedi et al., 2018).

The SCE area is dedicated to transport-related tasks, the network-wide scheduling of customer orders, and the monitoring of inventories (ten Hompel et al., 2013, p. 154). In total, 67 of the 248 identified articles were assigned to SCE tasks. Order management was represented by four articles, supply chain event management by 21, inventory management by 15, production management by 25, and, finally, transportation management by four articles. Compared to SCD and SCP, no one SCM subtask is particularly dominant in SCE, which suggests that ML is used more for many purposes in operational SCM tasks, and different areas benefit equally from self-learning algorithms. For example, ML is used for quality monitoring in supply chain event management (Myles D., Steven and Sengun, 2015), for ABC classification of products in inventory management (Li, Moghaddam and Nof, 2016), and for automatic defect detection in additive manufacturing processes in production management (Okaro et al., 2019).

According to ten Hompel and Hellingrath (2007, p. 299), a logistics network can only be harmonized and supply optimally synchronized with cross-company cooperation. In addition to collaborative demand planning, collaborative capacity planning, and collaborative inventory planning, supply relationship management and customer relationship management were also assigned to collaborative tasks in this article. This is due to the cross-enterprise activities of the two SCM subtasks. In total, 72 of the 248 identified articles were assigned to collaborative tasks. Nineteen of the articles address ML applications in collaborative demand planning, six in collaborative capacity planning, ten in collaborative inventory planning, 32 in supplier relationship management, and

nine in customer relationship management. As in SCE, several SCM subtasks stand out in the collaborative task area. These include, for example, cross-network analysis and the determination of customer needs (Kilimci et al., 2019) and risk-based planning of inventory across the supply chain (Ojha et al., 2018). The SCM sub-task supplier relationship management stands out somewhat from the other collaborative tasks with 32 articles. These tasks include the control of existing supplier relationships (Wilson et al., 2020) and a classification of the supplier base (Sabbagh and Ameri, 2020). It can be concluded from this that ML algorithms have great potential in not only the search for, evaluation of, and selection of potential suppliers but also in the control of existing suppliers.

In summary, ML is used particularly frequently for SCM tasks related to improving cross-enterprise collaboration with suppliers and customers. In addition, ML is also widely used for operational SCM tasks to monitor or improve production processes.

3.3 Industry Focus

The classification of the articles in relation to the targeted industry was based on the International Standard Industrial Classification of All Economic Activities (ISIC) classification system of the United Nations (2008). Thus, a comprehensible and consistent classification of the articles is possible by following concrete concepts, definitions, principles, and classification rules (United Nations, 2008, p. 3). Figure 4 visualizes the classification of the identified articles in relation to the focused industry. First, the articles were assigned to the superordinate ISIC classes manufacturing, transportation and storage, wholesale and retail, and no reference to industry. This was followed by a detailed assignment to the subclasses of the ISIC classification system.

It was noticeable that most of the articles examine questions and problems from the manufacturing sector. One hundred and seventy-seven of the 262 articles could be assigned to the manufacturing industry. The most frequent subclasses are manufacturing without industrial focus (33 articles), data processing equipment (29 articles), motor vehicles and parts (27 articles), and food and feed products (25 articles). For example, Cavalcante et al. (2019) addressed resilient supplier selection without reference to a specific manufacturing industry. Wang and Chen (2020) make cross-

company and collaborative forecasts for the manufacturing of printed circuit boards. Related to the manufacturing industry of motor vehicles and parts, Hong et al. (2018) addressed the identification of strategic value chain partners for the manufacturing of products for the automotive industry. In the manufacturing industry of food and feed products, Zakeri et al. (2018) developed a system for proactive monitoring of raw milk quality.

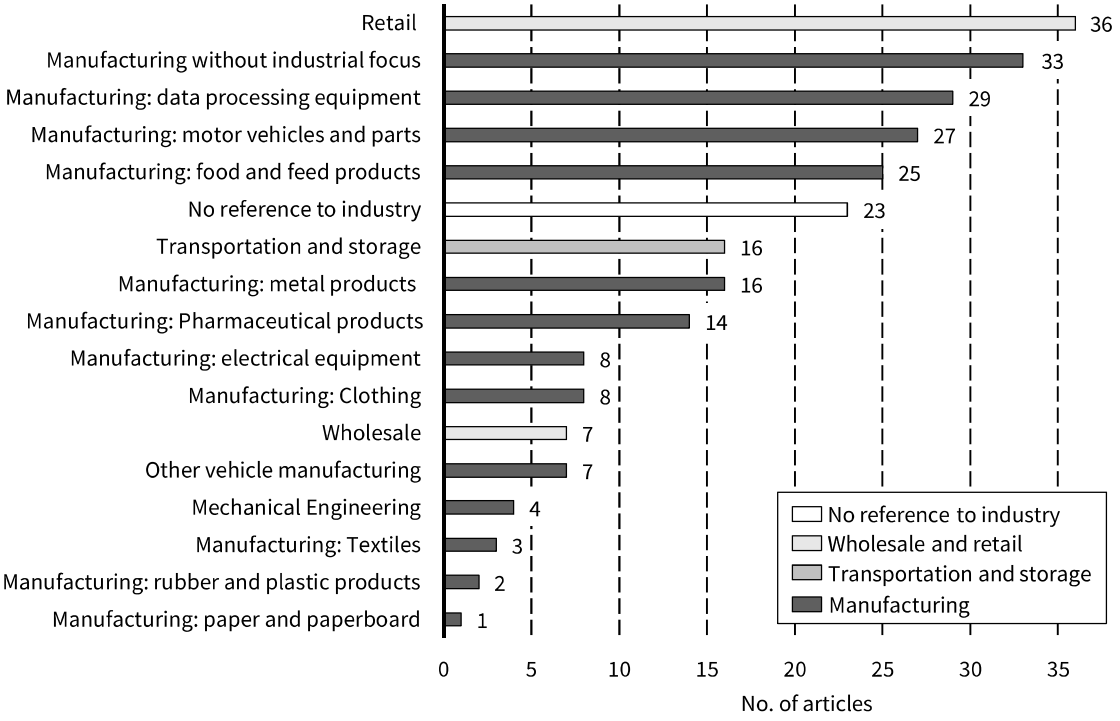


Figure 4: Classification in relation to the industry focus based on ISIC (United Nations, 2008)

The second most-addressed industry was wholesale and retail, with 43 identified articles, 36 relating to retail and 7 to wholesale. Pereira and Frazzon (2020) developed a method to synchronize demand in supply chains in retail. Priore et al. (2019) show how replenishment tasks can be dynamically determined in wholesale.

The transportation and storage industry sector accounted for 16 of the identified articles. Thus, it ranks third in terms of the most frequently addressed industry sector. In their

article, Zhang, Li, and Peng (2020) demonstrate how risks in the transportation of fresh products can be assessed and monitored.

The remaining 23 articles were assigned to the class “No reference to industry” because, as the designation indicates, they include no references to an industry, according to ISIC. The analysis of the identified articles related to ISIC industries showed that manufacturing as well as wholesale and retail particularly benefit from ML in the context of the various SCM tasks.

3.4 Data Sources and Types

ML applications or EDA require data that is available in structured or unstructured forms (Marsland, 2014, p. 6). Ideally, however, a high quantity of data should be available, it should be of high quality, and it should be both diverse and granular (Kersten et al., 2020). Therefore, in the following section, we first classify the identified articles in terms of the data sources used, following Ni, Xiao, and Lim (2020), which is followed by a classification of the articles in terms of the data types considered, following Seyedan and Mafakheri (2020).

As previously mentioned, ML applications require data for analysis (Marsland, 2014, p. 6). This data can be obtained from a wide variety of data sources as Ni, Xiao, and Lim (2020) describe in their literature review. Figure 5 shows the data sources that were used to examine the problems in the different SCM tasks in the 262 identified articles.

One hundred and fifty-three of the identified articles used historical data provided by companies for scientific research. Baryannis, Dani, and Antoniou (2019) used historical data provided by several companies in a manufacturing aerospace supply chain over a six-year period to predict supply chain risks. Furthermore, 47 articles used publicly available data for their research. One example is Wichmann et al. (2020), who generated supply chain maps using news articles. Twenty-seven of the identified articles analyzed data from laboratories with ML algorithms. Alfian et al. (2020) deserve a mention as a striking example with their perishable food traceability system, based on internet of things sensors and ML algorithms. A total of 25 articles included interviews with experts to generate or verify data. Badurdeen et al. (2014) developed a supply chain risk

taxonomy, which was subsequently incorporated into the ML analysis, through expert interviews. Finally, 11 of the identified articles used simulation data and 10 used data from other articles.

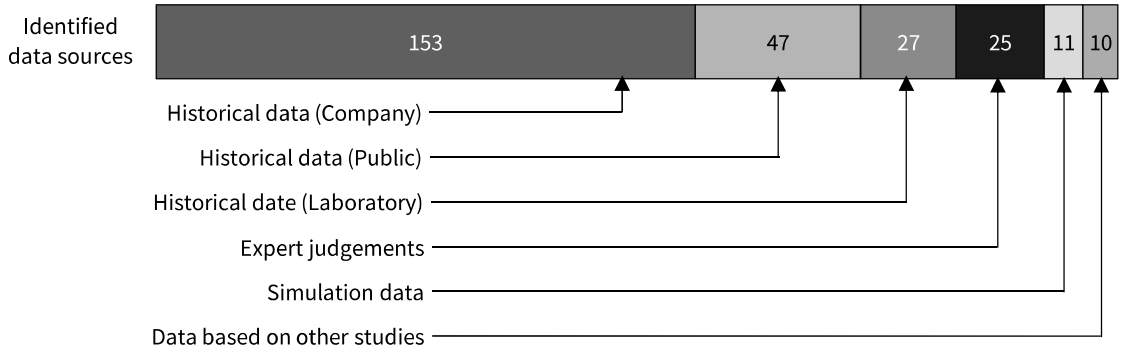


Figure 5: Classification in relation to data source, following Ni, Xiao, and Lim (2020)

Companies seem to have recognized the potential of ML in SCM and, therefore, make their data available for scientific analysis. In addition, publicly available data is often used in analyses with ML to gain new insights in the research area of SCM.

In addition to the data source, the data type also plays a significant role in the application of ML in SCM. Following Seyedan, and Mafakheri (2020), Figure 6 shows the data types that were used in the 262 identified articles for the ML analyses. It is noticeable that most of the data types include information regarding external partners or were sourced from operational SCM task areas. Seventy-seven articles used supplier data and interpreted it with ML. Brintrup et al. (2019) analyzed supplier-related data to predict supplier disruptions in the manufacture of complex equipment. Gružauskas, Gimžauskienė, and Navickas (2019) provide another example of using data that includes information about external partners. They evaluated sales-related data to evaluate the predictive accuracy of logistics cluster activities. A total of 51 articles used sales-related data for ML analyses. Demand data was analyzed in 49 articles in total. Bhosekar and Ierapetritou (2021) developed a framework for supply chain optimization in modular production, using demand data. A final class that should be mentioned in the context of data types that include information regarding external partners is customer data. Twenty-eight articles were assigned to this class, including Simeone, Zeng, and Caggiano (2020), who

evaluated customer data for decision making to recommend manufacturing solutions in a cloud environment. In addition, data types from operational SCM tasks play a significant role in SCM. There were 41 articles that used manufacturing data for ML analysis. González Rodríguez, Gonzalez-Cava, and Méndez Pérez (2019) used production-related data for ML-based production planning, and 39 articles evaluated inventory data to make predictions regarding backorders (Hajek and Abedin, 2020). Furthermore, 26 articles explored the use of sensor data in the SCM context. For example, Ma, Wang, and Wang (2018) evaluated RFID sensor data with ML to detect false-positive decisions. Finally, product-related data was evaluated in 25 articles. In this context, Zgodavova et al. (2020) interpreted product-related data to improve small batch production systems.

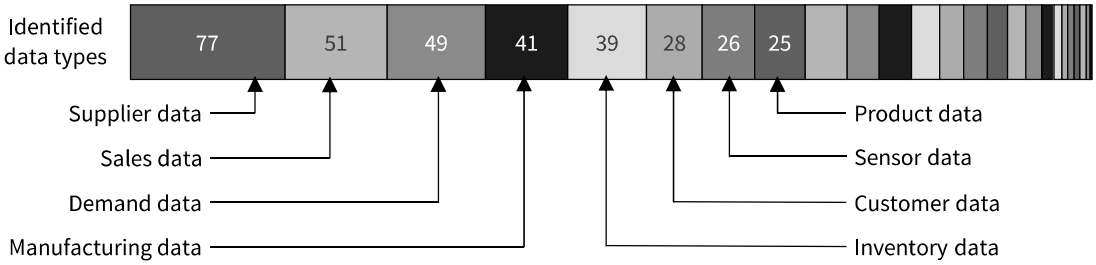


Figure 6: Classification in relation to data types following Seyedan and Mafakheri (2020).

In summary, data containing information regarding external partners, such as suppliers and customers, is particularly likely to be used for ML-based analysis to make strategic decisions in the SCM context. In addition, the application of ML in operational SCM task areas lead to improved processes. Particularly production and logistics-related data types are frequently examined for this purpose.

3.5 Machine Learning Algorithms

In addition to the data source and type, the choice of the optimal algorithm plays an essential role in ML applications. Marsland (2014) distinguishes between supervised, unsupervised, and reinforcement learning. Supervised learning refers to the analysis of structured input data and can be further differentiated to classification and regression algorithms (Marsland, 2014, p. 6). On the one hand, regression algorithms are primarily

used for forecasts and to predict the course of data points (Marsland, 2014, pp. 6-8). Classification algorithms, on the other hand, assign defined classes to data and bundle them based on previously learned rules (Marsland, 2014, pp. 8-9).

Unsupervised learning algorithms work with unstructured data and independently attempt to detect unknown patterns in the data to, for example, subsequently cluster them or to detect anomalies (Marsland, 2014, p. 6).

Reinforcement learning approaches are a hybrid of supervised and unsupervised learning. When the algorithm makes incorrect decisions, it is corrected, but it does not learn the solution. This process continues until the algorithm has independently derived the optimal solution through trial and error (Marsland, 2014, p. 6).

Figure 7 illustrates the classification of the identified articles and use cases in terms of the ML algorithms used, according to Marsland (2014), on the vertical axis and the underlying SCM tasks, according to ten Hompel et al. (2013) and ten Hompel and Hellingrath (2007), on the horizontal axis. In the remainder of this article, we first describe articles that use supervised learning algorithms for ML-based analysis. This is followed by examples of unsupervised learning and, thereafter, articles from the reinforcement learning class.

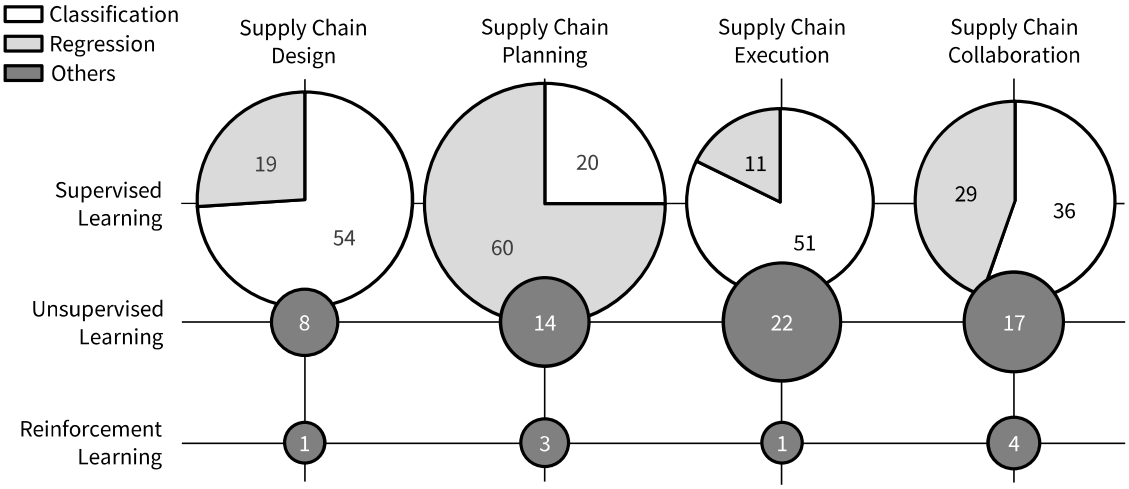


Figure 7: Classification in terms of algorithms following Marsland (2014); Ten Hompel et al. (2013) and Ten Hompel and Hellingrath (2007).

A total of 54 of the identified articles could be assigned in the classification algorithms class in the SCD. Harikrishnakumar et al. (2019) used classification algorithms to classify suppliers. ML applications that can be assigned to the regression class in the SCD are represented by 19 articles. For example, Brintrup et al. (2019) used regression algorithms to predict supplier risks. In the SCP task area of SCM, 20 articles used classification algorithms and 60 articles used regression algorithms. González Rodríguez, Gonzalez-Cava, and Méndez Pérez (2019) used classification algorithms for intelligent production planning in the SCP task area, and Priyadarshi et al. (2019) addressed the prediction of vegetable demand using regression analysis. In the SCE task area of SCM, 51 articles that applied classification algorithms for ML based analysis were identified. However, 11 articles applied regression algorithms for operational SCE tasks. In this context, Ahmadi, Javidi, and Shahbazmohamadi (2018) are worth mentioning because they used classification algorithms to identify counterfeits in the electrical industry. Amirkolaii et al. (2017) showed the potential of regression algorithms for predicting the demand of spare parts in the aerospace industry. Finally, in terms of supervised learning algorithms, in the SCC task domain, 36 articles could be assigned to the classification algorithms and 29 to the regression algorithms. In the collaborative SCM task domains, 36 articles describe the use of ML-based classification algorithms and 29 describe the use of regression algorithms. Illustrative examples include Abdollahnejadbarough et al. (2020), with their classification approach for supplier base rationalization, and Li et al. (2020), with their regression approach for sustainable production capacity assessment.

In addition to the supervised learning algorithms, articles that followed an unsupervised learning approach were also identified in all SCM task areas. In SCD, a total of eight articles followed an unsupervised learning approach. For example, Khalid and Herbert-Hansen (2018) showed how international location decisions can be made with clustering algorithms. In the tactical SCP, 14 articles could be identified. In this context, Meiners et al. (2019) investigated how production ramp-up can be accelerated and relationships in the process chain can be derived. There were 22 articles in the operational SCE domain. Becker and Intoyoad (2017) demonstrated how information on logistics processes can be extracted using ML in a data-based manner. Finally, 17 articles were assigned to

collaborative SC tasks (SCC). Sabbagh and Ameri (2018) developed an ML approach to cluster suppliers based on unstructured production data.

As previously mentioned, it was also possible to identify articles that used reinforcement algorithms for ML-based analysis. One article that could be assigned to the SCD is by Zhang and Bhattacharyya (2007), who determined the design of a supply network. From the SCP domain, three articles could be identified. Vanvuchelen, Gijsbrechts, and Boute (2020) developed an approach to solve joint replenishment problems using deep reinforcement. In the SCM task domain SCE, similar to SCD, one article could be identified. Döring, Dangelmaier, and Danne (2007) applied reinforcement learning to production systems in the automotive industry. Finally, four articles were identified in the SCC context. Peng et al. (2019) are investigated the prediction of supply chain wide capacity under uncertainty.

In summary, with the supervised learning algorithms in the SCD and SCE task domains, significantly more classification algorithms are used than regression algorithms. In the SCP domain, the opposite effect can be seen. In the SCC, classification and regression analyses are almost equally distributed. Unsupervised learning algorithms, however, are primarily used in the SCE domain. The SCM tasks SCP and SCC form the middle field in unsupervised learning context. In SCD, unsupervised learning is uncommon. Reinforcement learning does not seem to be used frequently in the SCM context in general and is rather underrepresented in all SCM task domains, compared to supervised and unsupervised learning approaches.

4. Discussion and Further Research

Data analytics and ML are becoming increasingly relevant, especially in the SCM context (Kersten et al., 2020). Therefore, the research objective of this article was to analyze for which specific SCM tasks ML is applied. To achieve this research goal, the following research question was derived and answered progressively throughout this article through the analysis of the identified articles in a scoping review, based on Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010):

> *"What is the current state of research on the use of machine learning in supply chain management?"*

In the remainder of this article, the core findings of this work are discussed, and two recommendations for further research that could examine the topic of ML in SCM from a new direction in terms of methodology and content are provided.

First, it is worth mentioning that only articles using EDA or SLR as research methods were identified. These articles either describe the detailed implementation of ML algorithms in the SCM context (EDA) or provide a systematic overview of the current state of research (SLR). Qualitative interview studies, quantitative surveys, or conceptual papers on ML in SCM describing, for example, procedural models for the step-by-step and situation-appropriate implementation of ML in the different SCM task areas, could not be identified for this scoping review.

Three main application areas for ML in SCM emerged in this scoping review. These areas are supplier management, which can be assigned to the SCM task areas SCD and SCC, demand management, which is predominantly applied in SCP and SCC, and quality management, that can be assigned to SCE. Articles that involved ML analyses in the main application areas of supplier and demand management often used structured data that contain cross-company information regarding external SC partners, such as supplier-, sales-, and demand-related data. It is worth mentioning that supplier management is almost exclusively considered in the context of the manufacturing industry, and ML applications in demand management are more prevalent in the wholesale and retail sector. Furthermore, supplier management and demand management differ in terms of the ML algorithms used. Articles on the topic of supplier management generally use classification algorithms, and ML applications on the topic of demand management use regression algorithms. In quality management, production, product, and sensor data are analyzed, often with structured data in combination with unstructured data. Both supervised and unsupervised algorithms are used. The three main application areas identified, supplier management, demand management, and quality management, differ fundamentally in terms of the industry addressed, data source, data types, and ML algorithms. Future work should explore the three identified main application areas for ML in SCM in detail, in terms of industry, data source, data type, and ML algorithms.

5. Conclusion

From this review, it can be concluded that ML in SCM has gained relevance over recent years, as the number of publications has increased. ML is frequently used for cross-company SCM tasks to improve collaboration with suppliers and customers or to monitor internal processes, identify weak points, and initiate mitigation activities in a timely manner. Manufacturing companies and retailers are particularly likely to make their data available to academia, which can be evidenced by the high number of articles relating to these industries, thus exploiting the potential of ML to improve their strategic, tactical, operational, and collaborative SCM processes. Publicly available data is brought in by researchers to generate further value-adding insights and, thus, enhance the performance of ML algorithms in the SCM context. The data types most frequently used include information about suppliers or customers as well as information from the production environment or warehousing. This again underpins the relevance of ML in terms of strategic cross-company as well as tactical and intra-company applications. If we consider the distribution of classification and regression algorithms in the individual SCM task areas, it is notable that they are distributed differently. This is because, in SCD and SCE, categorical decisions are made, such as "is this supplier eligible - yes or no" or "is the quality acceptable - yes or no." In comparison, SCP deals with continuous questions, such as "how is demand evolving?" The equal distribution in SCC can be explained by the fact that both categorical and continuous issues are discussed in this SCM task domain. Unsupervised learning algorithms, however, are primarily used in the SCE domain. This is because image or video data, which is unstructured data, are often interpreted in the context of quality and production monitoring. The main application areas of ML in SCM are in supplier management, demand management and quality management, and it differ fundamentally in terms of the industry considered, data source, data types, and ML algorithms.

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III.
Business Analytics

Supply Chain Analytics Implementation – A TOE Perspective

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Purpose: *Increasing quantity and sources of data and their potential to fuel value-adding applications in Supply Chain Management (SCM) are of considerable importance for corporations.*

Methodology: *We utilize a qualitative research design of semi-structured expert interviews.*

Findings: *Utilizing the Technology-Organization-Environment framework, we establish an integrated perspective: We propose that CSF possess a varying relevance to the success of the SCA (Supply Chain Analytics) project, depending on the initial drivers.*

Originality: *While the benefit and potential value of SCA is established, the implementation of the technology remains a challenge for companies. This paper combines the concept of "drivers" for adoption with Critical Success Factors (CSF) during the initial implementation.*

First received: 11. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Improving business processes based on data analytics is a major opportunity for companies to establish competitive advantages aside from classic productivity advantages or arduous and risky product innovations (Davenport, 2006). While this might sound like an old hat, the developments in data availability as well as the amount and properties of these data, indicate a new paradigm in analytics potential (McAfee, et al., 2012). Moreover, increasing data-driven decision making is associated with higher productivity as well as market capitalization (Brynjolfsson, Hitt and Kim, 2011).

However, despite the promises, a third of data analytics initiatives within companies do not live up to their expectations (NewVantagePartners, Bean and Davenport, 2018). Our findings suggest that this is in part due to a narrow consideration of relevant Critical Success Factors (CSF) on the part of companies – a more holistic perspective seems necessary. Additionally, generating a close fit between the drivers for adoption and the project to be implemented is useful. To do that we develop a categorization of drivers. Our focus are the initial stages of a Data Analytics (DA) project within the Supply Chain Management (SCM) function, i.e. a Supply Chain Analytics (SCA) project. These are often stated as Initiation, Adoption, and Implementation (Kwon and Zmud, 1987; Matta, Koonce and Jeyaraj, 2012). Arising issues during the operational phases of SCA are not the focus of our study. We consider SCA to be a technological concept, i.e., a driver of change related to the digital transformation in SCM (Kersten, et al., 2017) that is enabled by a set of underlying technologies and processes.

To provide a holistic view perspective, the Technology Organization Environment model (TOE, Depietro, Wiarda and Fleischer, 1990) is an established framework to approach technology implementation. It also has established roots within a diverse set of SCM adoption considerations (e.g. Lin, Lee and Lin; Chan and Chong, 2013) It is one model among many, with one primary differentiating factor regarding models in the same realm such as Diffusion of Innovation (DOI, Rogers, 2003) or Technology Acceptance Model (TAM, Davis, 1989) being its dedicated inclusion of environmental factors (Oliveira & Martins 2011, p. 119). This is crucial for our area of investigation, as SCM by its nature

relates to up- and downstream processes and thus considerations in the environment of the focal company.

The current paper aims to present a comprehensive perspective on reasons for a lackluster track record of SCA projects and provides recommendations for potential improvements on the path ahead.

To do that, we formulate the following research questions:

RQ1: “What are the primary CSF for successful implementation of SCA?”

RQ2: “Are different CSF varying in importance when considering the drivers for the respective SCA initiative?”

The paper is structured as follows. In section 2, a brief introduction into theoretical background is provided, establishing term disambiguation of the utilized phrases and determining the relevance of the topic at hand. Hereafter, Section 3 establishes our methodological approach, and provides the results of our preliminary, quantitative study, motivating the main study. We then present the qualitative interview study in chapter 4, diving deeper into CSF and drivers for SCA before providing a conclusion in Section 5.

2 Theoretical Background

2.1 Supply Chain Analytics

Data Analytics remains an evolving field with ambiguous definitions and connections to adjacent domains (Gröger, 2018). To clarify, we briefly outline our understanding of the term: SCA comprises numerous techniques with varying levels of sophistication (Alahakoon and Yu, 2013). It goes beyond purely descriptive approaches and aims to inform future decisions through data-driven analysis and exploration of relevant business problems.

Though in practice, many applications are based on Big Data, there is some progress to achieve value-adding outputs via the use of smaller data sets (using approaches such as Transfer Learning, cf. e.g. (Gao and Mosalam, 2018) and (Zhou, 2016) or Virtual Sample

Generation, cf. (Wanigasekara, et al.). Due to that fact, we prefer the term Advanced Analytics. We follow the broad definition *"Advanced [data] analytics is defined as the scientific process of transforming data into insight for making better decisions."* (Rozados and Tjahjono, 2014, p. 1100). We understand SCA broadly as *"[…] "the use of analytical tools and approaches in supply chain environment in order to make more informed decisions and ultimately improve supply chain performance."* (Zhu, et al., 2018, p. 48), thus encompassing all three major categories of Data Analytics; Descriptive, Predictive and Prescriptive Analytics. These are used to generate a better understanding of a field, build improved decisions on that understanding and by doing so "establish[] competitive advantages" (Wamba, et al., 2015, p. 235). In that endeavor, the underlying methods naturally include state-of-the-art techniques such as machine learning that are commonly attributed to the field of Artificial Intelligence.

Various researchers have brought forward the important overlap of data analytics with supply chain management (Waller and Fawcett, 2013). The universal increase in data volume is remarkable and naturally translates into the realm of logistics and supply chain management: Over 1.6 billion new data items are generated by a logistics network every month (Ilie-Zudor, et al., 2015). These increasing amounts of data are generated by more and more diverse sources. Unstructured data, that is difficult to analyze with traditional approaches, make up an increasing share (Raman, et al., 2018).

Besides increasing data, tools do deal with that data are also emerging both on the software side (e.g. frameworks such as Tensorflow or PyTorch that make it easier to implement analyses instead of building from the ground up (Lu, et al., 2018)) and on the hardware side (e.g. GPU and TPU to faster execute calculations for neural nets, the essential tool in machine learning (Fernandez Molanes, et al., 2018)).

With both more data and the means to generate value from these data, it is thus clear that SCA is a crucial capability for corporations today. In fact, "[…] [Big Data Analytics Capability] is a significant predictor of [Firm Performance]." (Akter, et al., 2016, p. 124). By enabling faster and more accurate decision-making, Analytics can be seen as "the only sustainable competitive advantage" (Cokins, 2013, p. 69), since all of Porter's (Michael, 1985) traditional strategic approaches are potentially eroded due to technological and market-based developments (Cokins, 2013).

2.2 Information Technology Implementation

Existing models considering the implementation of information technologies (IT) possess varying degrees of complexity, with different phases, as introduced e.g. in (2010, phases Agenda setting, Matching, Refining, Restructuring, Clarifying, Routinization) or (1987, phases Initiation, Adoption, Adaptation, Acceptance, Routinization, Infusion).

On a basic level, however, comparable models can be boiled down to three higher-order stages: Pre-adoption, Adoption und Post-adoption (Damanpour and Schneider, 2006; Kamal, 2006). These three macroscopic stages are conceptionally congruent with Lewin's (1947) 3-Stage Model of Change (Matta, Koonce and Jeyaraj, 2012). In the first stage, *unfreeze,* the organization is being prepared for a change. Correspondingly, this is where the initiation of the technology implementation takes place. The particular relevance of a "cognitive element" in this initial phase was already described by (Pierce and Delbecq, 1977). The awareness of a possibility for change or the pressure towards such a change can thus be seen as the individual perception of a decision-maker. This is where our study is positioned and the focus of our expert interviews lies: What are the drivers for this initial decision to adopt SCA and what are the CSF for successful implementation. We elaborate in section IV.

Theories considering the adoption of IT can be differentiated according to their focal entity: Either they focus on the individual or incorporate an organizational perspective (Fichman, 1992). Primary theories and models with an individual focus are the Technology Acceptance Model (TAM, Davis, 1989), the Theory of Planned Behavior (TPB, Ajzen, 1985; 1991), and the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh, et al., 2003) with the extension UTAUT2 (Venkatesh, Thong and Xu, 2012).

Theories with an organizational orientation include Diffusion of Innovation (DOI, Rogers, 2003) and Technology-Organization-Environment (TOE, Depietro, Wiarda and Fleischer, 1990). For TOE, Technology considers the factors that have technical connotations, Organization looks at the features and attributes of the organization and Environment is concerned with the surroundings in which the activities of the company occur (Bhattacharya and Wamba, 2018).

The different theories and models have corresponding focal areas and thus attract proponents and opponents. E.g. (2011) prefer the TOE framework, due to an inclusion of an environmental facet, which bears considerable implications for technological implementations. We use TOE as well in this paper, as it has been shown to match empirical results from IT adoption studies (Thong, 1999) and provides the holistic perspective our interview study has shown as beneficial.

3 Methodology

We utilize a qualitative research design of semi-structured expert interviews.

In a previous study to establish the relevance of our approach, we surveyed German SCM professionals, resulting in 104 partial and 86 complete records. The experts were recruited through the network of the Federal Logistics Association in Germany. We found a large discrepancy between the perceived relevance and the degree of implementation regarding the application of SCA (see Fig. 1). Based on this finding we conclude an apparent need for SCA in the companies. Due to the lacking nature of implementation efforts (as described in the introduction) we focus our research on SCA implementation to enhance SCA usage in general.

For our main study, we conducted 24 in-depth expert interviews to better understand the reasons for the discrepancy we found. The interviewees are based in Germany (though often in international corporations), our analysis is thus limited to a German context at this point. Our sample comprises the fields Plan, Source, and Deliver according to the Supply Chain Operations Reference Model (SCOR) classification. We exclude production-related functions. This was done to focus our study on the primary relevant use-cases, as the SCM-task *Production* accounts for only 7 % of research considerations of AI in SCM and Logistics (Hellingrath and Lechtenberg, 2019). We exclude the *Return* function as well, as there is a limited number of use cases at this point.

Since the aim of this paper is the theory-guided analysis of considerations like SCF and drivers for implementation, we use *purposeful sampling* (Patton, 2002). Patton differentiates a diverse set of specific approaches, this paper utilizes *criterion sampling*

combined with *purposeful random sampling*. The main criterion in the former sampling method is the occupation of the interviewees: The experts questioned operate at the intersection of supply chain management and data analytics and thus can provide domain application knowledge regarding the supply chain while simultaneously being familiar with technological, implementation, and application challenges regarding the SCA field. Our experts work in multiple industries but, due to their SCM focus, often face similar hurdles and opportunities in their business. The interviewees include both managerial as well as operative roles. The *purposeful random* nature of our sampling is expressed through the absence of prior knowledge regarding the success of the respective SCA initiative, thus reducing a selection bias.

Table 1: Interviewees for qualitative study

#	Position	Sector
1	Director Operations Analytics	Maritime operations
2	Product Owner BI	Consumer goods
3	Senior Analytics Consultant	Consulting
4	Data Analytics Specialist	Medical technology
5	Head of Software Development	Manufacturing industries
6	Artificial Intelligence Consultant	Consulting
7	Data Scientist	Electronics industry
8	Head of Data Ontology	Maritime operations
9	Lead Data Scientist	Information & Communications Technologies

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#	Position	Sector
10	Manager Artificial Intelligence	Information & Communications Technologies
11	Executive Analytics Manager	Consumer goods
12	Manager Logistics	Consumer goods
13	Manager Logistics	Manufacturing industries
14	Project Manager	Logistics Provider
15	Director	Logistics Provider
16	Project Business Partner	Aviation
17	Supply Chain Manager	Consumer goods
18	Distribution Planner	Luxury goods
19	Production Planner	Manufacturing industries
20	Head of Supply Chain Management	E-Commerce
21	Chief Collaboration Officer	Logistics Startup
22	Purchasing Specialist	Medical technology
23	Manager Procurement	Manufacturing industries
24	Manager CoE Data Analytics	Aviation

The semi-structured interviews were based on a questionnaire that was employed to structure the interview, with the option to dive deeper in topics that were not anticipated. This generated a compromise between comparability on the on hand and new insights and paths for future research on the other. The interviews were conducted in person and on the phone, then transcribed and coded as a qualitative content analysis. Since we aimed to find evidence for CSF and drivers we previously discovered in existing literature, but also remain open for new factors, we employed a combined system of a deductive and inductive course of action. Specifically, initial macroscopic categories were defined based on theory, sub-categories then emerged based on the interviews (Schreier, 2014).

The main research questions are stated as:

- RQ1: “What are the primary CSF for successful implementation of SCA?”
- RQ2: “Are different CSF varying in importance when considering the drivers for the respective SCA initiative?”

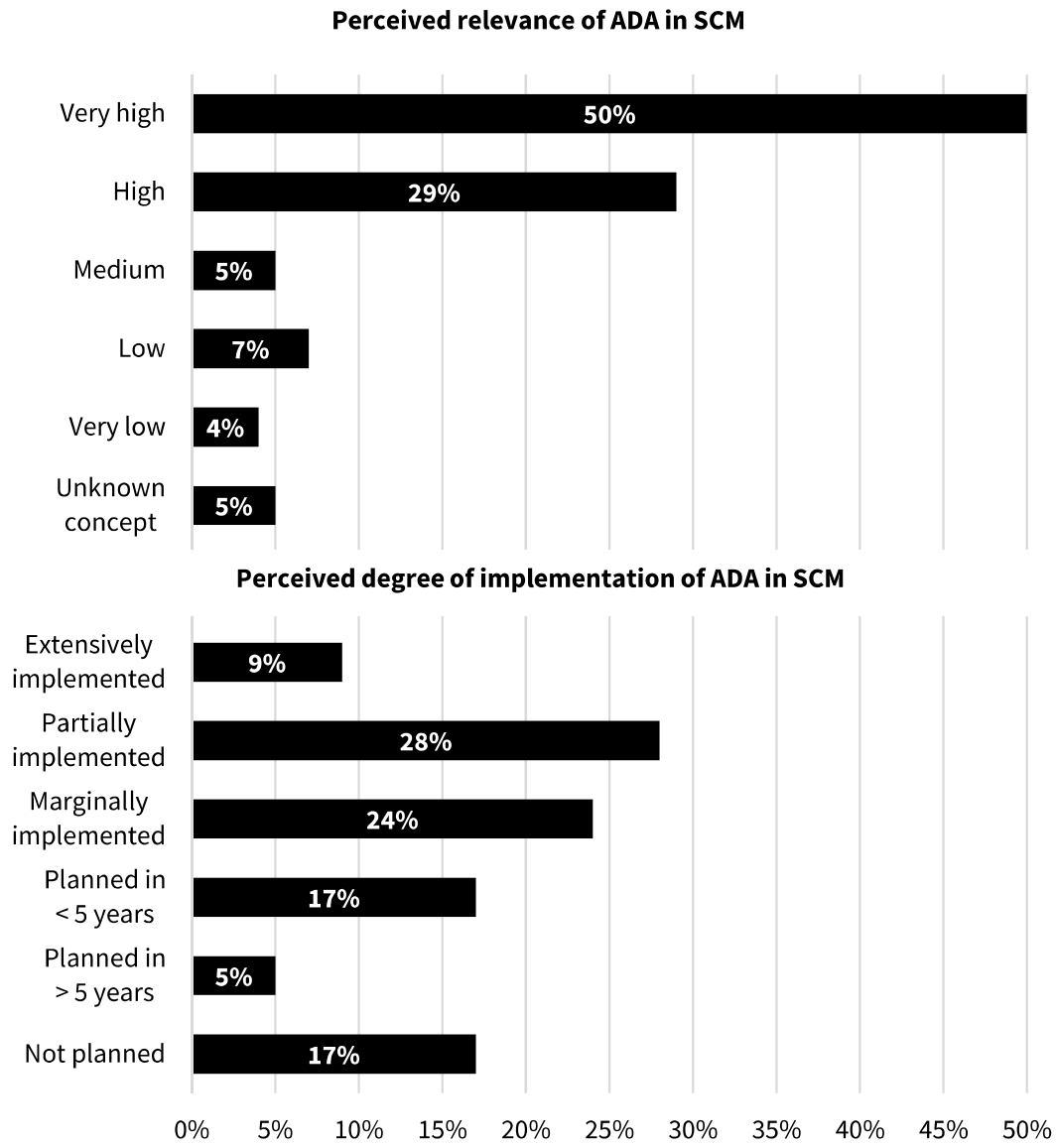


Figure 1: Perceived relevance and degree of implementation of Advanced Data Analytics in Supply Chain Management for respondents' own company (Lodemann and Kersten, 2020)

The question was stated as “Advanced Analytics in Supply Chain Management”, which we reframed as SCA in this paper

4 SCA Implementation: CSF and Drivers

4.1 Critical Success Factors

Literature identities a broad collection of facilitators and hurdles regarding successful IT implementation. The aim of defining CSF is to identify parameters that have a distinct effect on the success of an initiative (Haenecke, 2002). Critics have questioned the approach, e.g. stating that CSF are too simplistic to objectively represent reality and invite bias (Boynton and Zmud, 1984). Proponents of the approach counter that CSF help to identify the core, overarching factors that can subsequently be substantiated, and provide an initial top-down perspective where to focus ones attention (Boynton and Zmud, 1984), thus generating an easier path towards acceptance of senior management (Müller and Jugdev, 2012). We follow this argument and seek to attenuate the critique by focusing the CSF we identified to our narrow field of SCA and emphasizing their guiding, rather than all-encompassing, nature. CSF are regularly used regarding our field of investigation (e.g. (Gao, Koronios and Selle, 2015; Denolf, et al., 2018)).

The CSF are presented according to a TOE-differentiation. This emphasizes the holistic nature of the approach: Our evidence indicates that, as literature suggests, simply focusing on a purely technological approach does not suffice for overall success.

Table I does not claim to represent all CSF of data-driven endeavors but rather considers the most relevant ones for the particular case of SCA. We list those CSF that were identified by multiple experts and provide sources to show that these are also taken into account by literature. Not all literature sources are concerned with the focus on SCM, some just deal with SCA applications from a more general perspective. In this case, the CSF was mentioned by our experts but has not yet been discussed in SCM-related literature. To build a picture as complete as possible, more general sources were used to provide literature-based support for these CSF. Since we aim to provide the view of practitioners here, CSF that are proposed by literature but were not mentioned by our experts are omitted in Table I. Large collections of CSF for IT can be found in e.g. (Hameed, Counsell and Swift, 2012).

Table 2: CSF for Successful SCA Implementation

CSF	Source
Technology	
Data quality	(Lamba and Singh, 2018),(Kwon, Lee and Shin, 2014),(Moktadir, et al., 2019),(Wang, et al., 2016),(Wuest, et al., 2016)
Data security	(Lamba and Singh, 2018),(Moktadir, et al., 2019),(Richey, et al., 2016)
Data availability	(Wang, et al., 2016),(Wuest, et al., 2016),(Sanders, 2016)
Data variety / Data complexity	(Moktadir, et al., 2019)
Storage of (currently unused) data	(Richey, et al., 2016)
Technical Infrastructure	(Wamba, et al., 2015),(Wang, et al., 2016)
Organization	
Support/Involvement of Top Management	(Wamba, et al., 2015),(Lamba and Singh, 2018),(Schoenherr and Speier-Pero, 2015b),(Queiroz and Telles, 2018),(Wang, et al., 2016)
Selection of appropriate method	(Lamba and Singh, 2018),(Wang, et al., 2016),(Wuest, et al., 2016)

CSF	Source
Adequate resources	(Lamba and Singh, 2018),(Wang, et al., 2016)
Identification of relevant and appropriate use case	(Sanders, 2016),(Schoenherr and Speier-Pero, 2015b)
Data-driven focus of corporate culture	(Queiroz and Telles, 2018),(Wang, et al., 2016),(Sanders, 2016)
Integration into existing processes	(Schoenherr and Speier-Pero, 2015b)
Employee qualification	(Lamba and Singh, 2018),(Moktadir, et al., 2019),(Schoenherr and Speier-Pero, 2015b),(Queiroz and Telles, 2018),(Richey, et al., 2016),(Wang, et al., 2016),(Sanders, 2016)
Existence of product champions	(Bhattacharya and Wamba, 2018)
Structured change management approach during implementation	(Schoenherr and Speier-Pero, 2015a)
Time constraints / Time management	(Moktadir, et al., 2019)
Consideration of privacy issues	(Schoenherr and Speier-Pero, 2015a)
Environment	

CSF	Source
Cross-company cooperation	(Queiroz and Telles, 2018),(Kache and Seuring, 2017)
Up- and downstream integration of information systems	(Lamba and Singh, 2018),(Richey, et al., 2016)(Brinch, 2018b),(Brinch, 2018a)
Consideration of regulatory actors	(Nam, Lee and Lee, 2019)
Partner transparency	(Richey, et al., 2016),(Shen and Chan, 2017)
Development of technological standards	(Bhattacharya and Wamba, 2018)

4.2 Drivers for implementing SCA

The initial impetus to an SCA project can have diverse causes. We call these causes “drivers”. Different terms are used in theory as well as by our experts, e.g. “motivation”, “impulse”, “aim”, “reason” or “trigger”. Literature describes drivers for different information technologies across varying fields, however, the topic of drivers for SCA is scarcely researched.

The unifying characteristic for the different terms is the ex-ante nature of the driver, meaning that we look at the situation and observed drivers *prior* to adoption. Different benefits or side-goals often emerge during implementation, which are not in our focus. The drivers can be endogenous, originating from within the organization or even an individual decision-maker's perspective or exogenous, (as (Alles, 2015) uses the term) resulting from outside of the direct scope of the focal corporation.

Table 3: Categories of Drivers for SCA

Abbreviation	TOE classification	Categories of drivers for SCA
Endogenous types		
DA	T	Use available data to add value
TI	T	Apply new technological possibilities to build up competencies and communicate this internally
SI	O	Solve a specific (operational) issue
TR	O	Increase transparency/understanding in a particular area of business
Exogenous types		
TE	T	Apply new technological possibilities to communicate this externally
CO	E	Draw level with competitors who already use SCA
PA	E	Fulfill a demand by partners and customers

All drivers in Table II are assigned an abbreviation to refer to them more concisely here, as well as their primary relevant category according to the TOE framework. However: the different drivers can contain diverse nuances according to other areas: Driver SI can, for instance, contain technological elements, such as a difficult manual data collection task

that is easier executed employing a Natural Language Processing (NLP)-based data mining approach.

We try to underline this fact by the additional split in endogenous and exogenous types. While driver TE is classified as exogenous (and thus could be naturally considered an environmentally focused driver), our experts see the *initial impetus* as technological: Applying SCA as a technology, with the *subsequent benefit* of using this in external communications, such as employer branding or marketing initiatives, emphasizing the technological prowess of the company.

5 Discussion

5.1 CSF

One CSF that is not discussed by literature but was emphasized by the experts is "interdepartmental cooperation", meaning the intra-organizational exchange of information and ideally diverse setup of teams made up of different divisions.

We find that no expert considers all CSF that are proposed by literature. This is not surprising when taking into account the vast number of CSF that have been discussed in the past. More troubling to us is another finding emerging from this: Most experts are concerned with CSF that are more closely related to their background, i.e. practitioners with a technologically focused role (e.g. data scientist, data engineer) have Technology-CSF in mind, while others with more business (e.g. Supply Chain planners, Process Owners) or managerial roles – who are of course also involved in SCA projects – have the OE dimensions as their focal points. This is to be expected: One considers the domain with which one is familiar. The primary issue regarding CSF thus seems to be the unidimensional focus, rather than a general ignorance of relevant CSF.

When considering previous implementation difficulties, it became particularly evident that the consideration of a more diverse set of CSF would have supported the SCA effort. Most often, the focus is on technological CSF. We deduce from this finding, that companies are advised to focus on diverse teams that bring varying backgrounds, and hence perspectives, to the table. Additionally, "cross-qualifying" employees would be

beneficial: Educating a manager with deep knowledge of the business-related issues regarding technological challenges enables a more holistic perspective. In this spirit, (Landing AI, 2018) proposes a gradational approach for AI qualification: Broad, introductory courses for only weakly related functions or top-management and more concrete skills-building for tightly involved personnel.

5.2 Drivers

The differentiation between a necessity (through outside or internal forces) versus an opportunity to generate value-adding applications (Pierce and Delbecq, 1977) is a relevant distinction. While the former is brought about by pressure, the latter emerges through an innovative corporate mindset. However, we find no clear evidence whether this distinction results in varying implementation success.

Being DA-driven indicates a resource-oriented perspective. These projects consider existing, un- or underused data in the company with which value-adding products could be built or analyses executed. From there, other data silos that could be connected are considered to eventually build an SCA prototype.

An SI-driven implementation is usually supported by a concrete business case, which makes the argument for the use case easier and more data-driven (Marilex, Llave and Olsen, 2018). SI can refer to multiple different issues that are familiar from other IT applications within SCM, such as decreasing high costs of an operational process or reducing human error (He and Chen, 2008). SI is connected with performance expectancy, which is the perceived prospect of an individual employee to generate some benefit in their job-related activities through use of the technology (Queiroz and Wamba, 2019). Our experts expand this concept, including the perspectives of managers or other stakeholders that might not be directly impacted by the operational use, but still see the potential to alleviate a particular issue through the use of SCA. Looking at the more general case of drivers for IT usage in SCM, (He and Chen) point out some specific drivers that would fall in our SI category and that were also mentioned by our experts, such as cost reduction regarding an operational process or reduction of human errors.

Looking at technologically-driven projects, (Paolini and Fili, 2017) also identify technological development as an SCA driver, the concrete underlying aim however is not reflected upon. Our experts focus particularly on building knowledge as well as communicating the technology usage internally and externally. We condense these into TI and TE. TI is primarily concerned with building up technological know-how, generating buy-in from the employees, and developing a data-driven company culture. This is seen as strengthening the setup of the corporation as a technological leader beyond either the specific technology (TI and TE often aim to also include other technologies beyond SCA) or the specific use case. Creating a *sense of urgency* for employees additionally makes it easier to generate commitment for future projects by ideally producing results that can be referred to when building broader use cases. However, both TI and TE often extenuate the focus on a business case (though of course projects are preferred were such a positive case can be made, but this is not the underlying driver). TI-driven ventures are consequently often linked to the first steps a company takes in the field of SCA. TE focusses on the outside perception of the corporation, aiming to build an image of an advanced technological leader to attract talent or signal to customers.

Transparency is a common pursuit of SCA initiatives in SCM (Zhu, et al., 2018). Aiming to provide a clearer understanding of the status of their supply chain and consider emerging risks swiftly and efficiently, TR is described by the interviewees as a driver that emerges often from a “bad gut feeling”. This entails the intuition of not being able to build an accurate picture of the issues (TR is primarily issue-driven rather than opportunity-driven) in the supply chain.

Drivers such as CO and PA are faced by all kinds of businesses, relating to various technologies (Khan, Amin and Lambrou). CO is described by our interviewees as the necessity to close the gap towards competitors, who have built products and services out of their SCA capabilities or simply have become more efficient and thus more competitive. This external pressure is felt and drives SCA efforts.

The driver PA is related to social influence, which is described by (Queiroz and Wamba, 2019) in the context of Blockchain. The often implicit and indirect notion of social influence however is not stressed by our interviewees. Instead, quite direct inquiries by external stakeholders are related, especially from customers and supply chain partners.

The latter case occurs frequently, since some SCA use cases rely on upstream or downstream data from suppliers or customers to achieve their full potential. Since the ambition of a single firm is thus linked to their partners also providing high-quality data, the step for these linked companies to also establish SCA use cases (corresponding to our PA driver) is natural.

It should be emphasized, that no project is uniquely driven by one of our mentioned drivers. In practice, different drivers occur for the same project.

Merging our research streams of adoption drivers and CSF for SCA, we find evidence for varying relevance of CSF for different drivers in our qualitative data set. Our evidence indicates that it is particularly important to consider CSF from a different context than the driver. E.g. a DA driven project often already considers technological CSF sufficiently, but lacks understanding of the other, equally relevant areas. Our suggestion is thus to emphasize ones focus on organizational and environmental CSF when conducting a technologically driven SCA initiative. Correspondingly, the respective other contexts are to be emphasized for organizationally and environmentally driven undertakings.

We do not mean to indicate that some CSF are of lesser importance – of course, it is essential to also look at data quality and infrastructure even when the project is considered technologically driven. Our experts indicate, however, that these are considered in a disproportionately high manner, which means looking at the other areas seems to increase success probability during implementation.

6 Conclusion

Our results are twofold. First, we find that the CSF provided by literature are not consistently considered by the SCM practitioners we interviewed. There is a focus on technological factors, whereas CSF in the categories Organization and Environment are neglected more often. This is particularly the case in technologically driven SCA projects. This leads us to our second finding: Prioritizing CSF depending on the underlying drivers seems to increase likelihood for implementation success. Notably, emphasizing the area the project is not driven from seems to have additional value.

Reflecting on our limitations, we build our insights on a set of qualitative expert interview which, while in-depth and useful to identify thinking patterns and reasons of the interviewees, is too small a sample to provide reliable conclusions for a universal perspective. We do however include experts from diverse industries, indicating the potential to extract comprehensive patterns from our approach in the future.

Looking toward future research, providing further evidence for our findings via a quantitative study is necessary to establish the links between drivers and CSF on a broader sample size.

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A reference model for data-driven Sales Planning: Development of the model's framework and functionality

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Purpose: *Having accurate forecasts of future sales is mandatory for planning Supply Chains and providing the right distribution task resources. The usage of data in forecasting models enables precise planning and supports the company's competitiveness. This research shows a reference model framework that helps to establish data-driven sales planning in producing companies.*

Methodology: *The presented framework is derived from theoretical and practical challenges in a company where data-driven sales planning is not accomplished. The scope of the study originates from an industry project, and the developed framework forms the foundation for further research.*

Findings: *Data-driven sales planning is neither clearly defined nor the industry's norm, though data-driven methods exist for decades. The lack of methodical knowledge, incomplete data, and company characteristics cause diverse sales planning challenges. The research shows the requirements for integrating and advancing data-driven sales planning in companies.*

Originality: *This study clarifies the role of data-driven sales planning, identifies theoretical and practical challenges, derives requirements for the reference model and its functionality to support the establishment and advancement of data-driven sales planning in companies. The reference model aims for a comprehensive approach to counteract the mentioned challenges and guides the development of company-specific sales planning procedures.*

First received: 15. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Flexible response of Supply Chains (SC) to the increasing volatility in the market (Mohamed-Iliasse, Loubna and Abdelaziz, 2020) has become a crucial factor for the company's success (Serdarasan, 2013), as customers determine the SC's success by purchasing products (Beckmann, 2012; Daugherty, Bolumole and Grawe, 2019). Frequently, the need for products originates spontaneously in the market, e.g., from the customers (Nimmy, Arjun and Pillai, 2019), usually met by the company's distribution system (Schulte, 2017). The relevance of distribution logistics for the overall economic success of a company (Daugherty, Bolumole and Grawe, 2019) is reinforced by the need for a shorter delivery time and the possibility of customers to substitute an unavailable product (Beckmann, 2012). Thus, company-wide planning must supply the distribution system with products to meet the customer's demand. In this context, it is necessary to anticipate market sales, because it enables the SC to provide resources in advance of the emerging demand (Magaña, Mansouri and Spiegler, 2017; Boone, et al., 2019). With the help of sales forecasts as a crucial part of the sales planning (SP) task, it is possible to have demand-oriented production and, thus, supply the distribution system (Chase, 2016). SP is a key task in the SC (Serdarasan, 2013) that is primarily company-specific (Aviv, 2001), as, e.g., it varies depending on the type of product sold. This research focuses on make-to-stock-producing companies that are capacity-constrained because they strongly depend on accurate sales forecasts (Nimmy, Arjun and Pillai, 2019). The company's dependence on consumption in the market makes data-driven SP particularly important, as products have to be manufactured in advance to the customer's demand. Data-driven SP uses the company's data and quantitative forecasting methods to estimate the future customers' product demand. SP is a SC-planning task, which provides information for other planning tasks, like distribution or production planning.

The forecast of future sales figures can be carried out through various methods (Kumar and Mahto, 2013; Rushton, Croucher and Baker, 2017). Quantitative methods are focused in the presented study, which can be beneficial to plan the SC accurately (Vogel, 2015). Big Data has emphasized data usage for planning the SC (Chokkalingam and Vijayarani,

2017; Ni, Xiao and Lim, 2020). Moreover, the increased availability and variety of data (Gantz, Reinsel and Rydning, 2018), especially for forecasting (Boone, et al., 2019), and higher computing power enable using sophisticated methods, like Machine Learning (ML), to predict future sales. Nevertheless, Chase (2016) cites a study that indicates insufficient use of existing data in the area of SP, even though the usage of historical data has already played a role since the introduction of time series methods, like exponential smoothing (R. G. Brown, 1959).

In order to improve the appropriate usage of data in SP and, thereby, the SC planning, a reference model (RM) is developed that details data-driven SP as a planning task in the SC. The model aims to support companies to select the right level of complexity regarding their data-driven SP. This research forms a basis for a data-driven sales planning reference model (SP RM) by providing its framework. A literature review is used to answer the following research questions (i) *What challenges exist in establishing data-driven SP?* The identified challenges are additionally confirmed through expert interviews at an industry partner. *The detected challenges are used to derive requirements for the SP RM. Moreover, the choice of reference modeling as an adequate modeling method is argued. This approach answers the second research question:* (ii) *What elements must a model incorporate to help address the identified challenges in SP in the practical application?*

For this purpose, the role of SP will be positioned in the Sales and Operation Process (S&OP) in Section 2. This includes the methods for and characteristics of data-driven SP. In Section 3, the methodical approach to identify challenges in SP and how the model will be further developed is shown. Section 4 presents challenges from the literature review. They are further compared with the expertise from the industry partner. In addition, the catalog of requirements and necessary functions of the data-driven SP is derived. Section 5 explains the aim and the framework of a data-driven SP RM. Finally, the findings are discussed, limitations are identified, and further research is pointed out.

2 Theoretical background for data-driven sales planning in Supply Chains

In this section, the role and importance of SP in SC planning and its effects on the SC are given. The definitions help to identify the research gap served by this paper.

2.1 Positioning of sales planning within the Supply Chain

Ayers and Odegaard (2018) define SC from a customer's perspective, which reflects this research's understanding of the term. The SC aims to provide the end customers with physical products or services, uniting multiple suppliers through flows of goods, information, finance, and knowledge. Schulte (2017) sees the customers' demand as the initiation of the SC and the Point-of-Sale (POS) data as the basis of managing the SC. Endogenous and exogenous trends lead to higher competitive pressure (Schiffer, et al., 2020). Therefore, accurate planning is necessary to react adequately to changes in the market. Frequent sales forecasts are needed, as using the most recent information provides more flexibility to the SC (Beckmann, 2012; Schiffer, et al., 2020). SP is one of the various planning tasks in a SC and obligatory, as it gives companies an estimate in which range the sales will be. Based on these plans, it is possible to prepare the SC system for the next period to reach a robust availability of goods to satisfy the customers' needs(Chase, 2016).

Before investigating SP, a distinction of the terms demand and sales must be carried out to narrow down the objective of data-driven SP. In economics, the term demand is defined by the quantity of a particular good or service purchased by economic entities with sufficient purchasing power (Meffert, et al., 2019). Therefore, demand, describes the fundamental need of customers to purchase products. Sales are understood as the number of products sold by a given company within a certain period (Gutenberg, 1984; Meffert, et al., 2019) thus, it has a more specific meaning than demand. The actual overall demand of the market will not be known, as the company's sales data would have to consider potential purchases in unexploited markets (Syntetos, et al., 2016). Mentzer and Moon (2005) refer to this term as independent demand originating from the end consumer. The term sales will be used in this paper, referring to this explanation.

SP is one part of the Sales and Operation Process (S&OP). The S&OP synchronizes demand and supply in a company (Thomé, et al., 2012) and starts with an estimate of the expected sales (Schulte, 2017; Lütke Entrup and Goetjes, 2019). Following various studies (Nimmy, Arjun and Pillai, 2019; Mohamed-Iliasse, Loubna and Abdelaziz, 2020; Iano, et al., 2021), SP is a crucial task in the SC, since it permits inventory and supply planning to determine production or distribution. The key element of SP is to develop an unbiased forecast of demand to have a data-oriented information function and not an action-oriented design function (Pieroth, 2013). The adjustments of sales plans through other business functions, e.g., due to restrictions of the SC system, are not part of SP (Usuga Cadavid, Lamouri and Grabot, 2018) as understood by this study. Figure 1 illustrates this deduction.

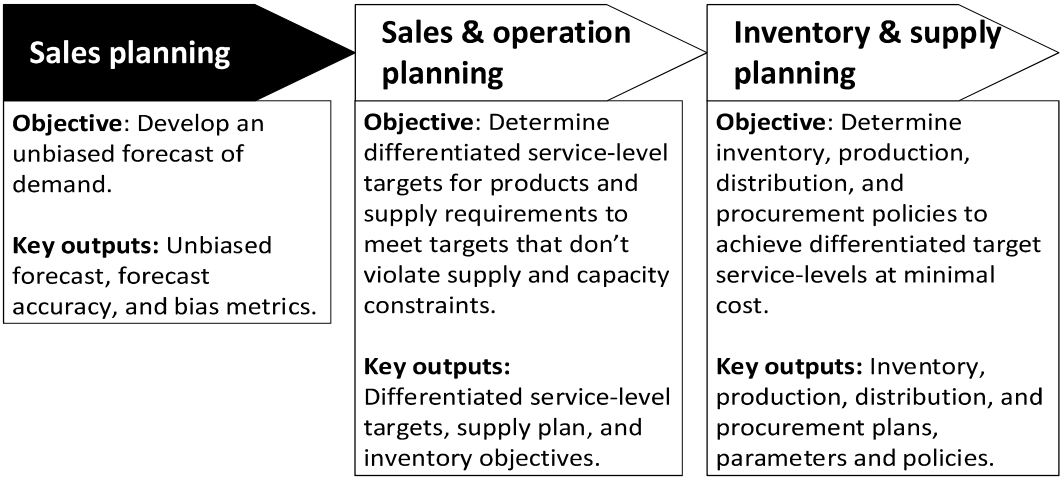


Figure 1: Delimitation of various Supply Chain planning tasks (according to Feigin, 2012)

SP can be conducted using numerous quantitative and qualitative methods. Figure 2 illustrates examples of some of these methods in the respective area. Qualitative methods are mostly subjective methods for assessing future development regarding the sales numbers, primarily verbal and rarely associated with numbers (Vogel, 2015). E.g., expert knowledge, brainstorming, or the Delphi method are used. This study focuses on using data from the IT landscapes in quantitative methods to provide objectivity of the SP to a possible extend.

Quantitative methods analyze empirical data with mathematical operations to derive a sales forecast (Vogel, 2015). The term data is often used as a conglomerate of the available contents of the information sources. The use of these data represents a necessary competitive factor for companies today (Ebener and Ebener, 2017). North (2011) states that the enrichment of data with meaning leads to information. It is impossible to delineate whether pure data sets or information exist in practice, as the designation of data attributes already goes beyond the data definition. As a basis for this paper, however, it can be stated that data are of great importance in data-driven SP. It makes use of primary quantitative forecasting methods to process numerical data using mathematical operations to obtain information about the market sales served by a specific company. 2

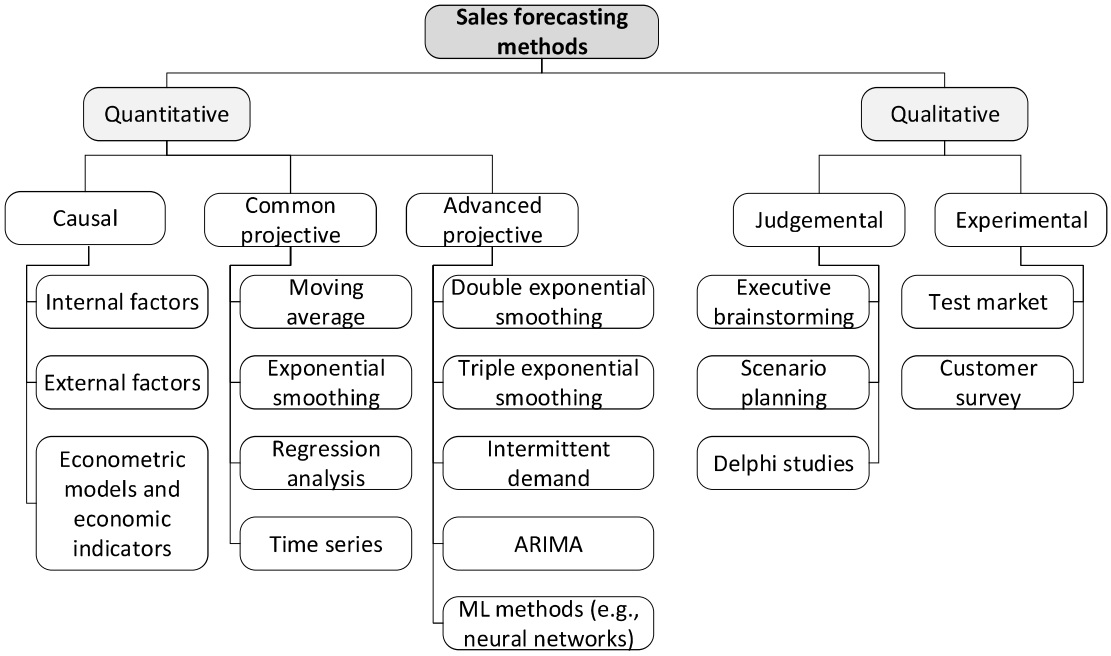


Figure 2 : Examples for quantitative and qualitative forecasting methods (according to Rushton, Croucher and Baker, 2017)

2.2 Reference modeling and deduction of the research gap

Reference modeling is used in numerous industry sectors (Fettke and Loos, 2004) to assist academics and practice. Some examples are business process engineering (Schwegmann, 1999), software engineering (Delfmann and Stein, 2007), or the design of production systems (Hartung, 2020). Schubel, Seel, and Schneider (2015) identify five topics in the logistics sector: Planning of logistics or production systems, SCM, digital factory, Computer Integrated Manufacturing (CIM), and Production Planning and Control (PPS).

A number of definitions (Scheer, 1998; Schütte, 1998; Schwegmann, 1999; Klinger and Wenzel, 2000; vom Brocke, 2002; Fettke, 2006; Fettke and Loos, 2007; 2009) exist, which do not provide a consistent understanding, as they come from different fields of expertise (Hartung, 2020). The major characteristics of the definitions identified above are presented to transfer the findings to the requirements catalog in Section 4.2.

- Recommendation character: RMs represent common practices or best practices for conducting business.
- General character: RMs are valid for a class of domains representing a simplified part of the reality and reducing diversity and complexity.
- Reusable character: RMs are conceptual frameworks that can be reused as a template for derived models.
- Modular character: RMs are modular and independent of the implementation software as they take on different perspectives.
- Clarity and uniformity character: RMs use a uniform and unambiguous language, for instance, to promote acceptance.

The RMs identified regarding the research object of this paper are: First, the Supply Chain Operations Reference Model (SCOR), which is an established RM (Beckmann, 2012) that aims to develop standardized processes to improve the exchange of information between companies in a SC. Uniform, comparable, and assessable processes are targeted, and best practice or software functionalities are shown (*SCOR,* 2010). In the model, demand planning and forecasting are defined and placed into the workflow. Possible tools, including spreadsheets and some forecasting methods, are discussed.

The level of detail is low, and, e.g., process steps to generate sales forecasts are not included (*SCOR,* 2010). Second, Continuous planning forecasting and replenishment (CPFR) is a framework to guide aspects of planning, forecasting, and replenishment processes through collaboration among the SC (VICS, 2002; 2004). The added value of the RM is based on the exchange of planning data instead of using sophisticated methods (VICS, 2002). SP is performed from the customer's side, as focused by this study. The task of demand planning is presented more concretely compared to the SCOR model. However, it remains generic and is presented in one process step called "create sales forecast" (VICS, 2002). In our opinion, this does not reflect the complexity of the SP task. Third, the RM of Gayialis (2013) uses knowledge modeling to optimize demand management and, thus, focuses on inventory and supply planning. Fourth, The business processes of SCs' for fruits are part of the RM of Verdouw et al. (2010). Processes are standardized to improve the creation of information systems and to increase the understanding of the management. There are few RMs for SC, especially for its sub-processes (Gayialis, et al., 2013). The study presented here addresses this gap, as the models mentioned above are not sufficiently precise concerning data-driven SP and focus on other or more general sub-areas.

3 Study's methodology

Three aspects regarding the methodological approach are explained here. First, a literature review was performed to identify the challenges in SP. Second, these challenges were checked and extended with a case study research to counteract them by defining requirements for the model. Finally, the methodical approach for developing the data-driven SP model is illustrated.

3.1 Methodology for challenges analysis

A literature review was performed to research the topic of data-driven SP and especially its challenges, mainly using Scopus (www.scopus.com), ScienceDirect (www.sciencedirect.com), and the catalog of the library of the Technical University Dortmund (www.ub.tu-dortmund.de). The review was conducted using the following

keywords in German and English language in different combinations: “data-driven”, “demand”, “forecast”, “reference model”, “sales”, “planning”, and “Supply Chain”. Approximately 200 sources were classified as relevant and reviewed, consisting of conference and journal papers, books, and surveys.

The research presented here is based on cooperation with an industrial partner, where data-driven SP was not established. Therefore, the challenges identified in the literature have been confirmed and extended with existing problems and challenges identified during the project time. The analysis of practical challenges for the SP task was performed with the help of a case study methodology. It is used to investigate a specific case in-depth and in a real-world context (Yin, 2014).

The cooperating industry partner is an international company that produces consumer goods, which are distributed through various external partners. The company aimed to advance the usage of data in the SC planning to raise customer satisfaction. Due to its great potential, SP was selected as the main area to advance. During the industry project, various methods were applied to improve data processing to generate adequate forecasts. Interviews were conducted with the management of different areas of the SC, such as planning, controlling, and operations, to understand the business model and, thereby, find factors that drive sales numbers. Furthermore, sales, customer service, operational logistics, IT departments, and various planning departments in different countries were interviewed to obtain comparable results. Data were gathered from multiple data sources, like the enterprise-resource-planning (ERP) or the customer-relationship-management (CRM) representing three markets to execute descriptive and prescriptive data analysis, e.g., Time-Series-Analysis. The research at the industry partner was used as an extension of the findings from the literature.

3.2 Methodology for a data-driven sales planning model

Reference modeling has been chosen for developing the data-driven SP RM. A corresponding procedure model complements the systematic approach to modeling and investigating the domain, explained here.

The RM is considered a modeling methodology in this research as it is helpful for theory and practice and can be used to strengthen an enterprise's market position (Fettke and Loos, 2007). The authors decided to use this method due to the following advantages, related to the sources in Section 2.2: Reference modeling aims to reduce effort to derivate a company-specific model. RMs moderate failure during the modeling process and improve the specified model's quality. The methodology further ensures transparency in a specific domain by consolidating knowledge and unifying the language. At the same time, RMs enable benchmarks and create a basis for comparing and assessing the current status quo.

Several procedure models for reference modeling have been found in the literature that show a large intersection. The approach of Akkasoglu (2014), following Schlagheck (2000), is chosen (Figure 3) since a feedback loop between the development and the application is integrated. Schubel, Seel, and Schneider (2015) criticize that it is unclear whether RMs are reused in practice. Therefore, the feedback from the cooperation partner has been used to increase the usability of the data-driven SP RM, thus, strengthen the practical relevance of the model.

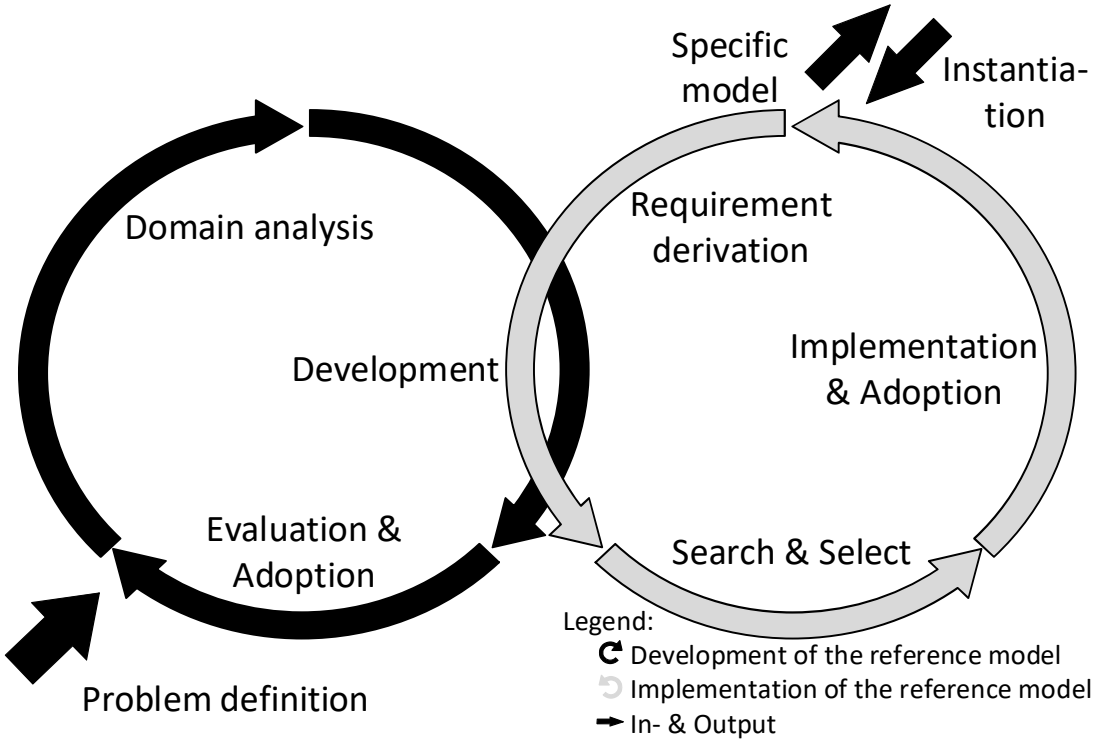


Figure 3: Procedure model for the development and implementation of reference models (according to Akkasoglu, 2014)

The procedure during the research is presented shortly according to the steps from the procedure model in Figure 3. During *problem definition*, practical challenges were analyzed in exchange with the project partner, and the research scope was defined. Afterward, a *domain analysis* in the form of a detailed literature review took place. Parallel to this, possible starting points were *searched and selected* in the company to achieve the target mentioned above. Continuous consultations with the partner and the results of the quantitative analyses helped to *implement* the data-driven SP in daily work. The company's characteristics were captured during *instantiation* with expert interviews, and the SP requirements in the company were derived. The *specific model* was realized in the form of a prototype that supports the data-driven SP. This prototype is a tool that processes the company's data within various quantitative forecasting methods. During the further *development*, the project experience derived a comprehensive model whose

validity can be transferred to other companies. *Evaluation and adaptation* are part of ongoing research activities.

4 Challenge analysis and requirements specification for the data-driven sales planning model

Challenges resulting from the literature review are presented and compared with practical problems, and required functions of the SP RM are presented to illustrate its benefits.

4.1 Challenges for data-driven sales planning

During the literature review, various challenges have been identified for the SP task, and grouped into three categories. The first challenge explores the "rising complexity in SC". The second challenge illustrates the heterogeneous characteristics of the "sales planning process". The third challenge is designated "rising complexity regarding information", describing data issues and the use of sophisticated methods, such as ML.

4.1.1 Rising complexity in Supply Chains

Rising complexity in SCs is a ubiquitous topic in many studies (Serdarasan, 2013; Schiffer, et al., 2020). Trends like globalization (Rushton, Croucher and Baker, 2017), digitalization (Ni, Xiao and Lim, 2020), and customer-centricity (Daugherty, Bolumole and Grawe, 2019) are mentioned. The volatility of markets is increasing (Mohamed-Iliasse, Loubna and Abdelaziz, 2020), which forces the industry to counteract with accurate planning to keep product availability high and balance the inventory (Sohrabpour, et al., 2021). The customers are a crucial factor for the SC (Nimmy, Arjun and Pillai, 2019) and conclusively for SP (Usuga Cadavid, Lamouri and Grabot, 2018; Iano, et al., 2021). The customers' expectations have risen significantly in recent years, and fast deliveries are now taken for granted (Daugherty, Bolumole and Grawe, 2019). Availability of goods is necessary in order to deliver them quickly, which in turn requires an accurate sales plan. Moreover, there is a tendency to sell products via various sales channels, e.g., simultaneously in

branches and through e-commerce (Syntetos, et al., 2016; Daugherty, Bolumole and Grawe, 2019), which is complicating SP, as more data sources can be considered in the forecast (Syntetos, et al., 2016). On the one hand, these developments make SP more complex (Tripp, 2019; Ni, Xiao and Lim, 2020) as markets become fragmented and dynamic. On the other hand, accurate SP can help operate the distribution system and raise customer satisfaction (Zhao, Ji and Feng, 2020).

4.1.2 Sales planning process

The forecasts of sales figures with data have a tremendous effect on the entire SC and have to be improved continuously (Nakano, 2009). SP is a multidisciplinary planning task (Beckmann, 2012; Riekhof and Brinkhoff, 2014) that can involve information from numerous departments, such as marketing and sales. According to various studies (Chase, 2016; Vereecke, et al., 2018), forecasting in practice has not advanced much regarding data usage and the planning process and still exhibits potential for improvement. Simple methods using historical sales data and expert forecasts are used frequently (Riekhof and Brinkhoff, 2014; Vereecke, et al., 2018), while forecasters in science tend to rather complex approaches (Green and Armstrong, 2015). SC sales forecasting is mainly conducted manually and based on the skills and knowledge of the data analyst (Seyedan and Mafakheri, 2020). Chase (2016), Syntetos et al. (2016), Seyedan and Mafakheri (2020), as well as Partida (2020) recognize that spreadsheets are still a common tool for the S&OP and the forecasting process. It appears that forecasting software tools are an issue to advance (Chase, 2016; Vereecke, et al., 2018), as these tools do not provide sufficient support for user-friendly presentation and processing of information across departments (Fildes, Goodwin and Önkal, 2019). SP takes place across departments, is complex and time-consuming (Seyedan and Mafakheri, 2020), requires many kinds of information, and, therefore, relies on the application of IT solutions (Mertens and Rässler, 2012). According to Syntetos, et al. (2016), there is a need for software solutions for SP, and its status is assumed immature (Alicke, Rachor and Seyfert, 2016). 3

The anticipation of sales is often confused or mixed up with financial, supply, or demand planning (Mentzer and Moon, 2005; Chase, 2016). Figure 3 illustrates the conflicting relationship between these four planning tasks.

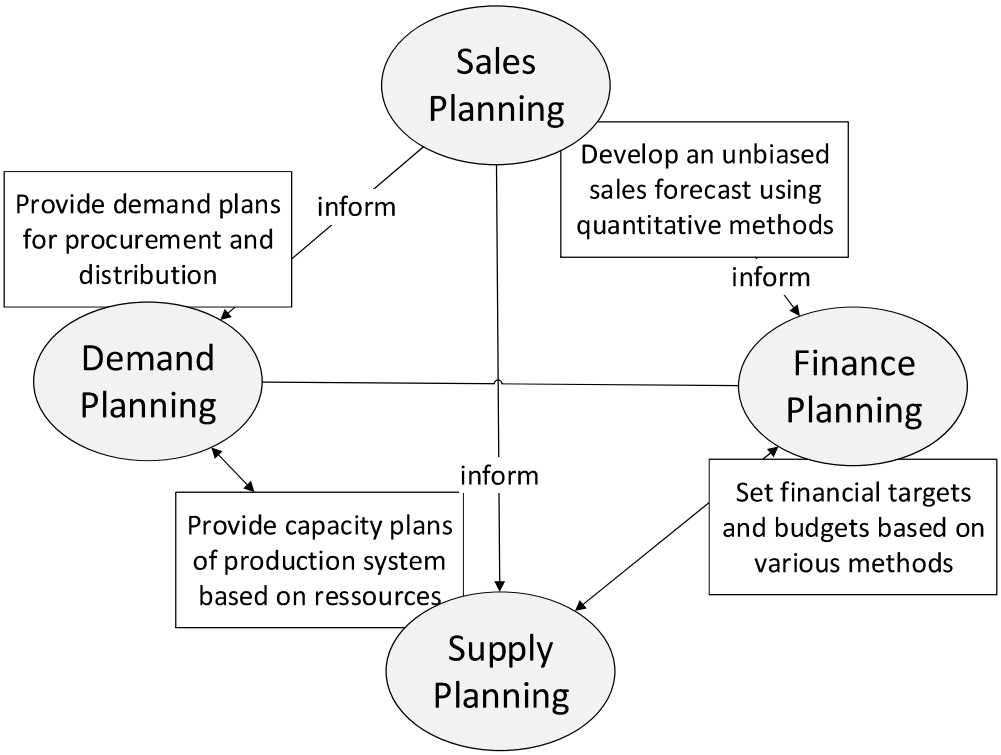


Figure 3 : Planning tasks and their objectives in Sales and Operation Planning (simplified illustration of respective tasks)

Finance planning is primarily a strategic task, defining goals for the following years, taking into account the respective business model. It is often influenced by a general desire for economic growth (Eilenberger, 2003). Resources limit supply planning, on the other hand. E.g., the focus lies on company-specific restrictions in the SC system, like production capacities (Lütke Entrup and Goetjes, 2019). SP and Demand planning are often used interchangeably. Referring to Mentzer and Moon (2005), it coordinates the dependent demand along the SC and, e.g., takes into account inventory and helps determine raw material requirements (*SCOR,* 2010). Misinterpretation of the tasks and synthesis of goals is a result of the vague delimitation of these business functions. Conclusively, the aim of data-driven SP is to create unbiased sales forecasts extrapolated

with quantitative methods using historical data from the IT landscapes to provide "objective" information in order to forecast the independent demand. These unbiased forecasts should not be confused with target setting or the operational execution, considering limited resources (Mentzer and Moon, 2005).

4.1.3 Rising complexity regarding information

Speaking of data-driven SP in times of Big Data and Artificial Intelligence being researched in many scientific areas, the role of data is of utmost importance (Camarinha-Matos, Afsarmanesh and Fornasiero, 2017). The amount of data recorded increases (Gantz, Reinsel and Rydning, 2018), and conclusively more data sources exist (Ebener and Ebener, 2017). This fact directly impacts the growth of databases in the associated IT landscape (Schiffer, et al., 2020). These data are becoming more important for accurate SC planning (Chase, 2016; Boone, et al., 2019). Knowledge should be extracted from data to understand which factors in the SC create sales peaks. Various sources note that data issues are critical (Beckmann, 2012; Camarinha-Matos, Afsarmanesh and Fornasiero, 2017; Schiffer, et al., 2020). E.g., Ni, Xiao, and Lim (2020) and Allen (2019) assume the lack of data as a fundamental problem in SCs. The survey of Vereecke et al. (2018) conveys a rather fundamental use of data and statistical forecasting methods for SP. One reason for this could be the low availability of data, their inadequate quality (Syntetos, et al., 2016; Makridakis, Spiliotis and Assimakopoulos, 2018), or missing knowledge in companies regarding data science (Hu, et al., 2018; Allen, 2019). The companies' databases are considered insufficient, leading Allen (2019) to see this lack of availability as an obstacle to the establishment of ML in practice. Data analysts spend 80 % of their time on data management (Chase, 2016). In order to achieve flexible SCs, automated and precise planning with sophisticated methods is necessary, which remains immature (Allen, 2019; Oosthuizen, et al., 2020). Creating sophisticated forecast models is time-consuming (Usuga Cadavid, Lamouri and Grabot, 2018) and challenging in SCM (Ni, Xiao and Lim, 2020). A SC is influenced by many factors, affecting the sales numbers (Serdarasan, 2013). These factors, such as sales promotions, must be integrated into the forecast models, while its recording and data representation are partially outstanding. Wenzel, Smit and Sardesia (2019) see potential usage for ML in SCM and various sources

(Mohamed-Iliasse, Loubna and Abdelaziz, 2020; Spiliotis, et al., 2020) concerning forecasting. Still, it has only been partially possible to use the data describing these factors to improve sales forecasting accuracy (Makridakis, Spiliotis and Assimakopoulos, 2018). More data and more complex procedures do not necessarily lead to more accurate forecasts (Green and Armstrong, 2015), as the effects of these factors cannot always be determined concretely (Spiliotis, et al., 2020). Furthermore, valuable data in an organization must be identified first (Chokkalingam and Vijayarani, 2017; Usuga Cadavid, Lamouri and Grabot, 2018). There was a contradiction in the scientific literature regarding the better suitability of simple (Green and Armstrong, 2015) versus sophisticated methods (Iano, et al., 2021) for forecasting (Spiliotis, et al., 2020). After years of gathering experience, the M4-Competition can state that both simple and sophisticated methods must be explored in the future, as the combination of these currently leads to the highest forecasting accuracy (Makridakis, Spiliotis and Assimakopoulos, 2020).

4.2 Catalog of requirements for the data-driven sales planning model

A frequently cited criticism relates to the varying scope and level of details of RMs (Fettke and Loos, 2007; Schubel, Seel and Schneider, 2015) and a missing evaluation method (Fettke and Loos, 2007). This criticism is met by creating a catalog of requirements before developing the RM for data-driven SP.

This catalog helps to develop the model correctly to counteract the challenges. It ensures formal correctness and focus during the model design. In this manner, it guides the development and helps to evaluate the model to meet theoretical and practical objectives and generate a remarkable benefit. Shortly explained, the requirement catalog determines what the model must be able to do and what has to be considered. The literature used in Section 2.2 regarding reference models was analyzed, and the claims for a RM were bundled. These general claims were synchronized with the identified challenges from Section 4.1 and transferred to the SP use case. The catalog was further expanded respecting the challenges in practice explained in Section 4.3. The requirement catalog for a data-driven SP RM and short descriptions are given in Table 1.

Table 1: Requirement catalog for the data-driven sales planning reference model

Requirement designation	Requirement description
Recommending	Aims to make recommendations to the model user, helping with implementation, execution, and extension of data-driven SP (considering common and best practices).
Generally valid	Creates a general overview in a domain (limiting itself to relevant aspects and clear applicability) by demonstrating relevant parts of reality and, thus, reduces complexity. Creates clear definitions and uses a unified terminology to create understanding and acceptance.
Reusable	Builds a conceptual framework using documented knowledge that serves as a template for deriving specific models in a particular domain.
Modular and expandable design	Software-independent; creates flexibility through its modular structure and, thus, enables dedicated model adjustment and expansion.
Aligned with standards	Systematical development of model and usage of appropriate and established methods (e.g., procedure model and modeling languages).
Consolidated methods	Merges existing quantitative forecasting methods and takes into account the respective application requirements.

Requirement designation	Requirement description
Positioning	Forms a reference value for the problem domain independent of the heterogeneous status quo and, thus, increases the comparability between companies (benchmark).

4.3 Comparison of the identified challenges with the company case

The project partner was supported in using its existing data as extensively as possible to create accurate sales plans. For this purpose, the SC was analyzed concerning its characteristics and customer requirements to identify sales-driving factors. The planning steps in S&OP and the respective use of methods were examined. The untapped potential was identified, and the usage of data in quantitative forecasting methods focused. There is considerable overlap between the challenges in the literature and those in the industrial project. Some of the challenges presented were more drastic at the practice partner than described by the literature. Some examples are given to illustrate this. The customer was one of the starting points for the research project with the industry partner. Its increasing requirements in terms of delivery times or sales channels were reflected in strong fluctuations in the sales figures. An increase in planning complexity due to serving many markets with different sales channels has also been confirmed by the experts. As described by the literature, spreadsheets were a frequently used tool at the start of the project, and simple forecasting methods or expert estimations were preferred. The mixing of planning objectives led to misleading communication and, thus, stockpiling of products that did not meet the demand. Furthermore, the use and storage of data still provides room for improvement, as the data structure and sources were distinctive. The simple and advanced forecasting methods produced acceptable results. Nevertheless, an improvement that is more remarkable was expected from sophisticated methods. The analysis of the case study through expert interviews resulted in the requirements "consolidation of methods" to help companies choose an appropriate

forecasting method and "positioning" to enable an assessment of the further development of SP. In summary, the authors assume that the lack of knowledge regarding quantitative methods and a missing awareness for the usage of data are reasons for a divergent maturity of SP, which strengthened the motivation for this research effort. However, adequate solutions in the literature to counteract these challenges do not seem to be sufficiently developed.

4.4 Determination of the functionality of the sales planning model

Due to various reasons, it can be stated that SP is a crucial and complex task, and its establishment is partly outstanding. The approaches in the industry are heterogeneous and diverse regarding the understanding of the SP task, the variety of forecasting methods, used data, and business procedures. Many producing companies create their sales forecasts based on pure domain knowledge or with the help of simple forecasting methods. At the same time, there is an urge for more precise planning. Referring to Riekhof and Brinkhoff (2014), 61 % of the companies surveyed produce forecasts based on historical data, while at the same time, 60 to 85 % would like to have a higher forecasting accuracy. This shows the rising importance of data usage in SP. SP is not clearly distinguished from other responsibilities in the S&OP, and planning objectives are confused. While data volumes and data sources are increasing, companies are not in the position to utilize them to improve competitiveness. It has further been shown that companies lack the expertise to use sophisticated methods. Based on experience, the authors claim that companies sometimes struggle to use simple forecasting methods. Accordingly, the authors assume that only a minority of companies make reasonable use of their data to predict future sales. It is obligatory to make the best possible use of the data available for SP and, thereby, support the success of the SC. The RM for data-driven SP, as presented in this study, promises to be of essential advantage for companies.

Figure 4 summarizes the challenges in SP on the left-hand side. The figure further shows the derived requirements for the SP RM. Before explaining the figure, functions for the SP RM are determined from the requirements. These counteract the challenges identified and, thereby, provide a frame for the resulting SP RM. The catalog of requirements

specifies a proper declaration of the SP RM functions. The functions of the model must meet the requirements to provide a benefit for practice and theory. How the SP RM framework considers implementing these functions is part of Section 5. In the following, some examples are given to illustrate the declared model functions. The rising complexity in the SC can be reduced as the model provides a template for companies to build specific SP solutions (*reusable*). The model helps to use data within a crucial planning task to support the overall efficiency of the value chain. Having a *generally valid* model with clear terms and definitions brings more transparency into the SP task. To counteract that forecasting has not advanced much in recent times, the model gives *recommendations* regarding reasonable complexity of the SP process and used forecasting methods. Companies can rely on the model independent of the used software and the level of their SP (*modular and expandable design*). The model allows the determination of the company's status quo regarding SP and shows possibilities for development (*positioning)*. The model is designed *expandable*. Thus, new forecasting methods can be added. A clear terminology and description of the SP task helps to prevent the mixing of planning objectives and promotes acceptance. The model is developed systematically. Existing knowledge is bundled and presented through adequate methods (*aligned with standards*). The model helps companies to identify forecasting methods eligible in their specific case and the data needed to predict future sales. *Recommendations* regarding the use of additional data and data sources in sophisticated forecasting methods need to be considered in the model. Levels of SP, e.g., from simple to advanced planning, have to be defined in the model to provide a benchmark (*positioning*) and comparability between companies.

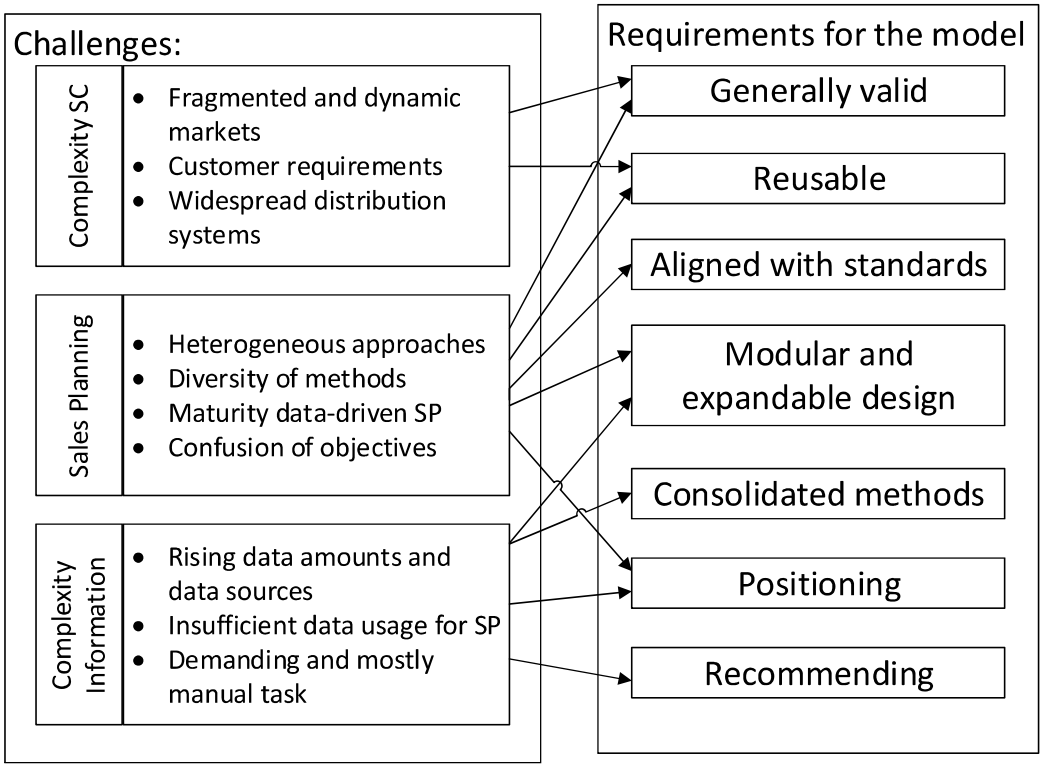


Figure 4: Identified challenges for data-driven sales planning and counteractive requirements for the reference model

5 Aim and framework of the data-driven sales planning reference model

In this section, the aim of the developed RM is presented to illustrate how the RM implements the requirement catalog. Subsequently, the RMs framework, the required levels in the model, and its functionality are evolved.

5.1 Aim of the data-driven sales planning reference model

The RM aims to counteract the mentioned tension (see Section 4). Based on this, a multi-level framework for the SP RM resulted, helping to design the SP task to reach an adequate forecasting performance. The model will illustrate the recommended quantitative methods for the SP process and the required information. The model

considers logistical and SP-relevant characteristics in the environment of producing companies. As the starting activity, the model's user parameterizes the RM. With the help of this parameterization, the functions that data-driven SP should provide are determined. Based on these functions, the model provides superior process sequences and concludes on relevant subordinate process steps. These subordinate process steps are further detailed in workflows to provide companies with detailed knowledge and guidance on data-driven SP. The model is supplemented by so-called information classes, which bundle corresponding data in defined categories. With these categories, the workflows of SP are brought into a context with the required information. Merging the functions of data-driven SP from the parametrization and the process steps with the assigned information classes generates detailed instructions for the planning task. The instructions can assist companies in designing their data-driven SP correctly. The data-driven SP RM will help to develop accurate sales plans and a transparent SP process. In addition, it will give advice for appropriate forecasting methods and the collection of valuable data. Furthermore, it gives orientation for the development of a forecasting model and helps as a benchmark, which shows a path for future orientation by defining levels of complexity regarding the SP task. The SP RM serves as an introduction to data-driven SP in the company and guides company-specific advancement regarding data-driven SP.

The data-driven SP RM could help companies to answer the following questions:

- How should existing data be used to predict future sales?
- How should the process of data-driven SP look like?
- What are the process steps to acquire a sales plan built with quantitative methods and starting with raw data?
- What is the current status quo regarding data-driven SP in the company, and how to advance this status?

5.2 The model's framework

The framework developed in this section demonstrates how the RM for data-driven SP can fulfill the requirements catalog and, thereby, derive benefits for practice and theory. The model levels are identified, and the functionality is shown to understand the

objective of each level and the transition between the levels. This study demonstrates the model's outer framework, and examples from the case study illustrate the inner model design, which needs to be detailed in further research. As an overview, the model's levels and short descriptions are shown in the following item list. In principle, a hierarchical top-down structure has been used that leads from coarse to fine. The terms in parentheses refer to the respective terms in Figure 5, which illustrates the model's framework in a simplified manner, indicated by "...":

7. Level **Instantiation:** The company's characteristics influencing the SP task are collected and used to instantiate the RM. Based on the parameters (P) that affect SP, the functions (F) needed in the company are determined to derive the proper process steps.
8. Level **Superior process**: In this level, fixed superior process sequences are defined. Each superior process sequence (1. Process sequence) has assigned process steps (1. Process step) that vary depending on the instantiation. The process steps are determined concerning the identified functions from the first level.
9. Level **Subordinate process**: The company-specific process steps from the level above are further detailed. Business Process Modelling and Notation (BPMN) is used as a modeling language to provide a step-by-step workflow to finish each process step and, thereby, superior process sequences.
10. Level **Information classes**: An information class bundles the data used in SP into defined categories. The Unified Modelling Language (UML) is used as a modeling language to attach data attributes to every information class. These Information classes are assigned to the workflows from level three.

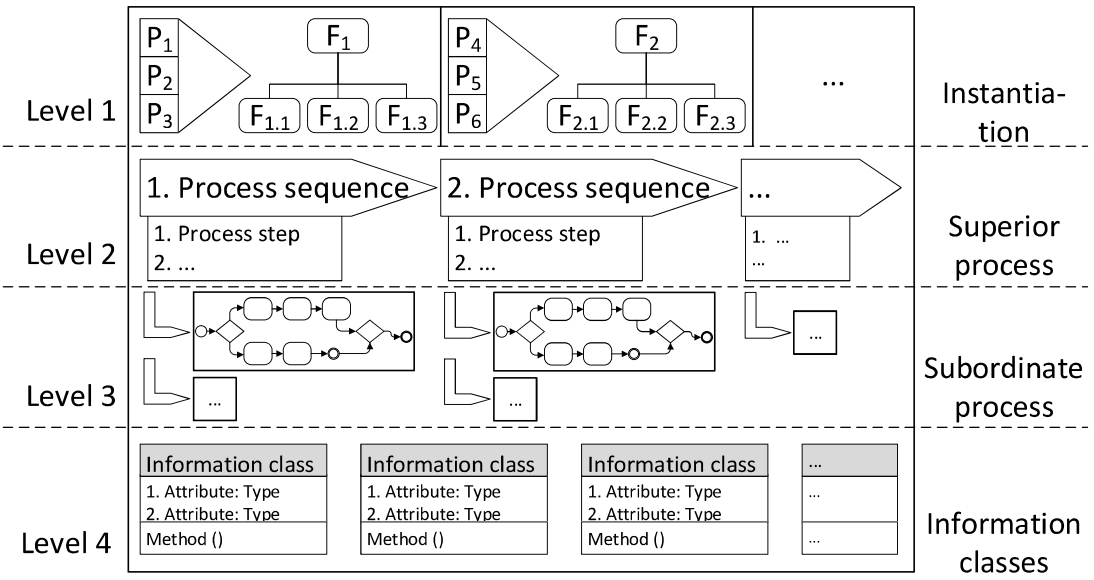


Figure 5: Exemplified framework of the data-driven sales planning reference model

The general framework has been designed in accordance with the catalog of requirements. The following methodical approach was chosen. Various possible actions were derived for each requirement in the catalog. The implementation of these actions in the RM was checked, and an adequate action was chosen. In this manner, the requirements have influenced the outer shape and the design of each level. All requirements not met within a model level are explained now. In the beginning, the topic was narrowed down to delimit the task of the model and, thus, obtain *general validity* for the model in the respective research topic. The model is intended to advise companies to introduce and continue data-driven SP, promoting the *recommending* requirement. Simultaneously, the model reduces complexity in the subject. It bundles knowledge and, thereby, provides a general orientation in this field. An instantiation level was created to adapt the general model to a concrete enterprise. Thereby, the model gives company-specific recommendations to improve the *reusability*. The requirement to *align with standards* is ensured using a procedure model that encourages a systematic development of the model. Furthermore, the *alignment to standards* is ensured by adapting existing modeling languages and using knowledge from state of the art, e.g.,

current forecasting methods. These forecasting *methods* are *consolidated* so that recommendations can be made for the usage of methods. The model forms a reference value for comparison of the complexity level obtained in companies, which is mainly determined by the forecasting method used. The reference helps to increase the comparability between companies (benchmark) and provides the *positioning* requirement. A *modular and expandable* structure is given since each level can be supplemented, and new levels can be created. Altogether, the SP RM promotes data usage for the SP task.

In the following, each of the model levels will be presented. Explanations are given regarding (i) the characteristics and main terms of each level, (ii) the requirements from the catalog that are met within the level, (iii) the input needed and the resulting output, (iv) the transition to the next level, and (v) the participants and target group. Finally, (vi) the methodical approach during the development is detailed, and (if used) the selected modeling language named, and (vii) an example of the inner model design is given.

5.2.1 Level 1: Instantiation

The instantiation level enables (i) the determination of the company-specific model. It adjusts the RM based on parameters, (ii) thus fulfilling the *recommending requirement.* (i) These parameters are used to determine which SP functions are needed in the company's use case. Therefore, (iii) the input to this level is the elaborated, company-specific parameters, and the required functions for the SP are the output. The determination of the SP functions (iv) takes place with the help of logical program sequences. Then, the identified SP functions subsequently determine which process steps are performed in Level 2. Domain experts are necessary for the parameterization (v), as they can use their business model knowledge to obtain an appropriate parameterization. Methodologically (vi), an extensive analysis in literature and workshops at the industry partner are conducted to identify the parameters that affect the SP task. A catalog of parameters is derived, and the relevant ones (affecting SP) are filtered and concretized. At the same time, all the functions that SP should fulfill are collected, categorized, and defined. (vii) For example, a company will define the following three parameters: (1) in which frequency data are collected, (2) in which

interval the planning should take place, and (3) over which horizon forecasts are created. The time intervals for creating forecasts designated as the "Iteration function" can then be defined with the help of these three parameters. This function is set to a weekly repetition, with each parameter's value, forecasting the next few weeks if data are collected adequately.

5.2.2 Level 2: Superior process

The superior process (i) defines the fixed process sequences needed to build data-driven sales forecasts. These sequences roughly represent the procedure for creating sales plans out of raw data. The process steps further detail each superior process sequence. Following this, the process steps are either necessary to be implemented or neglected, depending on the company situation. In this way, (ii) the model meets the *reusable* requirement and allows the derivation of specific models. (iii) The catalog of SP functions from Level 1 is used as input to define the necessary process steps for each process sequence. (iv) The identified process steps (for the company) can be further specified in the third level. The workflows in Level 3 are assigned to the process steps in this level. (v) The superior process level serves to inform involved entities in the S&OP how the forecasts are produced, meeting the (ii) *general validity* requirement, as it simplifies the complex task and raises understanding and acceptance of the involved entities. Methodologically (vi), various sources explaining the process steps of SP are considered. These sources will be bundled into a fixed process sequence and the assigned process steps. Correctness of this level is achieved through extensive scientific discussions with experts from IT, SC, and statistical research fields. (vii) The first process sequence, e.g., will be "Data gathering". If the instantiation shows that the available data only allow simple forecasting methods, process steps supposed to identify additional data sources are omitted.

5.2.3 Level 3: Subordinate process

The subordinate processes level (i) is more explicit than the process steps from Level 2. The workflows presented here give further detailed information on each process step. Concrete and systematic actions are defined for creating the forecast of sales (ii), meeting

the *generally valid* and *recommending* requirement. (iii) The identified process steps from Level 2 give the input, and the outputs are detailed workflows that specify concrete steps of actions in BPMN charts. (iv) A transition to the next level is unnecessary as the information classes are permanently assigned to the workflows in the BPMN charts. These workflows (v) primarily serve the responsible person to provide accurate forecasts and help him fulfilling his task. The workflows indicate the activities that can be automated through a suitable IT solution. (vi) The modeling language BPMN seems to satisfy (ii) the *align to standards* requirement, and the BPMN charts enable the definition of physical and computational processes. (vii) The workflow of the process step "data transformation", e.g., will clarify the preparations necessary to extract the sales numbers from the customer's order in the IT landscapes.

5.2.4 Level 4: Information classes

The information classes (i) help identify the company's suitable data to provide sales plans. (ii)The *reusability and general validity* requirements are met using generalized information classes. Data attributes are assigned to general information classes with adequate designations using plain text to circumvent the peculiarities regarding company-specific attribute designations. These classes provide a more common understanding for a set of enterprises. As an example, the identification keys in companies vary greatly, as some are sequential numbers, while others contain a date. It can be ensured that the model is helpful to various companies through bundling data with similar properties in information classes. (iii) The level's input consists of several information classes that reveal the necessary data in the SP. The output is the direct mapping of the information classes into the workflows from Level 3. (v) This level provides the information for the responsible person to produce the sales forecasts and helps IT departments prepare the technical infrastructure. (vi) UML is evident in expression and platform- and language-independent, thereby meeting (ii) the *align with standards* requirement. The *modular and expandable design* is given by the possibility to add or extend information classes. (vii) For instance, a central information class in this level will be the "order information", which contains, e.g., the identification key, the date

of purchase, and the ordered product quantity of the customers to extract the sales figures.

6 Conclusion

This paper presents the framework of a RM to help companies to implement and sustain data-driven SP. Challenges in SP were analyzed, and conclusions for the model were drawn to answer the first research question regarding the challenges for data-driven SP. The second research question focuses on the elements to be incorporated into the model. It is answered by first elaborating a definition of the term SP and second, by presenting the research gap as well as a reasonable modeling methodology. Furthermore, the research outlines a combination of difficulties identified in the practical domain and academic requirements into a model-specific requirements catalog. This catalog was further used to elaborate the objective and framework of the model. Each of the model's levels has been explained, and the methodical approach for development was presented. The model framework was applied exemplarily at the company, and its usefulness was confirmed in expert interviews.

The proper use of data for SC planning will be given greater priority in the future. SP forms a central element, which holds great potential due to new data sources and sophisticated forecasting methods. There is much knowledge in this field that needs to be bundled to make it more accessible to companies. Forecasting should have a more precise and distinct role in S&OP, as the use of data for sales forecasting is not yet fully established.

As a limitation, it should be mentioned that the presented framework has currently been developed only in reference to the case study and could be subject to further adaptations. The catalog of requirements must be further validated. It has to be proven to what extent the model can meet every respective requirement from the catalog. It is further necessary to validate the SP RM in additional companies.

According to the methodology presented here, the inner structure of the RM for data-driven SP needs to be further detailed to strengthen the model's general validity and increase the range of possible applications. The reasons for a relatively low

establishment of data-driven SP should be part of future investigations. A survey that clarifies the establishment of data-driven SP in the industry and the used methods is desirable. Overall, it appears that there are only a few generalizing models in the area of SP.

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Drivers of Customer Satisfaction with Waste-Disposal-Services - A PLS-SEM Approach

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***Purpose**: Prior studies on customer satisfaction research have focused on the private sector. However, few studies have looked at services of general interest.*

***Methodology**: Using a PLS-SEM methodology, we establish and adapt a theoretical model based on the well-known ECSI to the waste disposal service context and use a sample of 2062 responses to assess our results.*

***Findings**: Our results show that disposal performance is most important in explaining customer satisfaction, followed by price-performance-ratio and service hotline performance.*

***Originality**: For this study, we adapted a well-established model and extended it with the construct "waste disposal performance". We conducted expert interviews and tested the extended model in pretests before final data collection. We show that this construct is the most important driver for customer satisfaction in the context of waste disposal services.*

***Research limitations:** The data have been collected using self-reported questionnaires in Germany. Future studies should collect longitudinal data and test the model in other countries.*

***Managerial implications:** The most important implication of our study is that managers of waste disposal services should focus on the logistical aspects behind their services, such as timely disposal of waste to ensure customer satisfaction.*

First received: 24. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Services of general interest are defined as “a comprehensive state task to provide the goods and services deemed necessary for human existence” (Maurer, 2004, p. 6 ff.). In the course of the last few decades, the concept of services of general interest has changed in content. Some services seem to have lost their relevance for the state today, while others are moving back into the state’s focus due to various causes. One cause is the supposed decreasing service quality of private companies evoked in the profit orientation (Seckelmann, 2008, p. 273 ff.). Schmidt demonstrated in 2011 that the telecommunications, post and rail sectors are services of general interest that no longer are the focus of direct state provision (p. 209 ff.), as they have been partially or fully privatized over the past few decades. In addition to the services already mentioned, the household waste disposal service is also part of the provision of general interest.

Two very decisive factors in the political communication of the decision to privatize or nationalize the provision of services are, on the one hand, the increase in efficiency, which is reflected in the market price (Reeves & Barrows, 2000; Dijkgraaf & Gradus, 2003), and, on the other hand, the quality of the provision of services (Opphard et al., 2010). However, Bataille & Steinmetz (2014) concluded that local political interests leave little room “to establish a competitive exception area and entrepreneurial activity for the local authorities. The implementation of communal goals such as securing jobs or local value creation usually means an inefficient use of resources and thus unnecessarily high costs for citizens” (p. 9). In addition, Mühlenkamp (2007) argues that the public sector, as part of the privatization of services of general interest, tries to guarantee allocative efficient prices through the usual regulatory procedures, e.g. through incentive regulation, the efficiency limit or frontier concept. However, these processes contribute to the fact that price-regulated companies with the intention of making a profit are inclined to reduce quality (p. 709 f.).

2 Research Objective

This paper discusses the research question:

What drives customer satisfaction with waste disposal services in Germany?

On the one hand, the quality of disposal in Germany is determined by the Circular Economy Act, which states that the disposal of waste has the highest possible degree of recyclability. Put simply, the higher the quality of disposal, the higher the percentage of recyclable waste in terms of a circular economy. However, this only relates to the recycling of the disposed waste, not to the service provided. Here, the service quality is defined as the "ability of a provider to provide a service based on customer expectations at a certain level of requirements" (Bruhn, 1997, p. 27). The quality of waste disposal is therefore measured from the customer`s point of view and depends on their expectations, i.e. if they are satisfied with the waste disposal quality. Conversely, the degree of customer satisfaction indicates how high the waste disposal quality is.

As early as in the 1980ies, Churchill & Surprenant (1982) took up the "Confirmation /Disconfirmation-Paradigm" from psychology on the development of satisfaction in general and customer satisfaction in particular. A user/customer/consumer compares the perceived performance of a service with his expectations and is satisfied when these are met (Cardozo, 1964; Pfaff, 1972; Olshavsky & Miller, 1972; Anderson, 1973; Olson & Dover, 1976; Oliver, 1977, 1979; Swan & Trawick, 1980). Various models have been developed to measure customer satisfaction, such as the European Customer Satisfaction Index (ECSI, 1999). This study is based on the ECSI and aims to identify the main drivers of satisfaction with waste disposal services in Germany. In the following, we adapt a well-known model to the German waste disposal context and assess it with partial least squares structural equation modeling (PLS-SEM).

3 Methodology

We apply PLS-SEM, a variance-based statistical analysis method, that allows for analyzing the strength of the explanatory constructs' influence on the target construct in a path model (Hair, Hult, Ringle, & Sarstedt, 2021), in order to test the relationships in our model. Since one of this research method's main objectives is to establish, explain and predict a target construct, the constructs in the path model are arranged in causal-predictive relationships (Chin et al., 2020) and prior studies on customer satisfaction (e.g. Damberg, 2021). This type of research methodology supports the extension of existing theories and the development of new ones (Richter, Sinkovics, Ringle, & Schlägel, 2016). Researchers are advised to apply PLS-SEM when a theoretical framework is being tested from a prediction perspective, and the structural model is rather complex (Hair, Risher, Sarstedt, & Ringle, 2019). The PLS-SEM method has been successfully applied and become popular in social sciences disciplines, such as human resource management (Ringle, Sarstedt, Mitchell, & Gudergan, 2020) and information systems research (Chin et al., 2020). We used the SmartPLS 3 software (Ringle, Wende, & Becker, 2015) to assess our structural path model.

We base our theoretical model on expert interviews conducted in 2020/1 (Mischel, 2022) to identify which items influence the customer satisfaction with waste disposal services. We measured the satisfaction of German households with waste disposal services as part of the field of public services in an online survey in six Northern German Districts. Our total data set comprised 2860 responses. After missing value treatment, we are left with 2062 complete responses for further analysis. Our online survey included 28 items (Tab. 1), which were measured on a Likert scale from 1 to 5 (do not agree to fully agree). The survey was conducted in German and items were translated into English for the purpose of this paper.

Table 1: Items of Survey Constructs 1 - 3

Construct	Image	PPR	Expectations
Item 1	I know the company	The waste disposal quality is reasonable in relation to the fees	My expectations for the waste disposal are always met
Item 2	The company is reliable	The service hotline quality is reasonable in relation to the fees	My expectations for the service hotline are always met
Item 3	The company is customer oriented	The overall quality is reasonable in relation to the fees	My overall expectations are always met
Item 4	The company creates value for the society		
Item 5	The company is innovative		
Item 6	The company is responsible for the environment		
Item 7	The external appearance is appealing		

Table 2: Items of Survey Constructs 4 - 6

Construct	Disposal Performance	Service Performance	Satisfaction
Item 1	The waste is always picked up on the right day	The service hotline is always friendly	Overall I am satisfied with the waste disposal
Item 2	The several waste is always picked up to nearly the same time	The service hotline always reacts to my complaints in a solution-oriented manner	Overall I am satisfied with the service hotline
Item 3	The company that collects my waste always reacts flexibly	The service hotline can always answer my questions in an understandable way	The waste disposal company corresponds to my ideal overall
Item 4	The company that collects my waste works cleanly	The waste fee billing is easy to understand	Overall I am satisfied with the waste disposal and the service
Item 5	The company that collects my waste always deals with various special cases in the same way		
Item 6	The employees who pick up my waste are always friendly		
Item 7	The employees who pick up my waste can always answer my questions in an understandable way		

For our model development, we used the original ECSI model (ECSI, 1999; Kristensen, Martensen & Gronholdt, 2000) and adapted the constructs to fit the waste disposal context, especially by adapting the construct “Disposal Performance” with the new items “IMA_2”, “IMA_3” and “PER_2” to “PER_7” (Fig. 1). PLS-SEM is a suitable approach for the assessment of structural path models (Hair et al. 2017) and is well established in marketing and management research (Hair et al., 2012; Ringle et al., 2012).

The construct “Price Performance Ratio” is built of three items which rated the disposal (PLV_1), the service hotline (PLV_2) and the overall performance (PLV_3). The construct “Disposal Performance” is built of eight items which rated the several aspects of picking up the garbage directly at the households. And the construct “Service-Hotline Performance” is built of four items including complaints management (SER_2), customer questions (SER_3), friendliness (SER_1) and understandable billing (SER_4). The goal of this study is to identify the constructs which mainly influence the satisfaction with public waste disposal services.

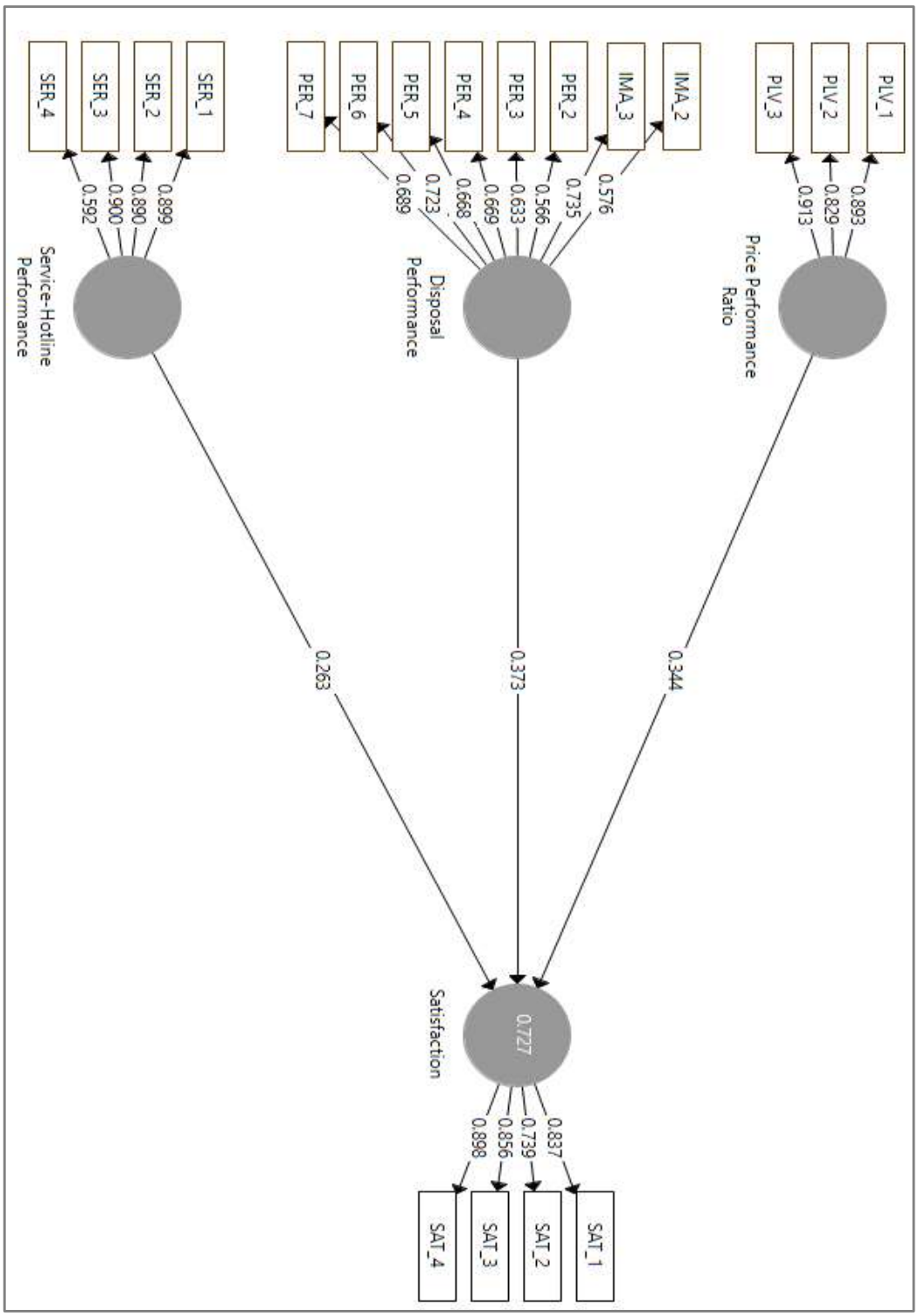


Figure 1: Theoretical Model

4 Data Description

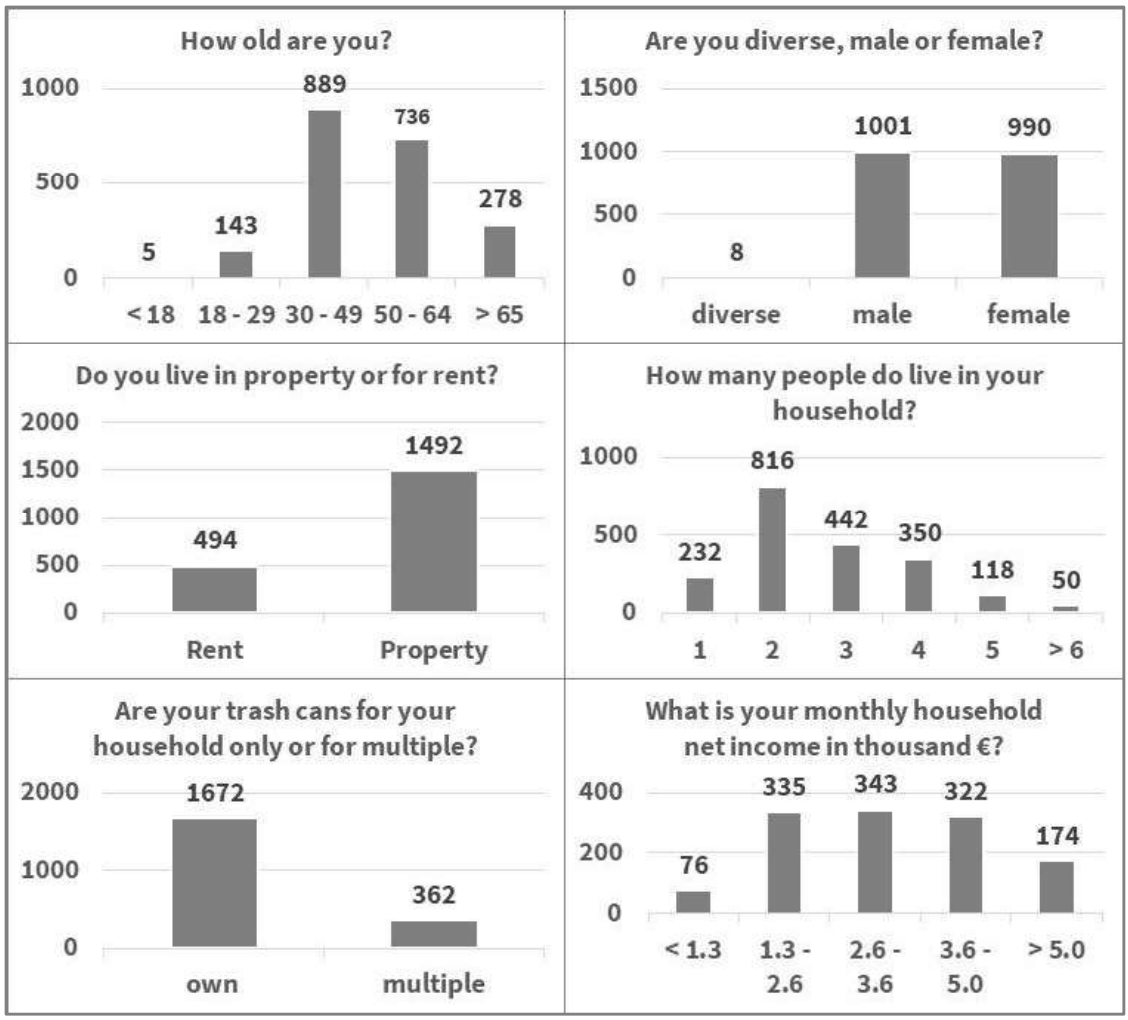


Figure 2: Demographic Data

Our demographic data show that the majority (79.2 %) of the respondents in our sample are between the age of 30 and 65 years. Compared with the German population with only 54 % of the age of 30 to 65 years (Destatis, 2021a, online), we cannot state that our sample reflects the German overall demography in this regard. One reason might be that we only conducted a single online survey.

51 % of the respondents in our sample are male, while 49 % are female. Compared with the German population, where 49.3 % male and 50.7 % female (Destatis, 2021b, online), there are only slight differences. In that point the survey reflects the German overall demography.

In Germany 55 % of the people live with 2 to 4 people in one household, while 42.3 % are single households (Destatis, 2021c, online). 75 % of the respondents in our sample live in their own property, while 25 % live for rent. In Germany 46.5 % of the households live in their own property (Destatis, 2021d, online).

In our sample 82 % of respondents have their own garbage cans, while 18 % use collection bins for several households. That nearly covers the proportion of own property and for rent. The net income is almost equal distributed (Fig. 2).

However, it is clear that people only participated in this survey when they had an issue with our topic and felt comfortable with using a digital device. That explains the age distribution and the own property rate of the respondents. One conclusion of the survey for Germany is that the waste disposal service quality is much more important for people when they live in their own property and use their own garbage cans.

5 Analysis

The assessment of the measurement and structural model follows Hair et al. (2021). We use the bootstrapping function with 10,000 samples and assess convergent, composite and discriminant validity. The item loadings of all our reflective constructs are satisfactory, i.e. above the recommended threshold of 0.7.

Afterwards, we assess the Cronbach`s Alpha (α), the composite reliability (ρ) and the average variance extracted (AVE). All values are satisfactory and above the recommended thresholds.

From our results (Table 3), we can see that all our reflective constructs meet the thresholds for Cronbach's alpha, composite reliability and the average variance extracted (AVE). The ACE for the construct "Waste Disposal Performance" is slightly below the threshold, but we kept the construct, as all other criteria were met.

Furthermore, we checked the variance inflation factor (VIF) of each item. With all values less than 5 and many of them less than 3, all values are satisfactory.

Next we check the Heterotrait-Monotrait Ratio (HTMT). Values higher than 0.9 indicate a lack of discriminant validity (Henseler et al., 2015; Hair et al. 2021). All our constructs have a HTMT less than 0.9 and we therefore do not assume any issues with discriminant validity.

Table 3: Construct Reliability

Latent Variable	**Item**	**Internal Consistency Reliability**	
		Composite Reliability	**Cronbach`s Alpha**
		> 0.7	**0.6 - 0.9**
Price Performance Ratio	PPR_1	0.911	0.852
	PPR_2		
	PPR_3		
Waste Disposal Performance	IMA_2	0.860	0.814
	IMA_3		
	PER_2		
	PER_3		
	PER_4		
	PER_5		
	PER_6		
	PER_7		

Latent Variable	Item	Internal Consistency Reliability	
Service Hotline Performance	SER_1 SER_2 SER_3 SER_4	0.897	0.840
Satisfaction	SAT_1 SAT_2 SAT_3 SAT_4	0.901	0.853

Table 4: Construct Validity

Latent Variable	Item	Convergence Validity			Discriminant Validity
		OLoadings > 0.7	**VIF < 5 ; < 3**	**AVE > 0.5**	**HTMT Value = 1**
Price Performance Ratio	PPR_1	0.893	2.777	0.773	NO
	PPR_2	0.829	1.644		
	PPR_3	0.913	3.019		
	IMA_2	0.576	1.339	0.436	NO
	IMA_3	0.735	1.581		

Latent Variable	Item	Convergence Validity		Discriminant Validity	
Waste Disposal Performance	PER_2	0.566	1.254		
	PER_3	0.633	1.529		
	PER_4	0.669	1.601		
	PER_5	0.668	1.533		
	PER_6	0.723	1.680		
	PER_7	0.689	1.696		
Service Hotline Performance	SER_1	0.899	2.956	0.690	NO
	SER_2	0.890	2.884		
	SER_3	0.900	3.071		
	SER_4	0.592	1.198		
Satisfaction	SAT_1	0.837	2.651	0.697	NO
	SAT_2	0.739	1.405		
	SAT_3	0.856	2.244		
	SAT_4	0.898	3.433		

Next, we evaluate the structural model by looking at the significance and size of the path coefficients. Our model explains 72.7 % of the variance in customer satisfaction (Fig. 1) and the construct “Waste Disposal Performance” has the highest importance in explaining the satisfaction with total effects of 0.373 and performance value of 77.040 (Fig. 3).

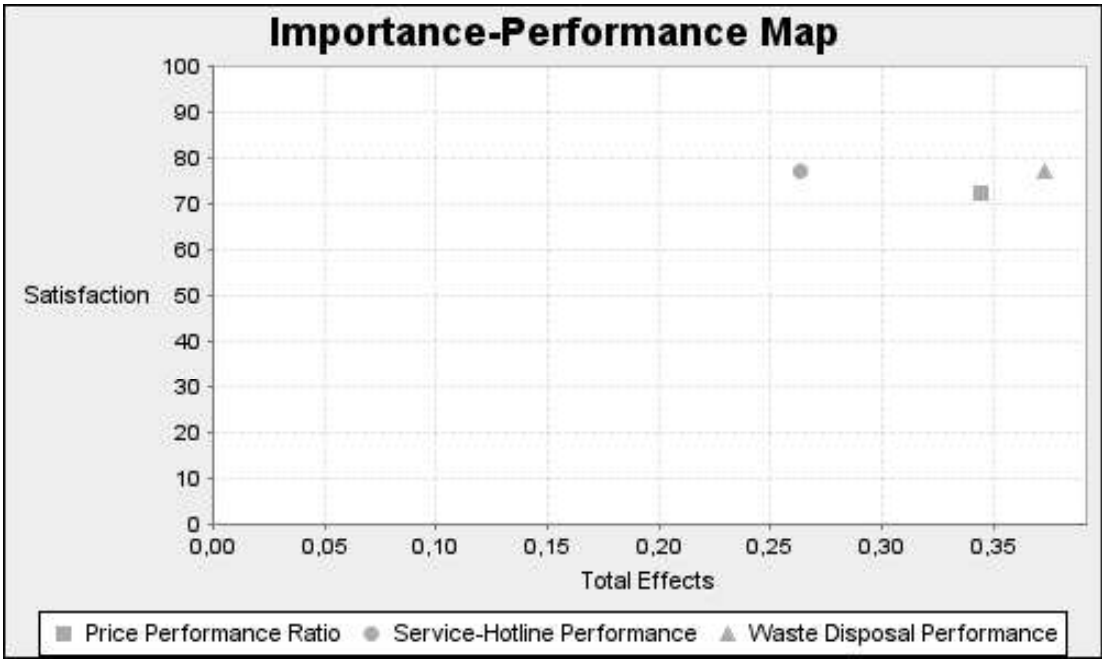


Figure 3: Importance - Performance Analysis

6 Discussion and Conclusion

Our results show that the newly developed construct – that had previously been developed in a pre-study with the help of expert interviews – is the most important driver in our model of waste disposal service satisfaction. This is an interesting result, as research within the public sector is generally scarce to the authors' best knowledge. This results further shows the relevance of applying and adapting well-known models from the marketing literature to researching the services of general interest.

Altogether, with our model, we show that the construct "Waste Disposal Performance" is the most important driver of satisfaction with waste disposal services in our sample. This means that especially the perceived reliability of the waste disposal service is the most important element. Reliability is here meant as the security that the waste will always be picked up at the announced day and that the company will work clean. That is shown in the most important item IMA_2 with a total effect of 0.102 and an item performance of

95.005. The most important item can be explained by the fact that companies can only reach the expectations of the households with great logistic planning.

Our results show that we can confirm our expectations gained from the expert interviews. Only in the case that garbage will not be picked up as mentioned, consumers/ households are likely to become unsatisfied. On a similar note, the garbage will not be picked up, when the waste disposal logistic is faulty. The fact that the most important driver for satisfaction is the reliability of the company, further confirms this assumption.

7 Implications for Research and Policy

With our study, we found new proven knowledge for political and scientific discussions of privatization or municipalisation of services of general interest. The results show, that it is not only the price that should play a role in the decision making process in public announcements. Our outcomes can help public institutions in defining the conditions of announcements more precisely. Last but not least, management decisions in the waste disposal companies can be made under better information. Management can figure out now what process changes and structural investments will have the highest impact on the customer´s satisfaction in combination with changing costs instead of only being concerned about the costs and hoping for any impact. Future research is needed in order to further validate the results of this study. It would be interesting to see the satisfaction levels of households in various European countries, for example in order to substantiate the findings and allow for the development of European-wide policies that also address recyclable waste policies in terms of the circular economy.

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Application of Social Media Data in Supply Chain Management: a Systematic Review

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Purpose: *Recently, big data has received considerable industrial and academic attention. Social media(SM) are becoming reliable big data sources that include various information such as customer's opinions, product reviews and trends. However, the supply chain management (SCM) field has been lagging behind other industries in adopting SM. Hence, this paper aims to explore the value of SM and its application in SCM with recommendation for future work.*

Methodology: *This paper reviews the existing literature systematically to highlight major research works and trends by using bibliometric analysis.*

Findings: *Our review results show that the research on SM and SCM has attracted significant attention over the decade. SM data has been used together with different analytical tools (e.g. text mining, sentiment analysis) to manage different supply chain activities (e.g. demand forecasting, production). However, the potential of SM has not been thoroughly investigated due to the inherent nature of SM data. Therefore, this study field is in its infancy. We suggest some directions can be considered for future research, e.g. sentiment indicators for SC related posts.*

Originality: *This paper is the first attempt to systematically analyse the interaction of SM data and SCM and to highlight the new approaches of adopting SM data for improving SCM.*

First received: 25. Apr 2021 *Revised: 18. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Traditional big data sources include machine data and transactional data, and so on. More recent calls to use big data in the SCM field (Aryal et al., 2018; Tsao, 2017; Wang et al., 2016) Web 2.0 applications (such as Facebook and Twitter) have grown explosively in recent years, contributing largely to the big data source (Chae, 2015). SM data is one of the most cost-effective and rapid methods of capturing the perspective of a larger audience on a particular subject (Singh et al., 2018). Although some academic articles have demonstrated the value of incorporating SM into SCM (e.g. Gruner et al., 2013; O'Leary, 2011), the practice of SM data in supply chain operations still needs further investigation. Indeed, few researchers have been able to draw on any systematic research into social media-based SCM (Huang et al., 2020). Therefore, this study provided a significant opportunity to advance our understanding of how SM data and supply chain integration work together.

To address this gap, the study aims to review the state-of-the-art of existing SM data and SCM literature from an academic view. To learn the current application of SM data and SCM, the prior researches are summarised and the knowledge gaps are identified in this study. Also, we attempt to suggest directions for future research and practice. This paper is informed by the following three research questions (RQs) to achieve the above aims:

- RQ1: What are the developments of SM data in SCM?
- RQ2: What type of supply chain activities might benefit from the SM data?
- RQ3: What are the potential research direction in this study area?

The remaining paper is structured as follows. Section 2 introduces the methodology used for searching and delimitation of the literature. Section 3 presents review results, including current research area development and classification of research topics based on different SCM activities. Section 4 discusses and suggests potential research directions. Finally, Section 5 describes the limitations and conclusions of this study.

2 Methodology

To address the research questions, the systematic literature review (SLR) / bibliometric analysis approach is adopted to explore the application of SM in SCM. SLR was first introduced in the medical research field, which is a method for conducting a structured, transparent, and reproducible review that adheres to a predefined and documented procedure (Devi and Ganguly, 2021; Durach et al., 2017). However, SLR is incapable of identifying the dynamics of knowledge evolution automatically. Therefore, this study will also adopt a bibliometric analysis to improve the review accuracy. The bibliometric method is used to bolster the SLR contribution through an objective assessment of academic papers, increased rigour, and the elimination of researcher bias (Phulwani et al., 2020). It has been widely used in the supply chain context (Aryal et al., 2018; Barbosa et al., 2018; Ben-Daya et al., 2019; Nguyen et al., 2018). This research method extends the scope of bibliometric study to levels higher than those found in traditional literature studies by screening and reviewing publications, thereby expanding our understanding of research areas and existing patterns (de Oliveira et al., 2018).

A set of inclusion and exclusion criteria should be predefined to help identify and prioritise relevant and significant research papers. According to Colicchia and Strozzi (2012), the following criteria were used:

- Select the papers published in English only.
- Limit the paper publishing period in the last decade.
- Ensure explicit relevance by requiring at least one keyword in the title or abstract of selected articles.
- Remove articles that are substantively irrelevant by excluding those that focus on extremely narrow aspects or contexts.
- Ensure the substantive and empirical relevance of the remaining abstracts by reading them.
- Ascertain that the remaining articles retain their substantive and empirical relevance by thoroughly reading them.

A combination of keywords including ‘Social media’, ‘Big data’, ‘Supply chain management’ were used to identify literature published in the past ten years (2011-2021)

from several well-known databases (e.g. Google Scholar, Web of Science, Elsevier, Scopus, Springer).

695 papers were identified from our initial search. We refined our search and carefully examined every single paper to ensure that only highly relevant research topics are included in our study. We are primarily interested in the user-generated data in SM platforms (e.g. comment and post) rather than the communication capabilities of SM (e.g. customer service). After removing duplicated papers, 172 papers are selected. Then we conducted a bibliometric analysis using Bibliometrix, a quantitative analysis software product, which contains a collection of tools for conducting quantitative research in bibliometrics and scientometrics (Aria and Cuccurullo, 2017; Moral-Muñoz et al., 2020). Figure 1 shows the process of our systematic review.

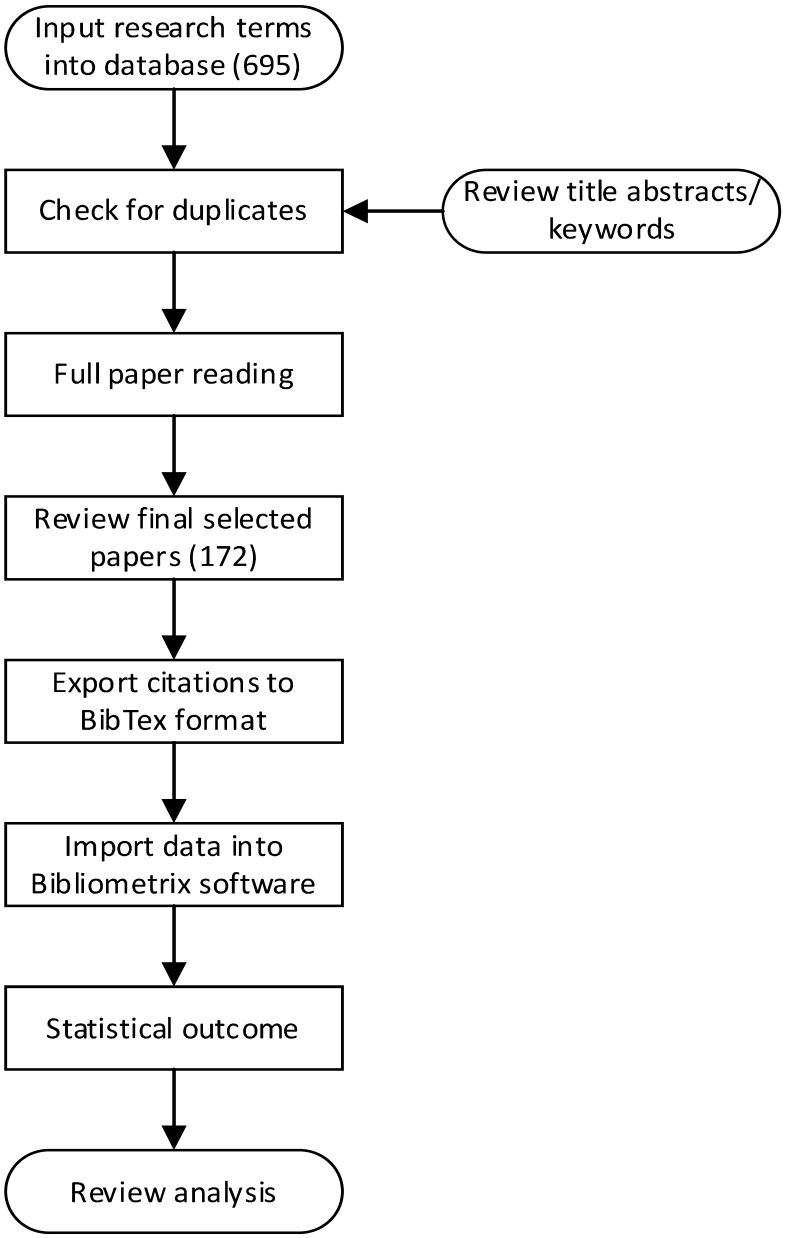


Figure 1: Process of systematic review

3 Result

Based on 172 selected papers, section 3 summarises the overall landscape of the study field by highlighting period, geospatial trends, and so on. Following that, we connect the selected samples to various supply chain activities and conclude with a detailed classification of social media functions.

3.1 Overview

To answer RQ1, this section analyses sets of statistical data from selected literature to ascertain the development and trend of our study field.

3.1.1 Number of publications by year

As illustrated in Figure 2, the literature on SM data and SCM is in its infancy with a 20.85% annual growth rate. Regarding SM in SCM, the first and the only one article appeared in 2011. Followed by no paper in 2012. Six to eight articles per year were published between 2013-2016. When it comes to 2017 to 2019, the number of published articles has increased to more than twenty papers every year. From 2020-2021 (till March), 65 papers have already been published. It obviously shows that the relevant research has increased significantly since 2017 because of the emergence of industry 4.0. This figure demonstrates that the use of SM continues to grow and has been widely considered and accepted by organisations and industries for improving SCM.

In the earlier year, most of the literature reported the applications of SM to retain information specific to SCM (Markova and Petkovska-Mirčevska, 2013). The current literature is increasingly focusing on the use of SM analytics to support decision-making, such as Singh et al. (2018), Tao et al. (2020), Tseng et al. (2019a).

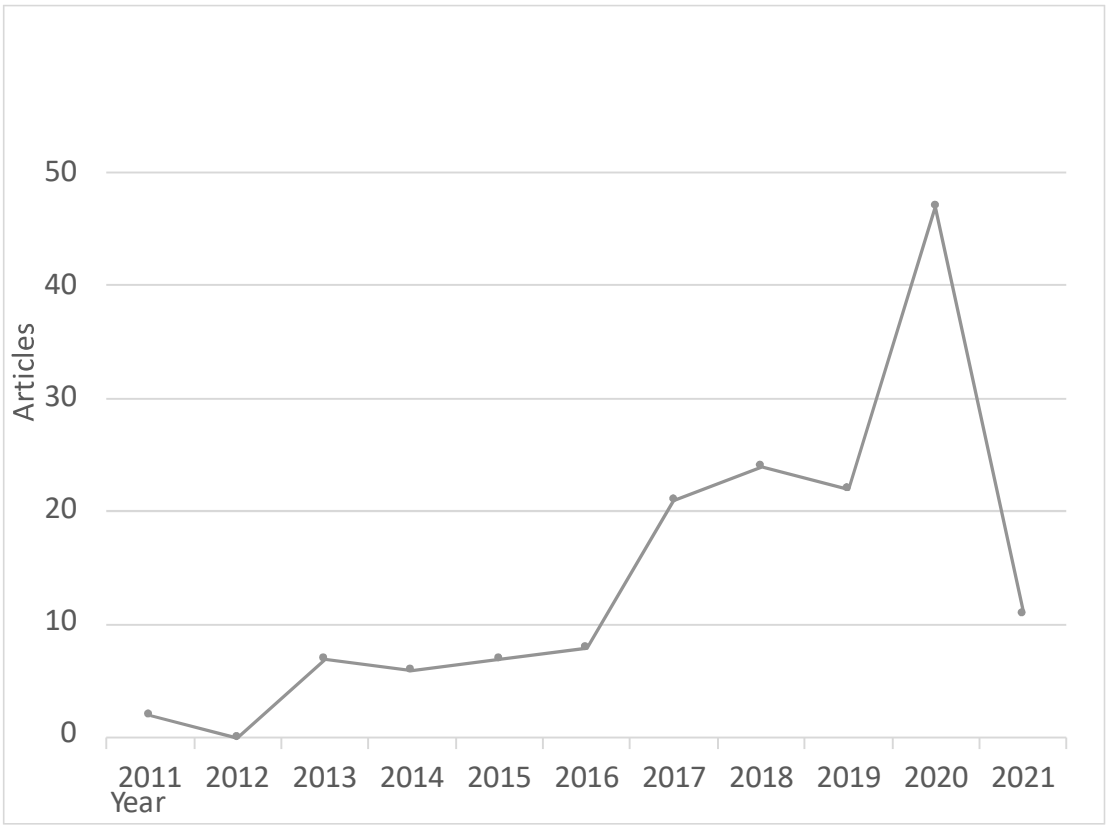


Figure 2: Number of papers published each year

3.1.2 Source dynamics

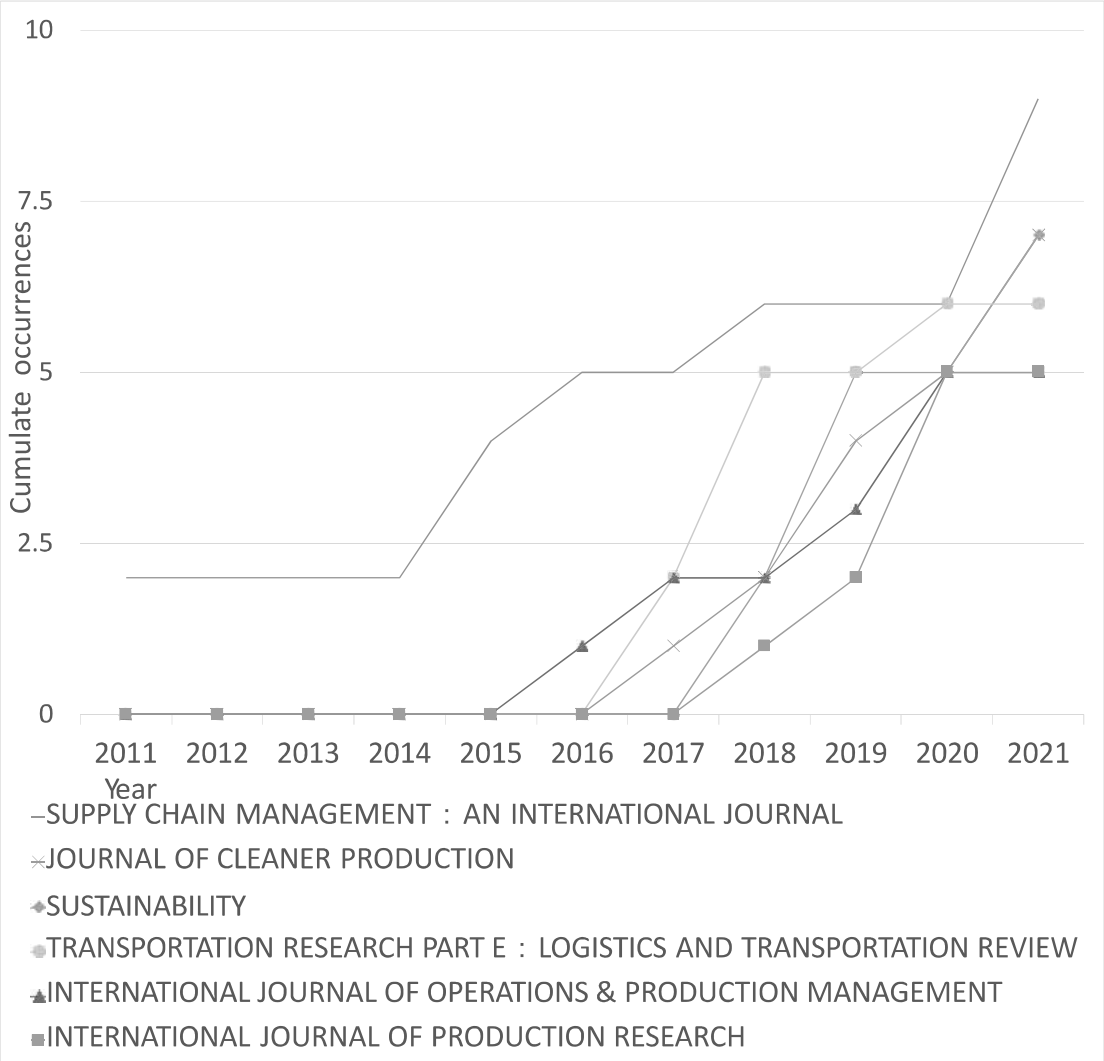


Figure 3: Source growth dynamics graphic

Figure 3 shows the annual growth of the most relevant papers published from the top six journals, such as Supply Chain Management: An International Journal, Transportation Research Part E: Logistics and Transportation Review, and International Journal of Operations Production Management. In addition, Table 1 shows the number of the paper published in different journals. They show an increasing trend as depicted by Figure . This topic is getting increasing attention in the academic field.

Table 1: Number of papers published in each journal

Source titles	No. of Articles	%
Supply Chain Management： An International Journal	9	5
Journal of Cleaner Production	7	4
Sustainability	7	4
Transportation Research Part E Logistics and Transportation Review	6	3
International Journal of Operations Production Management	5	3
International Journal of Production Research	5	3
Annals of Operations Research	4	2
International Journal of Information Management	4	2
International Journal of Production Economics	4	2
Production Planning Control	4	2
Operations and Supply Chain Management an International Journal	3	2
Production and Operations Management	3	2
Advances in Business Strategy and Competitive Advantage ABSCA Book Series	2	1
British Food Journal	2	1
Business Process Management Journal	2	1

Application of Social Media Data in Supply Chain Management

Source titles	No. of Articles	%
Computers Industrial Engineering	2	1
Decision Sciences	2	1
European Journal of Operational Research	2	1
IEEE Access	2	1
Industrial Marketing Management	2	1
Information Management	2	1
International Food and Agribusiness Management Review	2	1
International Journal of Physical Distribution Logistics Management	2	1
Journal of Big Data	2	1
Journal of Business Industrial Marketing	2	1
Journal of Fashion Marketing and Management	2	1
Journal of Global Information Management	2	1
Journal of Humanitarian Logistics and Supply Chain Management	2	1
New Medit	2	1
Journals with Single Paper	87	50
Total	172	100

3.1.3 Most relevant words

Figure 4 and Figure 5 show that the most frequently used terms in both the author's keywords and the abstract are SM, supply chain, big data, which conform to our research theme. It is important to note that sentiment analysis, Twitter, sustainability and knowledge sharing, are frequently mentioned.



Figure 4: Word cloud (Abstract)



Figure 5: Word cloud (Authors' keyword)

3.1.4 Papers published by document types

As Figure 6 shows, most of the published papers are research articles, while only 19 of them are review papers. This suggests a lack of SLR to comprehensively explore the application of SM analytics in SCM.

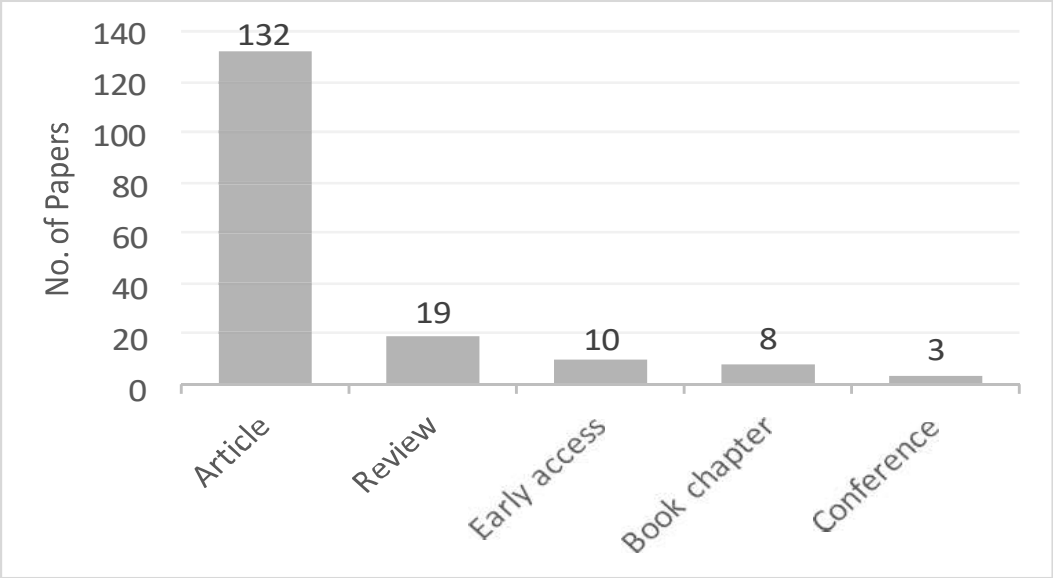


Figure 6: Papers published by document types

3.1.5 Paper Published by Country or Region

This section presents the number of studies in different countries or regions based on the corresponding author's country or region, including single country publications (intra country collaboration) and multiple country publications (inter-country collaboration). This figure aims to highlight countries or regions that have made higher contributions in this field. The United States and the United Kingdom have the most articles published, accounting for 19% and 18% of total publications respectively, followed by China, which contributes to 15% of them. According to Devi and Ganguly (2021), the United States and the United Kingdom are Industry 4.0 pioneers and have a stronger incentive to promote the application of user-generated data. As a result, researchers and practitioners have more opportunities and a more conducive environment for studying the relationship between SM data and the SCM. Other countries' low contribution may be due to a lack of resources and difficulties in acquiring SM data (Devi and Ganguly, 2021).

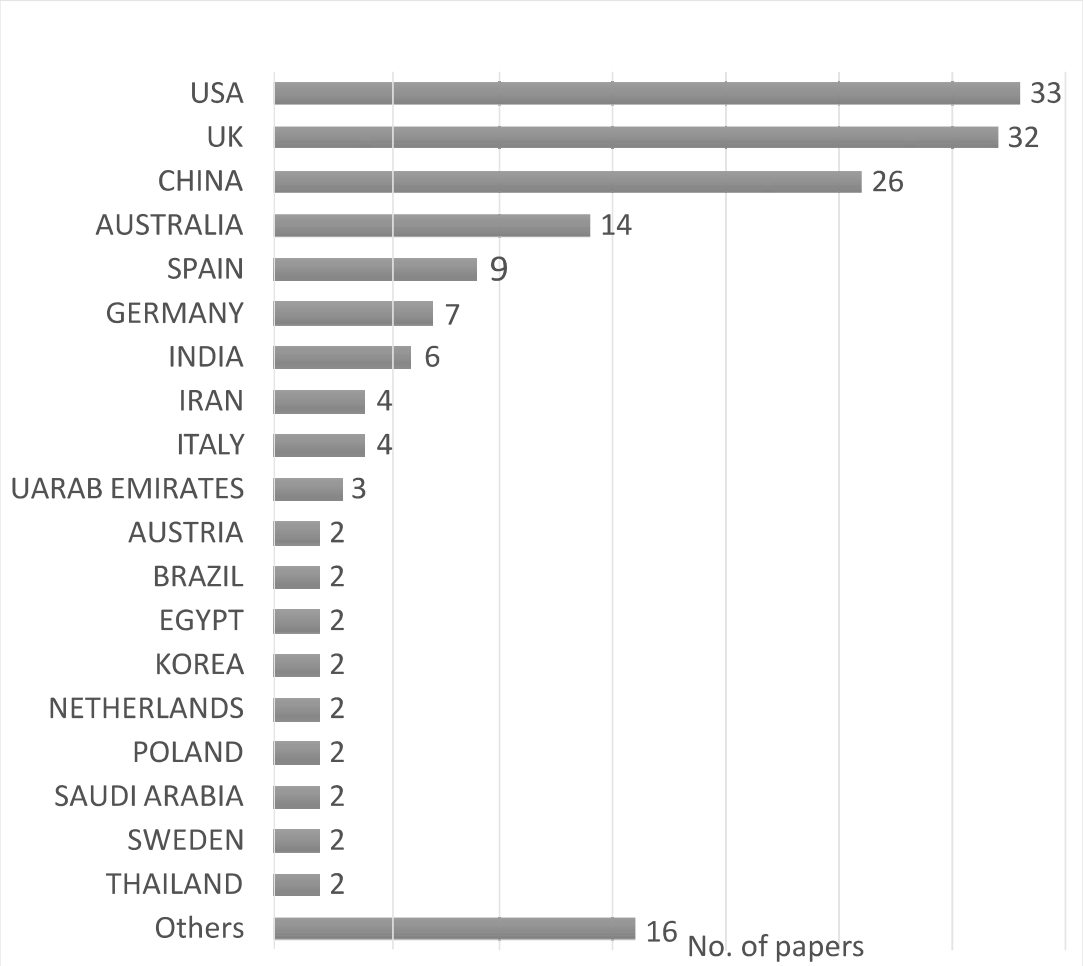


Figure7: Papers published by country or region

3.1.6 Trend topics by author's keywords

From Figure 8, it demonstrates a clear growth in the amount of topics from 2017. In particular, 'Big data/Big data analytics', 'Twitter', and 'Management' are among the top four author's keywords, and this indicates that:

- Big data is a connection between SM and SCM;
- Big data analytics could be applied to examine SM data;
- Twitter is a popular SM platform to provide data.

It is also worth mentioning that from 2020 the following keywords appear more and more frequently, including Twitter data, Facebook, industry 4.0, B2B, social media analytics, risk management and operation management. These high-frequency keywords may indicate future hot topics and development trends.

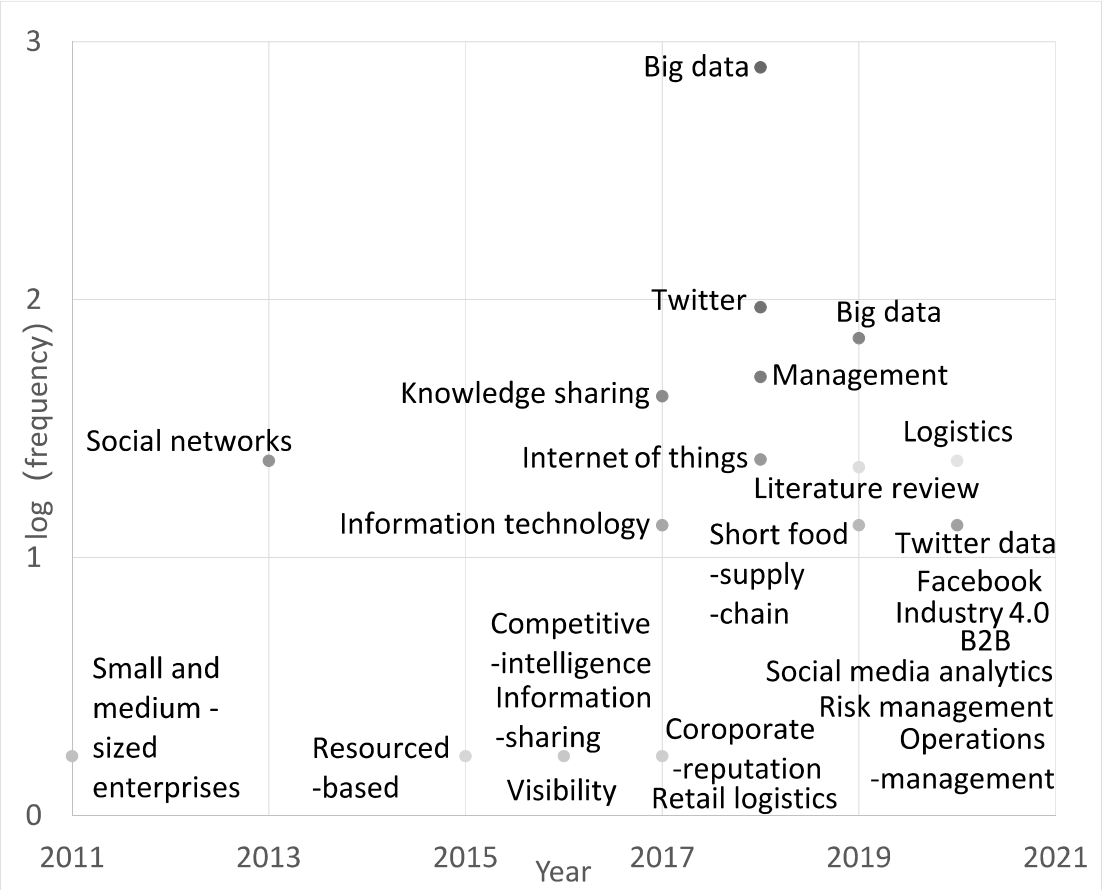


Figure 8: Trend topics by author's keywords

3.2 SCM activities

To address RQ2, this section summarises the supply chain activities related to the application of SM data based on 172 selected articles. Therefore, the primary supply chain activities that benefit from SM data can be identified.

3.2.1 Demand forecasting

Forecasting is a necessary component of planning and executing supply chain activities (Grant, 2017). An accurate forecast can significantly impact supply chain performance such as inventory cost and operational profitability (Cui et al., 2018; Devi and Ganguly, 2021; Huang et al., 2020). However, the complexity of forecast depends on many factors, such as product categories expansion, supply chain globalisation, shorter product life cycles, and increasing market competition (Boone et al., 2018).

To achieve accurate demand forecasting, a better understanding of customer need is required (Chong et al., 2016; Huang et al., 2020). In other words, the access to customer information plays an important role (Irani et al., 2017). Hence, some researchers proposed that SM information can be used as a new indicator to eliminate information asymmetry, thereby providing accuracy in demand forecasting and other supply chain activities such as inventory management. However, the internet/user-generated data is rarely used for prediction, perhaps due to the subjective nature of SM data (Cui et al., 2018; O'Leary, 2011; Risal et al., 2020).

More recently, the advancement in SM has enabled businesses to better understand customer behaviour through analysing data captured from various SM platforms. Traditionally, such analysis was done by conducting extensive market research (Boone et al., 2018). In fact, the rise of SM has significantly enhanced both the effectiveness and efficiency of demand prediction, thus helps to improve sales (Cui et al., 2018). As one of the big data sources, SM not only allows companies to capture the latest market trends in real-time but also helps them shape trends to influence customer behaviour (Boone et al., 2018; Huang et al., 2020).

SM platform allows user to freely express their attitude, opinions, thoughts, sentiments and share experiences (e.g. Twitter and Facebook) (Boone et al., 2018; Mishra and Singh, 2018). The size of SM data is enormous and scattered, but most data are unstructured data nature, such as texts, posts, pictures and videos (Mishra and Singh, 2018). Many researchers have attempt to uncover and analyse such information by using sentiment analysis, e.g. Singh et al. (2018), statistical analysis, e.g. Akundi et al. (2018), and machine learning algorithm, e.g. Chae (2015), He et al. (2013). For example, Cui et al. (2018) have

done an empirical study for forecast sales. They used the method based on natural language processing (NLP) techniques and introduced seven statistical models, such as simple linear regression, support vector and random forests.

3.2.2 Inventory management

The operations and SCM literature has been concerned with the issue of inventory management. Due to the immediacy and richness characteristic of SM data, it can provide timely shared information for the entire supply chain to help optimise inventory management (Huang et al., 2020). Inventory management and demand forecasting are closely related.

With the aid of big data techniques, businesses can collect data to help them coordinate demand and inventory volume (Irani et al., 2017). The information contributes to reducing the bullwhip effect and rationing pressure. For example, Choi (2016) explored that SM comments have an effect on a fashion retailer's confidence and belief in future product demand, which in turn affects the retailer's level of bounded rationality. The study result shows that positive comments on SM will give retailers more confidence to decide regarding inventory ordering. Therefore, SM has the potential to reduce the harm caused by the uncertainty of demand, thereby improving the supply chain effect.

3.2.3 Product development and production

Businesses can achieve higher customer satisfaction by developing and producing products that meet customer needs (Cheng and Krumwiede, 2018). SM data can suggest companies make better decisions about product development and production (Chong et al., 2017).

Huang et al. (2020) argued that by applying machine learning algorithms and data mining techniques to SM data, it is possible to automatically extract insights about customer preferences and requirements from SM posts, online review comments, and online community dialogues. To achieve an accurate understanding of SM data, many researchers suggested sentiment analysis, which determines the viewpoint and tone underlying a corpus of words to comprehend an individual's online attitude (Akundi et

al., 2018; Bhattacharjya et al., 2016; Mishra and Singh, 2018). Giannakis et al. (2020) examined how information gleaned from SM can aid in the decision-making process associated with new product development. In the study, the customer sentiments data is gathered through Twitter. The result shows that consumer sentiment can help identify the disadvantages of a new product or service.

In addition, big data analysis can also be used to identify more opportunities for manufacturing process improvement, thereby assisting process adjustment and product redesign (Giannakis et al., 2020; Huang et al., 2020).

3.2.4 Supply chain risk management

One major barrier to business is the risk of uncertainty. Supply chain risks are identified into various categories, such as risk source, risk consequence, risk probability or frequency, and risk detectability (Fu et al., 2014). There are four practices in supply chain risk management to cope with the risks and disruption, including risk identification, risk assessment, risk mitigation, and risk monitoring (Colicchia and Strozzi, 2012). Fu et al. (2014) proposed SM applications in supply chain risk management, including market uncertainty risk, social risk and SM risk, natural disaster risk, public health risk, labour risk, and network-related risk. The immediacy of SM data can help obtain information promptly to detect risks and disruptions (Wu et al., 2017).

Due to the outbreak of COVID-19 in 2019, many companies face the problem of supply chain disruption. Barman et al. (2021) studied the impact of COVID-19 on the food supply chain, and they found that SM platforms (such as Twitter, YouTube, Facebook) also serve as a conduit for outbreak prevention, crisis response, and disaster management personnel to manage and access basic data gathered by relevant organisations easily. During a disease outbreak, SM helps disseminate information from reliable sources and can be served as a source of opinions and experience (Fu et al., 2014). Therefore, SM is an essential tool for companies to make decisions and strategies during the emergency period. However, due to the unstructured nature of big data, it is also challenging to capture the accuracy of information (Akter and Wamba, 2019).

3.2.5 Other activities

Other uses of SM data in supply chain operations follow a similar pattern by using big data analytics, such as content analysis, sentiment analysis, text mining. As a result, we will not discuss each activity in detail in this section but will instead provide some supplements as follows:

- In the delivery and logistics aspect, transportation-related data can be gathered from SM in order to suggest vehicle routing and tracking updates (O'Leary, 2011).
- In the marketing aspect, companies can detect trend direction and know consumer preference by analysing customer SM posts and online comments (Mishra et al., 2017).
- Information and knowledge sharing on SM enable to improve the visibility and efficiency of the supply chain (Cui et al., 2018; Devi and Ganguly, 2021; Grant, 2016; Grant, 2017; Grant and Preston, 2019). For example, O'Leary (2011) proposed that creating an internal network can help employees or partners share information or knowledge in a timely manner.
- SM not only enables supply chain partners to share information about reverse logistics effectively but also enables companies to make timely decisions about product return predicting (Huang et al., 2020).
- Also, SM data allows companies to evaluate the supplier or partner's performance as a sourcing evaluation and selection (O'Leary, 2011).
- In human resources management, SM data analytic allow companies to find out the match candidates (Fisher et al., 2014).
- SM data can support companies to make the decision about sustainability development (Tseng et al., 2019b) For example, Tseng et al. (2019a) found that supply chain sustainability capabilities can be enhanced by integrating qualitative data and quantitative data in SM platforms.

4 Future research directions

To answer RQ3, this section discusses and suggests future directions. Our analysis results suggest that the research about SM data in SCM is still limited but growing rapidly. We believe this topic has great potential. Based on systematic and critical analysis of the topic, we propose the following future directions to researchers in SM/SCM :

- Developed countries publish more papers than developing countries. We propose that future research examine differences in consumers' SM usage habits or cultures across these countries and regions to determine whether these differences significantly affect SM effectiveness.
- Sentiment analysis is a critical technique for analysing SM data. Many pieces of literature discussed sentiment analysis, but few of them mentioned how to measure sentiment in the context of the supply chain. We suggest the future study consider/develop new sentiment indicators for supply chain actives related posts.
- Although SM data will bring certain benefits to SCM, its negative consequences and mitigation strategies are rarely discussed in detail. We suggest that future research examine the challenges of using SM data in SCM and develop potential solutions.
- The framework for SM analytics related to SCM lacks discussion in selected literature. Therefore, the relevant framework for specific supply chain activities must be reviewed and it may suggest the need of a new framework.

5 Conclusion and limitation

This study conducted a systematic review of the current literature on SM, big data, and SCM. The purpose of this study is to uncover the growth trend of this study field and to investigate the application of SM data in the context of SCM, as well as to describe its benefits. The findings indicate that, although the topic is still in its infancy, it has the potential to significantly improve the efficiency of companies' SCM, for example, it can help improve the accuracy of the demand forecasting and offer suggestions to product design. Industry 4.0 lays the groundwork for SM data analytics and SCM, and it can make companies improve their competitive edges. Although the study added some new insights to the existing literature, this study still has many limitations. We used a limited number of search terms, and future research may consider to include additional related terms to increase the number of results. Another limitation is that selected papers in this literature review are mainly from academic journals. Additional materials (e.g. industrial reports) may be included in the future to bolster the review's finding.

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IV.
Innovation and Technology Management

Exoskeletons: Productivity and Ergonomics in Logistics – A Systematic Review

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Purpose: *Exoskeletons are robotic wearables that have the potential to positively support employees during physical working operations. However, the technology is rather young, and long-term studies that could positively influence exoskeletons with respect to health, productivity, and ROI (and thereby support investment in it) are lacking. Accordingly, logistics companies are cautious about investing in exoskeletons. This paper identifies the research gaps that should be addressed in further research to change this situation.*

Methodology: *Based on an extensive literature review following the systematic approach of vom Brocke et al. (2009), this paper surveys current research regarding the impact of exoskeletons in intralogistics with respect to productivity and health.*

Findings: *Since exoskeletons in industrial contexts have been used mainly in pilot trials so far, few findings from long-term studies are available. Accordingly, the sustainable positive influence of exoskeletons on productivity and health cannot be empirically proved.*

Originality: *This paper identifies research gaps for a novel technology that could transform a sector which is characterized by a high proportion of manual labor, a high age average, a shortage of skilled workers, and beside increasing complexity.*

First received: 16. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

“Exoskeletons are wearable robotic systems that integrate human intelligence and robot power” (Chen 2016, p.1). Two goals are relevant to considering the implementation of industrial exoskeletons in operational logistics processes: Improvement of productivity and optimization of ergonomics (Dahmen et al. 2018a). Because logistics processes are still affected by a large amount of physical work, rising requirements, cost and performance pressure, and a lack of labor, strategies to reduce back-pain issues affected by repetitive lifting and moving of goods are needed to cover rising needs and requirements in this industrial sector. Exoskeletons have the potential to reduce back pain and support workers in lifting and moving processes (Constantinescu et al. 2016 I), especially in areas where layouts and working conditions cannot be easily changed (Ippolito et al. 2020). Exoskeletons can enhance strength, endurance and capacity and can thereby help to cover volatile peaks of demand, (reached especially during the Corona crisis). They can help to reduce repetitive strain occupational injuries, and their financial consequences (Bogue 2018, Burton 2020, Xie et al. 2014).

44 million Europeans suffer from musculoskeletal disorders (MSDs), 25% suffer from back injuries, and 23% of sick days in Germany are related to back injuries, caused by physical work. This leads to 10 billion euros of gross loss and 4% of gross national product annually (Bogue 2018, Burton 2020, Constantinescu et al. 2019, Koopman et al. 2020). Thus, exoskeletons exhibit huge economic potential both for countries and for companies.

Though exoskeletons have the image of being highly valuable for logistics and manufacturing optimization, statistical evidence and long-term studies that prove their effect on productivity and health and thereby support investment decisions are missing. So far, no reasons for this fact have been given, though the potential of exoskeletons to optimize productivity and ergonomics is stated in many articles.

By using a systematic literature review focused on empirical data and future research, this paper aims to discover why there is no holistic empirical evidence regarding the impact of exoskeletons in logistics.

2 Research Methodology and Literature Search Process

To determine why there is no holistic empirical evidence about the impact of exoskeletons in logistics despite many relevant articles in the literature, a systematic review of exoskeleton literature was conducted to follow out the thought that new knowledge is created by the combination of existing knowledge (Vom Brocke et al. 2019). The goal of this review was to compile scientific insights and empirical data based on structured testing and field research, thereby to identify further areas for investigation.

For the literature review for this paper, the theory of vom Brocke et al., based on Baker, and Durach et al. was chosen as an approved methodological framework, thereby facilitating a structured scientific overview of existing findings. While vom Brocke et al. follow a general approach, which fits rather well with exoskeleton technology, Durach et al. bring the industrial aspect of Supply Chain Management in (Baker 2000, Brocke et al. 2019, Durach et al. 2017). This combination provided a good fit for our research focus.

Based on the mentioned combined frameworks, the literature review used for this paper followed six process steps (Figure 1): 1) Definition of the research question; 2) definition of the research scope; 3) research conceptualization and definition of keywords; 4) literature search (database search based on keyword search); 5) literature analysis, evaluation and synthesis; and 6) research results and further agenda.

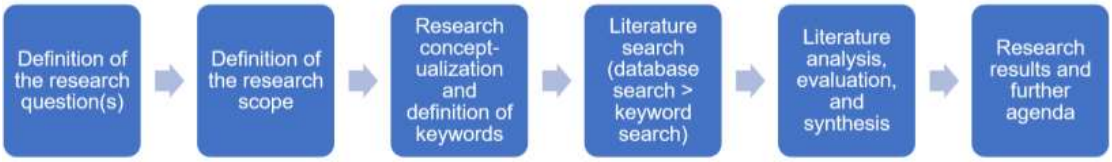


Figure 1: Literature-review process applied in this paper

In the following, the literature search process for this paper is described.

The research question defines the focus of the scientific work and the research scope (Phase 1): *Why is there no clear statement in the literature regarding the effect of exoskeletons on productivity and ergonomics in logistics?*

Characteristic	Categories			
Focus	Research Outcomes	Research methods	Theories	Applications
Goal	Integration	Criticism		Central Issues
Organisation	Historical	Conceptual		Methodological
Perspective	Neutral perspective		Espousal of position	
Audience	Specialised scholars	General scholars	Practitioners/politicians	General public
Coverage	Exhaustive	Exhaustive and selective	Representative	Central/pivotal

Figure 2: Taxonomy of literature reviews (following Cooper 1988, p. 109)

Based on the research question, a taxonomy matrix was created (Figure 2) to define the scope (Phase 2) of the literature analysis (Cooper 1988). Research outcomes were used, to understand why there is no clear statement in the literature regarding the effect of exoskeletons on productivity and ergonomics in logistics yet. An integrational approach was chosen to determine whether data exists already. This section summarizes the available data from a neutral perspective to shape future research investigation based on the current status quo. Focus groups for this paper include specialized scholars and practitioners from logistics, productions, and process disciplines. To initiate further research, an exhaustive and selective literature research procedure was chosen.

Keywords exoskeleton literature review

Keyword 1	with	Keyword 2	with	Keyword 3	or	Keyword 4	or	Keyword 5
Exoskeleton synonyms		*Discipline*		*Literature*		*Productivity*		*Health*
exoskeleton		logistics		literature review		productivity		ergonomic
exoskeletons		intralogistics		literature analysis		productiveness		ergonomics
exoframe		intra-logistics		literature search		efficiency		health
exosuit		production		literature study		optimization		sick days
muscle suit		manufacturing		literature investigation		performance		spinal disc
hardsuit		assembly				key performance indicator		spinal disk
power armor						profitability		intervertebal disc
powered armor						capability		intervertebal disk
powered suit						viability		demographic change
						increase in efficiency		demographic transition
						improvement in efficiency		back pain
						impact		muscle pain
						effect		physical stress
						invest		muscle stress
						investment		heart rate
						return on investment		
						economic		
						economicalness		
						economic efficiency		
						economic efficiency		
						economic viability		
						economic analysis		
						economic feasibility		

Figure 3: Keyword search concept

A catalogue of keywords was created and combined (Pateli and Giaglis 2004) to conceptualize the study (Phase 3, Figure 3). Synonyms were included, and the current state of research between the logistics and manufacturing literature was compared, as exoskeleton use was found to be mainly related to manufacturing. Further investigation was set to productivity and ergonomics content and empirical data. The first aim was to find out, if literature reviews already exist regarding exoskeletons, logistics, and impact on productivity and ergonomics by systematically screening reputable online data bases. The outcomes were documented in a concept matrix as a starting point for future research. Only English papers, preferably peer-reviewed ones, were considered; papers related to rehabilitation or the military were excluded.

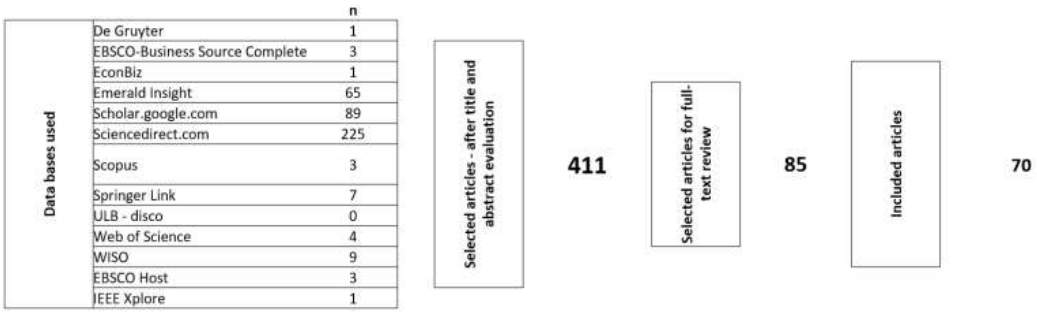


Figure 4: Paper extraction of the literature search

A total of 411 publications were identified in 13 databases (Phase 4). Title and abstract evaluations based on relevance, accuracy, and purpose were applied; whereby 85 articles were selected for a full paper analysis. After forward and backward analysis, 70 papers were included in this systematic literature review (Figure 5).

3 Literature Analysis and Synthesis

According to Cooper's taxonomy, the focus of this paper is set to identify missing research gaps (Phase 5). The findings were synthesized and documented in a concept matrix, thereby providing information regarding the content coverage, methodologies, and empirical data of the included articles to lay foundation for further scientific research into the application of exoskeletons in logistics and their influence on productivity and employee health.

Various synonyms for keywords were evaluated. *Exoskeleton* is the most common noun, found in the literature. *Powered suit*, *exosuit* and *muscle suit* created hits, while words like *exoframe*, *hard suit* or *power(ed) armor* did not yield much data. Therefore, the main keyword for the analysis became *exoskeleton*. More than 22,000 hits were found in all databases by searching only for *exoskeleton*. Many sources were found which are connected to the military and the rehabilitation of the elderly and invalids.

Taking the database of Emerald and combining *exoskeleton* with manufacturing terms such as *production*, *assembly* or *manufacturing* yielded 345 hits (10.05.2021), while the result for the combination with *logistics* or *intra-logistics* provided only 21 articles. This phenomenon suggests that a limited number of papers of exoskeletons in logistics exist compared to manufacturing. This finding can be retraced in other databases as well, as the results were familiar. Selected papers covered general information about exoskeletons (de Looze 2016), procedure models for implementing exoskeletons in logistics (Feldmann et al 2020) workplace designs to use exoskeletons (Dahmen et al. 2018a), and exoskeletons for age management (Grah 2020). In most papers, the potentials of exoskeletons are mentioned, but rather few papers provide specific data (Table 5).

Table 5: Concept Matrix

source	exoskeleton/exo-frame/exosuit/...	logistics	production/manu-facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton SJ type	weights	tasks
Baltrusch et al. 2018	x						x	positive and negative results, decrease of performance in 7 out of 10 tasks (carrying, walking; improvement just in one. Difficulty increased in many of the tasks when wearing the ES; suitable for static tasks)	kg, time recording, distance. questionnaires	passive trunk ES	5-25 kg boxes	lower lifting, carrying, forward bending, one handed bank position, 6 minute walking test, sit to stand, stair climbing, ladder climbing, bending the trunk, wide stance, rotation of the trunk, squatting
Baltrusch et al. 2019	x						x	17 % decrease of metabolic costs during lifting 17 % increase during walking	energy expenditure, kinematics, muscle activity, metabolic costs	passive trunk ES		5 minutes of repetitive lifting, 5 minutes of walking w/wo ES
Bances et al. 2019	x	x	x		x	x		83 % reduction of injuries at assembly lines, liftable weight increased up to 50-70 %		passive ES at Ford		
Bogue, R. 2018	x	x	x									
Brown et al. 2003	x	x										
Burton 2020	x							analyzed fatigue reduction of shoulders and biceps, liftable weight increased about 50-70 %				

source	exoskeleton/exo - frame/exosuit/...	logistics	production/manu- facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Butler 2016	x	x	x		x	x		improvement in productivity of 27-86 %; workers worked more efficient, more accurate and longer; muscle pain was reduced	muscle activity			welding and painting tasks
Chen 2016	x					x						
Chu et al. 2014	x				x							
Cimini 2020	x	x	x									
Cochran 2020	x		x			x						
Constantinescu et al. 2016 I	x		x									
Constantinescu et al. 2016 II	x		x									
Constantinescu et al. 2019	x	x	x			x						
Dahmen and Constantinescu 2020	x		x	(x) *no logistics, no productivity, no ergo.*	x	x						
Dahmen et al. 2018a	x		x		x	x						
Dahmen et al. 2018b	x		x									
Daub 2017	x											

source	exoskeleton/exo-frame/exosuit/...	logistics	production/manu-facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
De Looze et al. 2015	x		x	(x) *general ES review*			x	reduction of muscle activities in back, shoulder, arms, and legs (10–40 %); reduction in lumbar spine (23-29 %, static bending, dynamic lifting and lowering); Muscle activity reduction with active ES (20-35 % dynamic lifting, 40-65 % static holding, 70 % holding above head	26 ES from 40 papers, effect of physical loading for 13 ES; laboratory tests in small groups, statistical tests missing; muscle activity	passive and active; early stage ES	0.4-20 kg loads	holding, lifting, static bending, dynamic lifting and lowering
de Vries et al. 2019	x			(x) *arm ES*			x	reduction of muscle activity in the arms and shoulders (42 – 62 %), reduction of physical load w/wo ES, mixed findings and mixed results	muscle activity, realistic work activities	arm ES		over-head drilling, sanding, manual lifting, carrying weights, stacking and turning, gluing
Diefenbach et al. 2021	x	x										
Dimitropoulos et al. 2020	x		x									
Di Pascale et al. 2021	x		x		x	x						
Edirisinghe 2019	x											

source	exoskeleton/exo-frame/exosuit/...	logistics	production/manu-facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Feldmann et al. 2020	x	x		(x) *focus procedure models*	x	x						
Fox et al. 2019	x		x	(x) *general ES review*	x	x						
Geregei et al. 2020	x	x			x	x	x	reduction of muscle activity (32 % bending, 40 % turning, 64 % squatting), no statistical difference between working w/wo ES, higher concentration in finding documents due to less fatigue with ES	muscle activity; logistician in a bank finds and handles documents, productivity comparison w/wo ES, laboratory simulation, labor productivity not accessed; speed in finding documents w/wo ES	ExoChair		moving documents, packed in standardized boxes; bending, turning, squatting
Gopura et al. 2009	x			(x) *ES design*								
Grazi et al. 2019	x											Data based on primary literature
Hoffmann et al. 2020	x											
Hyun et al. 2019	x		x					reduction of muscle activity, enhancement of weight	muscle activity	H Vex		upper arm task above head in manufacturing

source	exoskeleton/exo - frame/exosuit/...	logistics	production/manu- facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Ippolito et al. 2020	x	x	x			x	x	58 % reduction of muscle activity, general reduction of muscle activities, wearing an ES; extension of movements of injured fingers	computer analysis, muscle activity	finger ES	15 kg	lifting stone quarters, unloading
Jo et al. 2019	x						x					
Kaasinen et al. 2020	x											
Karre et al. 2017	x											
Karvouniari et al. 2018	x		x			x						
Kawale and Sreekumar 2018	x		x									
Khakurel et al. 2018	x					x						
Koopman et al. 2020	x						x	21 % reduction of compression force (static bending), 14 % lumbar flexion reduction (lifting), 13-21 % reduction of compression force for static bending, 14 % in average for lifting, indicating a reduction of strain	muscle activity, compression forces, kinematics	passive back ES	10 kg	lifting a box with three techniques (free, squat, stoop) in six height positions, bending
Kuhlmann and Klumpp 2017	x	x										
Lanotte et al. 2020	x											

source	exoskeleton/exo-frame/exosuit/...	logistics	production/manufacturing/assembly	literature review/analysis/search/study investigation	productivity/effectiveness	health/ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Lee and Cha 2021	x	x					x	reduced fatigue due to load carrying, increased walking lap times (productivity loss)	statistical analysis, 10 volunteers, 3 phases, lap time as measurement of effectiveness	higher limb ES	15 kg	10 meter walking without load and without ES, walking with load and without ES, walking with load and with ES
Li et al. 2021	x	x				x	x	reduction of reduction oxygen level by 9,45 %, thermal discomfort during lifting	motion capturing, sensors, dynamometer (movement of joints), oxygen levels, thermal response tests	passive ES	20 kg	lifting loads of 20 kg from the ground up to 1.5 meters lifting of a 10 kg box to a 74 cm height; courier company
Liu et al. 2021			x				x					data on thermal response to wearing an ES during lifting and resting
Maltseva 2020	x		x									
Miehe et al. 2020	x		x		x	x						
Moyon et al. 2018	x		x		x		x	lower heart rate	heart rate w/wo ES comparison			work above head
O'Sullivan et a. 2015	x		x		x							
Poliero et al. 2020	x				x	x	x	12 % reduction of lumbar muscle activity, no clear evidence; efficiency increase for lifting, efficiency decrease for walking	muscle activity w/wo ES	passive back ES	1,2–16,2 kg loads	non-lifting activities: lifting, carrying, re-placing, walking evaluation of switching features on and off
Rogge et al. 2017	x											

source	exoskeleton/exo - frame/exosuit/…	logistics	production/manu- facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Romero et al. 2016	x		x									
Roveda et al. 2020	x											
Sahashi et al. 2018	x								motion sensors			
Schmidler et al. 2015	x											
Schnieders and Stone 2017	x			(x) *ES design*								
Schröter et al. 2020	x				x		x	reduced fatigue, improved concentration, lowered concentration errors	influence on human cognitive functions, hypothesis: higher productivity due to higher concentration and less errors; items per time		crossbars of 3,5 kg	positioning of a crossbar of 3,5 kg two meters above standing level, above head; fixing the crossbar by using a hammer
Sgarbossa et al. 2020	x	x	x									
Spada et al. 2017	x						x	increased stamina in holding, time reduction in 2/3 of tasks, time extension in 1/3 of tasks, higher fulfillment rates by 1/3; 30 % performance increase by decreased fatigue	laboratory testing w/wo ES; semi-structured interviews		3,5 kg	static task (standing upright, holding a load of 3,5 kg), repeated manual material handling task (moving of a 3,4 kg load between two positions), precision task (following a line at a wall with a pen)

source	exoskeleton/exo-frame/exosuit/...	logistics	production/manu-facturing/assembly	literature review/ analysis/search/ study investigation	productivity/ effectiveness	health/ ergonomics	empirical data	experimental results	measurement method	exoskeleton (ES) type	weights	tasks
Stadler and Scherly 2017	x		x									
Staub and Anderson 2019	x		x									
Sylla et al. 2014	x		x		x	x		16,72 % reduction of mechanical energy, decrease of the process cycle time, productivity increase	untrained volunteers; reflexing markers, floor scales, motion capture technologies	ABLE ES	1,335 - 1,935 kg tool	screwing task 2 meters above the ground
Theurel 2019	x			(x) *general ES review*								
Todorovic et al. 2018	x		x	x	x							
Toxiri et al. 2018	x											
Toxiri et al. 2019	x		x				x	muscle activity: w ES < wo ES, best results for active ES	muscle activity w/wo ES	active and passive ES, lower back ES	7,5-15 kg	movement of loads between 2 positions
Van der Vorm et al. 2015	x		x			x						
Winkelhaus and Grosse 2020	x	x										
Winter et al. 2019	x	x				x	x	moderate relief effects of 5-10 %, no difference in bio-mechanical efficiency while lifting; decrease of productivity for walking tasks; no difference in cycle times for lifting	warehouse; acceleration sensors, motion recording and electromyographic measurements (EMG)	passive ES	3-50 kg	lifting the load, carrying and placing, walking without load, carrying in pairs w/wo passive ES, 5 -15 m of walking
Xie et al. 2014	x											
Yong et al. 2019	x				x		x	reduction of muscle activity: 24–39 %	muscle activity		0, 5, 10, 15, 20, 25 kg	lifting of loads w/wo ES

4 Research Results

This chapter presents the results of the research analysis. Productivity and ergonomic impacts are considered separately. We begin with a general overview of the image exoskeletons have in most analyzed articles.

Image of exoskeletons in literature

In all the papers that were analyzed, exoskeletons are considered as a way to improve worker performance as measured in terms of productivity, quality, and efficiency in logistics at least in sub-processes, and depending on the device and user attributes (Constantinescu 2019, Butler 2016, Dahmen and Constantinescu 2020). Precision increase is valued as an aspect of performance and workplace increase (e.g. of air-freight forwarders or ship builders), though cycle times might increase (Dahmen and Constantinescu 2020, Constantinescu et al. 2019, Diefenbach et al. 2021, Feldmann et al. 2020, Kawale and Sreekumur 2018). Enhancement of strength and an increase of motion intension are supposed and therewith, an achievement of higher performance (e.g. to carry and lift heavy loads and reduce risks for injuries; Chen 2016, Cimini 2020, Kuhlmann and Klumpp 2017). Scientists even see the potential that exoskeletons could replace loading technologies like forklifts (Brown et al. 2003, Burton 2020).

It is expected that exoskeletons can reduce injuries and fatigue, especially for tasks related to extended standing, heavy lifting, moving, carrying, pushing, pulling, assembling, repetition, constant bending, and un-ergonomic body postures when the required level of vigilance needs to be high and constant (Braces et al. 2019, Bogue 2018, Burton 2020, Constantinescu 2019, de Vries et al. 2019, Edirisinghe 2019). Exoskeletons are seen as a technology that may be used to support the Logistics 4.0 operator in the future (Di Pascale et al. 2021, Kaasinen et al. 2020; Karre et. al. 2017, Romero et al. 2016, Schmidtler et al. 2015, Winkelhaus and Grosse 2020). Exoskeletons also show potential for use in the biological transformation of hybrid manufacturing (Dimitropoulos et al. 2020, Miehe et al. 2020).

However, there are also negative assumptions: Productivity decrease due to limitations of movements and motions are expected (Dahmen and Constantinescu 2020). Effectiveness may vary, while decision makers have to consider the benefits compared to the costs of exoskeletons (Toxiri et al. 2019).

The positive impact of exoskeletons regarding ergonomics and health is attested in literature (Constantinescu et al. 2016 I). Exoskeletons are thought to have the potential to reduce workload; to support the upper body and hips during heavy-load handling; to prevent muscle pain, stress, and injuries; and to reduce costs and sick days due to musculoskeletal disorders (MSD; Bogue 2018, Braces et al. 2019, Brown, et al. 2003, Cochran 2020, Chu et al. 2014, Constantinescu et al. 2016 I, Khakurel et al. 2018).

Also, the social component is relevant: Exoskeletons can support the reintegration of disabled workers and can enable elderly people to extend their longevity and retain the capability to fulfill their tasks. Employers benefit in terms of resilience and cost reduction, flexibility regarding shortages at the job market, and by avoiding investments in automation technology (Dahmen and Constantinescu 2020, Staub and Anderson 2019).

In the future, exoskeletons may collect data on heart rate, stress responses and fatigue and thereby keep workers healthy and productive (Khakurel et al. 2018, Maltseva 2020).

Thus, most of the literature expects exoskeletons to impact productivity and ergonomic optimization, but it does not prove that this will happen. Most papers do not provide empirical data (compare Figure 5) and build on each other by referring to a limited number of test scenarios which state that it “might be” that exoskeletons will influence ergonomics or that it is “foreseen” that researchers will measure the impact of exoskeletons with simulations (Karvouniari et al. 2018, p.3 & 6). However, the impact of ergonomics still “has to be critically proven for all situations”, as Dahmen et al. wrote in 2018 (a, p. 3).

Therefore, the authors analyzed and systemized existing empirical data in the literature regarding productivity and ergonomics in industrial processes.

Data-based findings regarding the productivity of exoskeletons in the literature

Compared to the number of papers reviewed, the number of papers that deliver data is small (19:70 = 27, 1%, Figure 5).

Baltrusch et al. tested a passive trunk exoskeleton in general tasks which are not directly related to logistics. The exoskeleton affected performance both positively and negatively. A decrease of performance occurred in seven out of 10 tasks. Still, the potential for use in static, repetitive bending tasks was described (Baltrusch et al. 2018). Efficiency was found to increase in lifting, but to decrease in walking (Baltrusch et al. 2019).

Butler executed a field test in a welding company. He expected that the welders would feel less fatigue and would increase productivity. In a test scenario, he demonstrated an improvement in productivity of 27-86% due to the better blood supply in the muscles of the workers. The workers worked more efficiently, more accurately and longer, and muscle pain was reduced (Butler 2016). He found that exoskeletons can prevent fatigue by slowing muscle activities, which can reduce the risk of injuries during work (Butler 2016).

Ford tested passive exoskeletons in 2015-2016 and reported an up to 83% reduction in injuries on assembly lines (Bances et al. 2019), Iowa State University analyzed fatigue reduction in shoulders and biceps (Bances et al. 2019, Burton 2020).

Range of motions (e.g. arm ranges) can be increased by exoskeletons and liftable weight can be increased up to 50-70% (Brown et al. 2003, Butler 2016).

De Looze et al. conducted a review of 40 papers and 26 industrial exoskeletons in 2015, analyzing potential impacts on wearers (De Looze et al. 2015). Thirteen exoskeletons were evaluated regarding the effect on physical loading, holding, lifting, and bending. Reductions in muscle activities between 10% and 70% were evaluated (De Looze et al. 2015). For active exoskeletons, muscle-activity reduction between 20% and 70% (dynamic lifting, holding above head) was documented (De Looze et al. 2015).

Studies with arm exoskeletons showed a reduction of muscle activity in arms and shoulders (42 to 62%) and an extension of working endurance in realistic work activities (de Vries et al. 2019). Overhead manufacturing tasks were also evaluated (de Vries et al.

2019). Reduction of physical load was measured to compare ability with and without exoskeletons. Mixed findings and mixed results were documented in the studies (de Vries et al. 2019).

In another example, muscle-activity reduction of between 32% and 64% were demonstrated for the bending, turning, and squatting tasks of logisticians in a bank (Geregei et al. 2020). Searching for documents with an exoskeleton was faster than without, thereby showing a connection between relaxed muscles and concentration due to less fatigue and less muscle activity (Geregei et al. 2020).

Reduction of muscle activity and the enhancement of weight handled during an upper-arm and upper-head task were registered in manufacturing. Muscle activities were reduced with the exoskeleton working with and without load (Hyun et al. 2019).

Koopman et al. evaluated a passive back exoskeleton. They measured a reduction of compression of 21% while bending and of 14% while lifting (Koopman et al. 2020).

Lee and Cha did a statistical analysis of walking tasks with and without loads and exoskeleton, taking lap time as measurement of effectiveness (Lee and Cha 2021). They demonstrated that the exoskeleton reduced fatigue of workers while carrying loads. At the same time, the lap times increased, using an exoskeleton compared to walking without one. This means a decrease in productivity (Lee and Cha 2021).

Li et al. analyzed a logistics operator who lifted 20 kg loads with motion-capture software, sensors, and a dynamometer treadmill. The oxygen level was reduced by 9.45% (Li et al. 2021).

Poliero at al. tested exoskeletons in lifting, carrying, re-placing, and walking with 1.2 to 16.2 kg loads, with and without exoskeletons. Lifting activities were supported well, but a negative impact for activities like carrying was found. Lumbar muscle-activity reduction up to 12% was measured, but no clear evidence for exoskeleton efficiency was found (Poliero et al. 2020).

Schröter et al. 2020 analyzed the influence of support systems on human cognitive function in construction. The exoskeleton reduced fatigue, improved concentration, and lowered concentration errors (Schröter et al. 2020).

Spada et al. tested exoskeletons in static and repeated manual tasks. A 30% performance increase due to decreased fatigue was observed. Stamina in holding was increased. Time reduction was reported in 2/3 of the cases and time extension in 1/3, but the task was fulfilled by three times more volunteers with an exoskeleton than without (Spada et al. 2017).

Toxiri et al. compared the effects of exoskeletons while moving weights between two positions. In all cases, muscle activity with an exoskeleton was less than muscle activity without one. The active one especially showed efficiency (Toxiri et al. 2018).

An analysis of lifting tasks based on muscle activity was conducted by Yong et al. They demonstrated a reduction of muscle activities by 24% to 39% (Yong et al. 2019).

Only one example for exoskeletons in logistics was found. Picking, lifting, and carrying of parcels from pallets in a warehouse was evaluated with acceleration sensors, motion recording and electromyographic measurements (EMG). Moderate relief effects of 5% to 10%, no difference in efficiency while lifting, and a decrease of productivity for walking were identified (Winter et al. 2019).

Data-based findings regarding the ergonomics of exoskeletons in the literature

Compared to studies focusing on productivity of exoskeletons, there are even fewer empirical studies available regarding the ergonomics of industrial exoskeletons.

Many papers describe prototype testing of exoskeletons. Roveda et al. (2020) presented a design methodology for an active exoskeleton aiming to support the lower back by redistributing the spinal load and thereby relieving the operator (Roveda et al. 2020). Rogge et al. present the Stuttgart Exo-jacket and describe how functions could be designed and the impact of the exoskeleton can be analyzed. However, they mention that there are no standardized test procedures for exoskeletons (Rogge et al. 2017). Designing an exoskeleton is seen as difficult, as criteria include weight, performance, and comfort (Lanotte et al. 2020). Descriptions of the Robo-Mate project were summarized by O'Sullivan et al. (2015), and a qualitative study and interviews with farmers were conducted in 2020 (Omoniyi et al.2020). Schnieders and Stone (2017), and Stadler and Scherly (2017) summarized designs and exoskeleton types (Schnieders and Stone 2017).

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Fox et al. (2019) describe the potential positive and negative effects of exoskeletons: e.g. reduction of forces, mechatronic support, reduction of strain, and transfer of loads. However, they do not provide concrete, quantified data (Fox et al. 2019). Furthermore, the impact of exoskeleton use depends both on the individual worker's health, body, and muscle conditions and on load characteristics like shape, weight, volume, and workplace (Fox et al. 2019).

Due to a lack of conversion methods to identify ergonomic impact, most available ergonomic investigation is based on virtual simulations (Constantinescu et al. 2019, Dahmen and Constantinescu 2020, Dahmen et al. 2018b). A computer analysis for lifting examined a reduction of muscle activity of 58% with an active exoskeleton. In addition, tests with finger exoskeletons proved the extension of movements of injured fingers (Ippolito et al. 2020).

Koopman et al. evaluated compression forces, muscle activity and kinematics, emphasizing that the exoskeleton might reduce the risk of low back pain during static bending and lifting activities (Koopman et al. 2020). The compression force was reduced by 13% to 21% for static bending and by an average of 14% for lifting, thus indicating a reduction of strain (Koopman et al. 2020).

Heart-rate measurements for ship-builder analysis demonstrated a much lower heart rate working above the head with an exoskeleton than without (Moyon et al. 2018).

Sylla et al. evaluated the ergonomics of an exoskeleton used to hit a target two meters above ground with a screw gun. They used reflection markers, floor scales, and motion-capture technologies. The exoskeleton reduced the mechanical energy up to 16.72% and decreased the process cycle time, which means a productivity increase.

5 Discussion

As demonstrated, only a limited amount of data is provided by the literature (Figure 5) to cover the influence of exoskeletons for operational logistics processes. Most articles that provide data regarding exoskeletons in an industrial context take pilot trials as a basis. Long-term studies are missing, and real-life data is rare, as most data is created in laboratories or by computer simulation. Accordingly, the sustainable positive influence of exoskeletons on productivity and health cannot yet be proved empirically. Therefore, two research questions are formulated for future investigation based on the findings of this systematic literature analysis:

RQ 1: Do exoskeletons increase productivity in logistics operations?

RQ 2: Do exoskeletons positively affect the health/ergonomics of workers in logistics?

To answer these questions, the following research gaps and potential further investigation must be considered:

No clear statements regarding the effects of exoskeletons

In the literature, you can find risk-management strategies, implementation procedures, decision guidelines, and other useful information regarding industrial exoskeletons; but no clear statement of the effects of exoskeletons exist at present. Most authors attribute to exoskeletons a high potential to support operational challenges like productivity, efficiency, ergonomics, safety, and integration of the elderly, but most papers do not provide appropriate data. It stands to reason that exoskeletons can improve productivity, but it is not clear to which extent.

Understanding the advantages of exoskeletons is partly given, disadvantages of exoskeletons or shifts of stain to other regions of the body are not analyzed yet.

Need of long-term studies

Most data provided by the literature covers trials and short-term test results. Long-term studies of the use of exoskeletons in industry have not yet been published (Dahmen et al. 2018a, Feldmann et al. 2020, Fox et al. 2019, Winter et al. 2019). Studies with appropriate numbers of participants, continuous screening, and long periods of use are needed to

validate the effects of exoskeletons in practice and their potential to reduce work-related musculoskeletal diseases and sick days (Dahmen and Constantinescu 2020, Daub 2017, de Vries et al. 2019, Geregei et al. 2020).

Deeper investigation in logistics processes and tasks

In the current literature, only single-handling tasks, like static holding or dynamic lifting were evaluated. The trials were conducted mainly in laboratories, not in authentic environments that truly cover the challenges of logistics processes. Long term studies have not yet been conducted in factories or logistics facilities under real working conditions (Lee and Cha 2021, Poliero et al. 2020).

The complexity of logistics operations with experienced logisticians like changing packaging sizes and weights, picking, packing, forklift driving and changing tasks within one work shift have not been covered: The high diversity of tasks and features of exoskeletons makes it difficult to create a general estimate of whether and how exoskeletons support productivity increase (Dahmen et al. 2018a).

Standardized productivity-measurement methods for exoskeletons

To analyze the positive or negative efficiency of exoskeletons in logistics, a concrete scientific assessment methodology based on data is needed (Dahmen and Constantinescu 2020). Suitable methodologies for calculating the operational impact of exoskeletons based on key performance indicators (KPI) are needed (Dahmen et al. 2018a, Dahmen et al. 2018b). Methods-time measurement (MTM; or an analysis according to *Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung* (REFA)) is an option for the evaluation of these KPIs (Lee and Cha 2021). Optimization of time, cost and quality can be used to evaluate the return on investment potential of exoskeletons (Dahmen et al. 2018a, Dahmen and Constantinescu 2020).

Standardized ergonomics-measurement methods for exoskeletons

Data regarding effects on ergonomics is rare. Loads that are reduced at one body part might be increased at another (Fox et al. 2019), and counter activating due to external forces is possible (De Looze et al. 2015). Lifting and carrying of loads, static working postures, and repetitive work require a uniform scheme to examine the impact of exoskeletons (Daub 2017).

Limited variety of measurement technologies – new technologies needed

The main analysis methods used to evaluate ergonomics are the measurement of muscle activity and heart rate. Alternatively, computer simulation is used. New technologies that evaluate the impact of exoskeletons are needed. Virtual simulation might be useful, but concrete data is still missing. One option to collect data could be the transformation of exoskeletons to smart wearables, connected to the Internet of Things (IOT). This could create feasible real-time data and the option to document productivity increase and cost savings by data analytics and machine learning (Constantinescu et al. 2016 II). Exoskeletons need sensors to analyze the impact on the human body depending on the individual attributes of the wearer (Braces et al. 2019, Lee and Cha 2021). A continuous improvement in performance, ergonomics, risk of disorders and stress levels might be possible in future (Braces et al. 2019, Hoffmann et al. 2020, Ippolito et al. 2020, Sahashi et al. 2018, Sgarbossa et al. 2020).

Economic evaluation of exoskeletons

Also, the economic impact of exoskeleton effects needs to be addressed. Monetary and non-monetary methodologies, like static (cost comparison, return on investment, pay-off method) and dynamic (net present value, internal rate of return, equivalent annual cost) methodologies can be applied to document the effects in productivity and ergonomics (Todorovic et al. 2018). Key performance indicators, like cycle time, throughput, overall equipment effectiveness, or reduced overtime, can provide a basis for the evaluation of product and process quality (Baszenski 2012, Bokranz and Landau 2012, REFA 1997, Todorovic et al. 2018). For ergonomics, the reduction of sick days and the motivation of the employees are mentioned most (Todorovic et al. 2018). Evaluation could be applied in three phases: as-is situation, optimized situation with exoskeleton use, and comparison of both situations over a certain time (Todorovic et al. 2018).

6 Conclusion

The objective of this paper is to identify research gaps that should be addressed in further research to demonstrate the influence of exoskeletons on productivity and ergonomics of workers in logistics operations. This academic examination and additional empirical evidence will support the investment in exoskeletons to counter operational peaks, labor shortage, and high rates of sick days in future. A systematic literature review was conducted to analyze the current *status quo* in the literature.

To this point, there had been no literature review which systematically covered exoskeleton impact on productivity and ergonomics in logistics. This paper closes this gap.

Based on the findings from the literature, detailed information regarding the investigation processes was created and summarized in a concept matrix, thus providing an overview of exoskeleton articles, involved industries, effects and empirical data.

Most papers emphasize an effect of exoskeletons on productivity and ergonomics which would economically support an investment, but most papers do not provide data. The data that is presented, is based mainly on temporary tests and trials with few selected tasks that do not cover the whole range of logistics processes. Long-term studies, particularly ones regarding the impact of ergonomics, are lacking. There is currently no clear procedure for tackling productivity and ergonomic benefits. Furthermore, the use of sensors and computer calculation has not yet seen development.

Based on these findings, two research questions were formulated to pursue the study of this processually and socially important topic: *RQ 1: Do exoskeletons increase productivity in logistics operations? RQ 2: Do exoskeletons positively affect the health/ergonomics of workers in logistics?* Further research is needed to create relevant data. Deeper investigation of logistics processes and mid- and long-term studies regarding productivity and ergonomics are needed to prove the positive influence of exoskeletons. Extension of applied technologies, such as sensors or simulations, could support further research. In particular, the development of smart exoskeletons as part of the Internet of

Things could transform a sector currently characterized by a high proportion of manual labor, high age average, a shortage of skilled workers, and increasing complexity.

Negative impacts have not yet been studied. Long-term evaluations and additional measurement technologies are needed to evaluate the influence of exoskeletons on the health of their wearers.

Limitations are given. Literature reviews cannot be complete and always represent a snapshot of time. More research results might become available or may be published soon.

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Digitization of the Car: Impact on Automotive Logistics

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Purpose: *The digitization of the car is advancing in the four prominent areas called CASE (Connected, Autonomous, Shared & Services, Electric). The respective changes to the product structure will further increase the complexity of automotive logistics. This paper has methodologically clustered these changes and identified the impacts on logistics.*

Methodology: *Via a systematic literature analysis, the automotive product structure has been categorized into six main clusters and subclusters. Subsequently, the anticipated changes in the product structure triggered by digitalization have been classified. In the last step, the resulting impacts and necessary developments for logistics have been deduced.*

Findings: *In the course of the digitization of the car, only very few systems and modules remain unchanged. Adaptations in the product structure can be expected to accelerate in the future. Conceptual solutions for automotive logistics are necessary. First approaches, as well as remaining gaps, have been identified.*

Originality: *Digitalization and technological trends pose new challenges on logistics not yet met by scientific literature, though practice offers first conceptual ideas. This paper is the first to methodologically and holistically identify the implications of the digitalization of the car on logistics, thus providing the basis for assessing conceptional solutions.*

First received: 12. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Challenges for the Automotive Industry

The German automotive industry is currently facing major challenges. Customer trust in German original equipment manufacturers (OEMs) has been affected by the diesel scandal and the associated diesel debate (Koch, 2018; Teichert, et al., 2020, p. 618). The trade conflict between the United States and China (Erber, 2019) also impacts on the sales of German cars: Sales in the important Asian market, for example, have fallen as China mainly imports German cars which have been produced in the United States (Frankfurter Allgemeine Zeitung, 2018).

Right in the middle, the German automotive industry has been hit by the Corona crisis which has especially demonstrated the vulnerability of automotive production, when production came to a prompt standstill at all manufacturers. One reason for this, in addition to protecting employees and collapsing demand, has been the interruption of the global supply chains (Köllner, 2020). As it was early suspected (Buchenau, 2020; VDA, 2020), the restart of these supply chains caused major problems for many OEMs and exposed weak points, making it difficult for production to regain former volumes (Zimmermann, 2020; Speck, 2020).

Aggravating, the automotive industry has been undergoing a transformation that is unique in its over 125-year history (Christian Hochfeld, 2017). This change is primarily driven by environmental regulations and rapidly developing information technology: On the one hand, the combustion engine is step by step replaced by electric drives. On the other hand, the digital transformation of the car is gradually enabling more and more tasks to be taken over by embedded IT that were previously the responsibility of the driver. Winkelhake (2019, p. 36) calls it the "mobile data center" and an "IP address on wheels".

In the course of this digital transformation of the car, only very few systems and modules remain unchanged and adaptations in the product structure can be expected to accelerate in the future. These changes will naturally affect the automotive supply chains and it is crucial to be prepared in context of global competition. Yet, this issue has not been met sufficiently by scientific literature, though practice offers first ideas. Hence, this paper addresses the issues to identify the implications of the digitalization of the car on

the supply chain and logistics and deduce necessary conceptual solutions for automotive logistics.

For this purpose, the digital transformation of the car has been analyzed in-depth (chapter 2) and the triggered changes in the product structure have been methodologically classified (chapter 3). The impacts on supply chains and logistics have been analyzed (chapter 4) and novel pathways for supply chain development have been deduced. This contribution closes with a summary and a perspective on future scientific work.

2 The Digital Transformation of the Car

Stricter regulations for emissions, lower battery costs, widespread charging stations, and increasing consumer acceptance will continue to drive the spread of electric cars, i.e., hybrid, plug-in, battery electric, and fuel cell cars in the upcoming years (Buss, et al., 2018, p. 32; Vallée, et al., 2018, p. 93; Krug and Schulze, 2020, p. 59; Statista, 2020). Current forecasts predict that by 2030, electrified cars will represent 50 percent of new cars sold (Felix Wilker, 2017). The speed of deployment will be determined by the interaction between consumer demand (driven in part by the total cost of ownership) and regulatory pressures, which will vary widely at the regional and local levels (Mosquet, et al., 2020). Acceptance rates will be especially high in developed, crowded cities with stringent regulations and consumer incentives (tax incentives, special parking, and driving privileges, discounted electricity prices, etc.) (Buss, et al., 2018, p. 30).

Furthermore, with battery costs rapidly declining over the next few years, electrified cars will become cost-competitive with conventional cars, providing the key catalyst for market penetration. Advances in charging technology, range, and awareness will further improve the customer value proposition (Mohr, et al., 2016, p. 12). Moreover, continued improvements in battery technology and respective costs will make local differences less significant (Buss, et al., 2018, p. 32; Statista, 2020). So all over the globe, electrified cars are expected to gain increasing market share over conventional cars (Buss, et al., 2018, p. 28; Kasperk, et al., 2018, pp. 143–144). But it is important to note that in addition to fully electrified cars, a large proportion of sales will still fall to hybrid-powered cars, i.e.,

the internal combustion engine will stay relevant beyond 2030 (Kasperk, et al., 2018, pp. 143–144). According to BMW CEO Oliver Zipse, electric, combustion, and hybrid cars will coexist on the assembly line in the future, especially as long as customer preferences have not yet been determined in full (Wimmelbücker, 2017; Riering and Johannsen, 2020). In consequence, a further diversification of automotive products is to be expected for the near future. According to Prof. Dr.-Ing. Lutz Eckstein, the number of offered, differing automotive products will continuously increase as the established segments are supplemented by new, e.g., automated shuttle cars (Reichenbach, 2017, p. 23).

Nevertheless, it is worth noting, that the digital transformation of the car does not stop at the electrification of the powertrain, but changes to the car can be observed in all areas of the product structure. Particularly due to the development of autonomous driving, which has attracted a great deal of attention in recent years (Brenner and Herrmann, 2018, p. 427), the share of electrical and electronic hardware in the components of a car has been increasing for decades and also for some years now the software share (Gärtner and Heinrich, 2018, p. 7). The integration of a wide variety of intelligent assistance systems has similarly and significantly increased the complexity of parts (Krumm, et al., 2014, 190 ff.; Kampker, et al., 2016, p. 167). Affected are the proportionate costs of electronic components, whose share is expected to rise by 50 percent until 2030 (Nikowitz, 2016, p. 184). And in addition, the electrification of the car allows the introduction of further innovative services. For example, cloud-based services are proposed as part of the car architecture to realize maintenance and software updates (Patterson, 2017, p. 32). As a positive side effect, customers may conveniently customize a car to their specific preferences via cloud service (Herchet, et al., 2015, p. 42); an important factor when it comes to the increasingly important business model of car-sharing.

In summary, subsumed under the simple term “digital transformation”, the car becomes metamorphosed into an automated, connected, and electric system. Daimler refers to this combination of developments with the expressive acronym "CASE", which stands for "Connected", "Autonomous", "Shared & Services" and "Electric" (Daimler, 2018). Although this development has been observed for years, the disruptive change in the automotive industry will continue for several years, as consumers, technology, and

products still need time (Mohr, et al., 2016, p. 12). The significance of this development for the supply chain will be discussed after the induced product structure changes have been analyzed more thoroughly in the next chapter. Therefore, a systematic literature review has been performed. The digital databases ScienceDirect, Springer Link, and Google Scholar have been searched for recent publications (2013 to 2021) describing changes in the product structure of the car or the CASE megatrends.

3 Product Structure Changes driven by Digital Transformation

The product structure of a traditional car based on an internal combustion engine is characterized on the highest level by six module clusters (Figure 1), namely drive unit, powertrain, body and exterior, chassis, interior, electric and electronic (eVchain.NRW, 2014, pp. 20–22). In the following, the anticipated changes in these clusters will be discussed with special regard to a battery electric vehicle (BEV) and the autonomous car.

In the domain of the drive unit and the powertrain, no component remains unaffected in the course of the electrification of the powertrain. In the case of the drive unit, the combustion engine and fuel system, the air supply (for cooling), and the exhaust system are eliminated. Instead, an electric motor, an energy storage (in the case of the BEV, the battery pack), a thermal management for the battery, and a charging system are integrated as new systems. Changed modules comprise the engine management system, the engine cooling system, and ancillary units, with the latter being eliminated depending on the car's architecture (eVchain.NRW, 2014, p. 87; Buss, et al., 2018, pp. 28–29; Pawlikowski, et al., 2018, p. 6). Regarding the battery electric powertrain, all components, i.e., drive shafts, differential, axle drive, and prop shaft, are eliminated except for the transmission, but which changes significantly in the electrically driven car (eVchain.NRW, 2014, p. 87; Buss, et al., 2018, pp. 28–29; Pawlikowski, et al., 2018, p. 6).



Figure 1: Product Structure Clusters (cf. eVchain.NRW, 2014, pp. 20–22)

In the body and exterior domain, especially structural reinforcements are necessary due to the necessary protection of the battery pack and in consequence also the passengers from exploding batteries (Dieringa, et al., 2013, p. 257). Furthermore, as described in the patent of Daniel et al. (2015), attachment parts like the bumper become more adaptable, e.g., can change the rigidity by altering the tension of tension members based on sensor data in case of a collision. Also, a change in the bodyshell and lightweight design can be identified (Friedrich and Krishnamoorthy, 2017, pp. 14–15). Other systems and modules (front and rear body, passenger cell, frontend and rearend, doors and flaps, glazing, and lighting) remain mainly unchanged in the body and exterior domain.

In the domain of the chassis, it can be observed that all systems and modules are changing (braking system, suspension and damping, steering system, wheels and axles/suspension) in analogy to the drive unit and powertrain domain (eVchain.NRW, 2014, p. 87; Pawlikowski, et al., 2018, p. 6).

Regarding interiors, due to the lack of exhaust heat from the eliminated combustion engine, a positive temperature coefficient heating element (PTC) needs to be integrated to heat the air inside the car. Passenger protection will benefit from advancing digitalization, i.e., the development of more efficient sensor technology, through fast reacting and thus safer protection systems (Mattes, 2017, p. 278). The door system will change into a much more intelligent system, especially for cars used in car-sharing: Communication with the door system, i.e., unlocking and locking, will be realized via smartphone applications (Janasz, 2018, pp. 127–128). There are also efforts to allow for activation of advanced functionalities that relate to the door system, e.g., the DHL drop function for private cars (Daimler, 2019; Szybisty, et al., 2020, p. 470). The interior electronics, as well as the instrument cluster, will change significantly as new parameters (e.g., battery charge level, recuperation data) will have to be integrated. There is also a trend towards a central information and control unit (Ruck and Stottan, 2015, p. 24). For example, Tesla has integrated a 17-inch touchscreen display as an information and control unit into his Model S and Model X (Lambert, 2019), thereby reducing the number of parts and simplifying final assembly. The car's seating is also facing changes. There are already concepts for autonomous cars where front seats can rotate so that passengers can sit vis-a-vis when needed (Schlott, 2016, p. 10). This allows for business meetings to

be relocated to autonomous cars. In autonomous cars, another area of interest is the cockpit. Developments look into a car without a steering wheel or with a retractable steering wheel (Pfeiffer, 2016; Winkelhake, 2019, p. 92). And the air-conditioning system, the trim, and acoustics as well as the lightweight design are changing mainly in the process of the electrification of the powertrain.

In the last domain of electric and electronic, the change can be identified in the field of comfort electronics. This is driven, among other things, by the increasing connectability of the car with the smartphone and other devices, allowing the car to be accessed remotely or content to be shared with the car (Winkelhake, 2018, p. 88; Möller, 2019, p. 444). Communication and entertainment will change as a result. For instance, extended entertainment (movies) and the idea of the car as an extension of office space could be supported by fully autonomous cars (Chai, et al., 2021, p. 155). Safety electronics will be driven forward by advancing digitalization. For example, predictive safety systems that can recognize hazardous situations before they occur are already under development (cf. Ji, et al., 2017). The other systems and modules already existing in the domain of electric and electronic are changing, particularly in the course of the electrification of the powertrain (onboard network and bus system, powertrain electronics, chassis electronics, and power supply). New systems and modules of high-voltage wiring, DC/DC converter/charger, DC/AC converter, and engine management will be integrated (eVchain.NRW, 2014, p. 87; Pawlikowski, et al., 2018, p. 6).

Figure 2 summarizes the identified anticipated changes in the product structure due to its digital transformation. Hereby, the focus has been especially laid on battery electric vehicles (BEV), hydrogen-powered cars will introduce further additional or modified components (Buss, et al., 2018, p. 29).

In summary, very few systems and modules remain unchanged in the process of digitizing the car. Moreover, the integration of new systems and modules and the elimination of existing ones is to be expected. The product structure will continue to change at an ever-faster pace in the future, analogous to the acceleration in the development of information technology. Especially software is used to provide a broader range of functions and services, including mobility services, enhanced safety, location-based services, in-car content, and remote diagnostics (Mohr, et al., 2016, p. 14). The

discussion revealed that not only the single module or system in the product structure changes but there are new dependencies created in both the area of hardware and software compatibility of components. These changes will be defined especially by software.

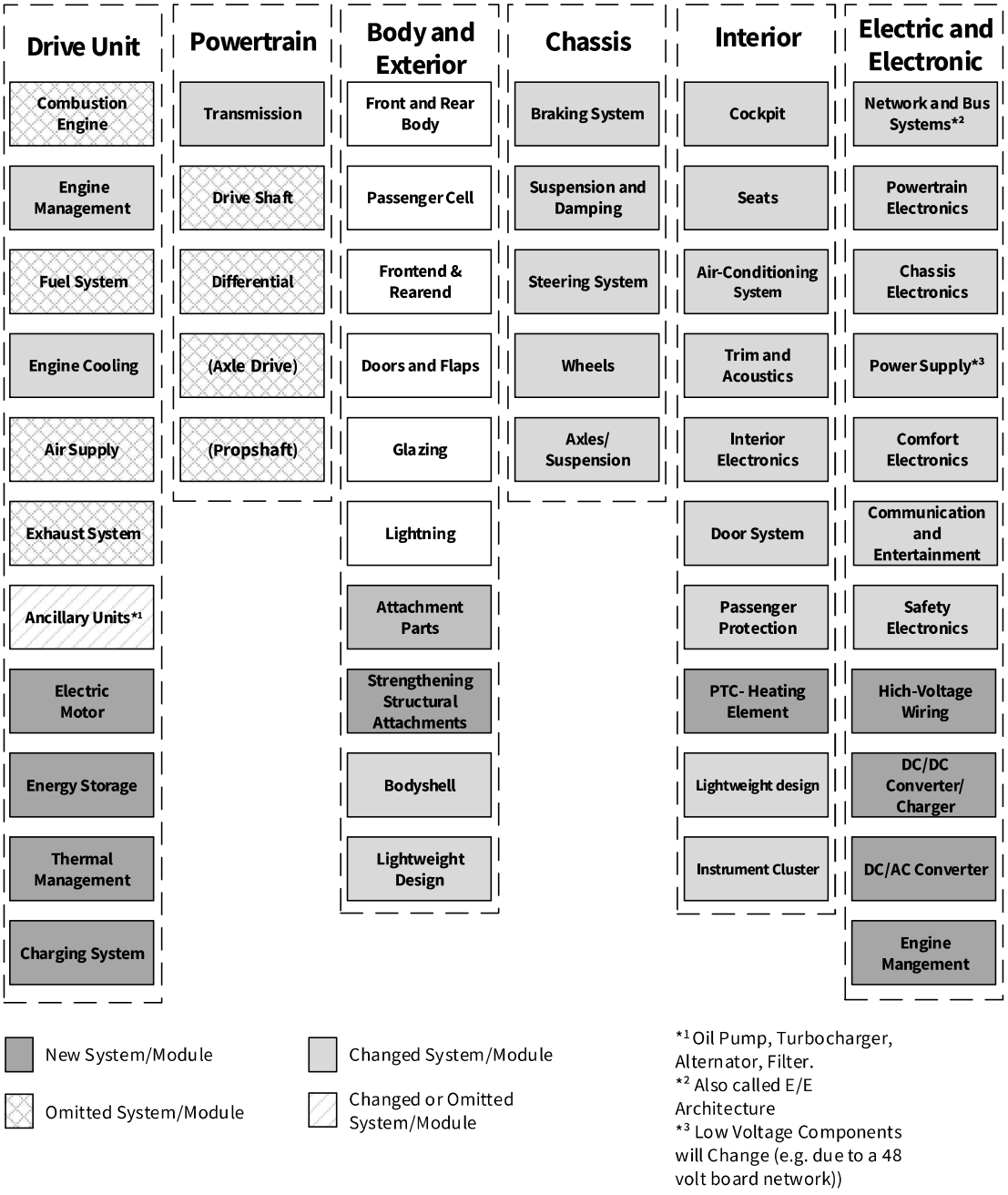


Figure 2: Changes in the Product Structure of the Car due to Digitalization

In the following section, the impacts on supply chains and logistics in particular will be discussed.

4 Impacts on Logistics

Since the beginning of industrial car production at the start of the twentieth century, the structure of the automotive supply chain has changed constantly (eVchain.NRW, 2014, p. 16). In the early days, car manufacturers mainly sourced components from suppliers and produced only a few by themselves. The sourcing strategy changed significantly with mass production from around 1915 onwards. Then, many car manufacturers have started to increasingly produce their own components and implemented a stronger vertical integration. From 1950 onwards, driven by the greater complexity of cars and the emerging customer demand for individualized products, car manufacturers reduced the depth of their own value creation. To cope with the complex logistics of high vertical integration, tasks were outsourced to selected suppliers who produced complete systems. These suppliers were integrated strongly into the development to increase the offered variety (Schonert, 2008, pp. 16–17; eVchain.NRW, 2014, p. 16). So, car manufacturers have been concentrating their efforts on the assembly of parts and modules, product marketing, coordination of suppliers, and distribution of the final product (Meißner, 2009, p. 1). This complementary shift in competencies between car manufacturers and suppliers has been manifested in the well-known automotive supplier pyramid: The OEM serves at the top of the supplier pyramid as an integrator, (left side of Figure 3; Zijm, et al., 2019, p. 90; Hoßfeld, et al., 2020, p. 428).

With the identified changes in the product structure due to the digital transformation and the resulting importance of electronic and software components, some authors predict that OEMs could be pushed into the role of the supplier for mobility services in their own supply chain, while the strategically most important role in this supply chain could be taken on by information providers (Gärtner and Heinrich, 2018, p. 7). Components that serve corporate identity and functional safety will probably continue to originate from the car manufacturer, with suppliers taking on advisory roles. Suppliers, on the other hand, will continue to supply sophisticated electrical control units (ECUs) including

encapsulated systems (e.g., seat controls), low-level components (e.g., sensors), or hardware-related software, e.g., for touch controllers. Furthermore, due to their specialization and technological lead, suppliers will continue to provide certain components more efficiently than the car manufacturer (e.g., suppliers for air conditioning systems).

In this scenario, especially the system and module suppliers (today Tier-1) have a direct and increasing influence on the fulfillment of customer orders. In consequence, Buss et al. (2018, p. 63) introduce the Tier-0.5 supplier as the new supply chain stakeholder between the OEM and the Tier 1 supplier. Tier-0.5 suppliers offer even larger, more complex, and highly integrated systems. Examples include full alternative powertrains (e.g., the electric powertrain) and complete systems for the implementation of autonomous driving. Furthermore, other authors predict that OEMs will lose the top position in the supplier pyramid by 2035 and will be relegated to second place in terms of value creation to service providers like Uber and Lyft (Yole development, 2016, p. 59). These predictions of the Tier-0.5 supplier, the service provider at the top of the supplier pyramid indicate the dynamics that are already in place in the automotive supply chain (see Figure 3, middle).

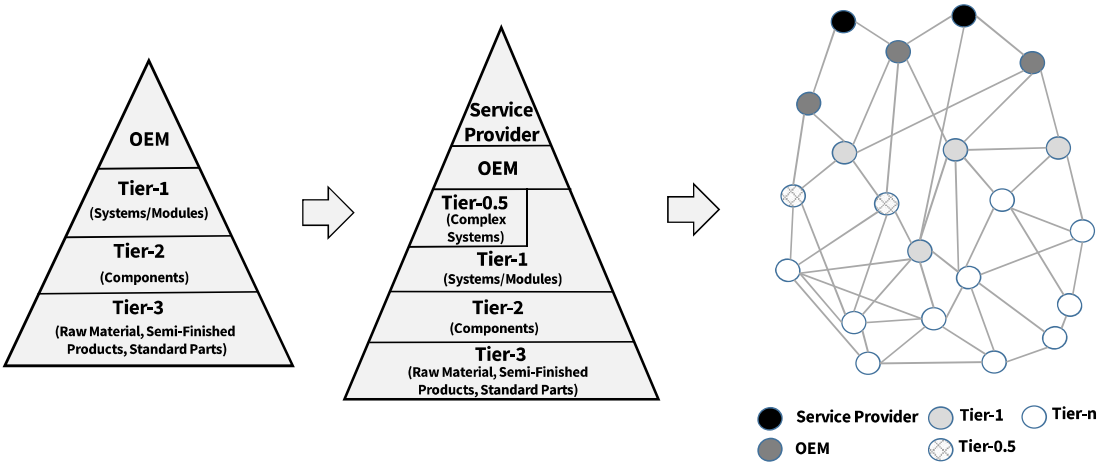


Figure 3: The Transformation of the Supplier Pyramid into a Supply Chain Network

But the transformation of the supplier pyramid might not end here. Hoßfeld et al. (2020, pp. 428–429) believe the previously inflexible product structures and also the strict existing hierarchies in the supply chain must break open. The introduction of cyber-physical systems (CPS) and the internet of things (IoT) open up new possibilities for a more real-time-oriented cooperation and collaboration in the supply chain. Only this change in the value chain structure from a strict hierarchical pyramid to a more open and flexible network will enable, among other things, more flexible responses to the fast-moving demands of the markets and potentially disruptive introduction of new car concepts and business models by competitors. The traditional rigid supplier pyramid is being dissolved and transformed into a true supply network (see Figure 3, right side).

Nevertheless, the new possibilities for cooperative collaboration might increase the already existing complexity of the supply chain. Suppliers will develop more and more systems and subsystems, which contain software drivers for car functions. As mentionend, some hardware components will be eliminated (e.g., the physical manual), and other existing hardware-based dependencies can be reduced (e.g., component wiring). The respective functionalities are taken over by software components running on domain control units (DCUs): Multi-DCUs could host radio and navigation applications within a networked cockpit (Tuzar and Schöpp, 2015, p. 30). But, the car manufacturer only needs to be involved in software development to ensure the smooth interaction of all functions. The development processes will therefore be less oriented towards components than towards functions. For the integration of these functions into the car, an electronic control unit is needed as a platform (Schuller, et al., 2017, p. 350). This, of course, is of central importance for supply chain management in general and logistics in particular, which acts as a cross-sectional function between development, procurement, production, sales, and after-sales (Fruhner, et al., 2017, p. 100). The digital transformation of the car will have an immense impact on the demand and capacity management in the supply chain: Ensuring end-to-end compatibility of the various electronic and non-electronic components becomes more and more relevant and need collaborational new approaches.

Today, platform strategies and modular concepts form the basis for the high volumes and high variation resulting from individualization but also country-specific

requirements (Gärtner, 2018, p. 18). In addition, an increasing degree of modularity is expected for the embedded software modules. Over 100 ECUs are already part of a modern car and control the various mechatronic subsystems (Budaker, 2017, p. 168). And all these components are subject to constant development cycles on both the hardware and software sides. So, it is relevant not only to know which component is a hardware and/or a software component but also the respective hardware or software version and its compatibility with other components. Here, certified standards such as AUTOSAR (AUTOSAR, 2021) will be beneficial to ensure the combined functionality of components integrated into one system. But consequently, product complexity (including platform strategies and modularity) and production complexity are impacted and need to be addressed by logistics.

Especially concerning compatibility, it is necessary to take a look at innovation cycles. These are significantly shorter in the electrical industry (semiconductors, ECUs, embedded systems) than the typical car life cycle and the corresponding technical component life cycle (Krumm, et al., 2014, p. 190; Kampker, et al., 2016, p. 168). New versions of a car series are introduced every four to six years today, innovation cycles in consumer electronics (e.g., smartphones) last only about one year (Winkelhake, 2018, p. 77). The incentive for car manufacturers to upgrade electronic functions, components, or parts (and to involve respective new supply chain partners) is increasing. And additionally, after a few years of use, many electronic systems will be outdated and maybe become even obsolete. The corresponding cars can only be sold to used car customers by granting large discounts if not countered by updates on components, e.g., by integrating Apple CarPlay in an aged car (Moynihan, 2014). In sum, an accelerating change of car models within their entire life cycle can be observed. In this process, lifecycle and electronic innovations in components have to be constantly adapted to predefined structures. Managing the various innovation cycles is already a major challenge for logistics today and will become even more important with ongoing digitalization. Hence, innovation cycles and thus innovation cycle complexity represent the third area of impact on logistics.

Logistics as a cross-functional discipline has to develop the supply chain structures and collaborative processes that efficiently support planning and order management,

procurement, production, and distribution under this complexity. It is also the logistics strategy that decides on the cost-efficient variety of variants, for example by preferring early or late configuration and the appropriate logistics concept. The basis for decision-making is always the anticipated sales and production volume of models and components. This information is interdependent in a variety of ways and required is an information base that subsumes all information given from engineering, sales, production, and customers and allows to derive resources and capacities required and thus to manage the supply chain. Furthermore, the mentioned dependencies need to be integrated thoroughly to support developers, assembly plants, and external service providers at any time in integrating new modules, parts, or software components quickly into an existing car structure and into the logistics processes in every phase of the product life cycle. This also applies to the supply chain of after-sales and spare parts business: to ensure compatibility with existing components, control units, interfaces, connections to energy sources, and energy consumers as well as to enable smooth handling of logistics, a complete insight into the car structure is required. It is not only the availability of components on the hardware and software side: the objective is to minimize obsolescence risks in the spare parts inventory.

Today, lack of this form of transparency does not necessarily result from the fact that the relevant data is not available, but rather from the fact that it is extremely extensive, distributed across different software systems and supply chain partners that often have no interfaces to each other and in parts inconsistent.

Consequently, to handle the digital transformation of the car, and the transformation of logistics, this collaborative information base needs to be formed from existing sources. A digital shadow of the product and supply chain needs to be build up, accessible for all stakeholders in the supply chain to support transparency and to avoid inconsistencies. Concepts like the distributed-ledger-technology (e. g. blockchain technology) might help to handle data integrity and security (cf. Guerpinar, et al., 2020, p. 157).

5 Conclusion and Future Work

The automotive industry is experiencing transformation at an unprecedented pace and will have to continue to adapt. The digitization of the car is advancing in the four prominent areas called CASE (Connected, Autonomous, Shared & Services, Electric) and adaptation in the product structure can be expected to accelerate in the future. These developments will further increase the complexity of automotive logistics and new conceptual solutions are necessary.

In this contribution, the automotive product structure has been categorized via a systematic literature analysis into six main clusters and subclusters, and anticipated changes in these clusters triggered by digitalization have been classified. It has been revealed that only very few systems and modules remain unchanged and that new dependencies arise between models, components, and parts.

Logistics as a cross-functional discipline has to efficiently provide and manage the supply chain, i.e., has to deal with the impacts on supply chain complexity, product and production complexity, and innovation cycle complexity. Therefore, automotive supply chains need to develop from the strict hierarchical structure to a more open and flexible network which allows for supply chain partners to enter and exit more freely and thus allows for more flexible responses to the fast-moving product developments, business models, and markets. The conceptual basis forms a collaborative information model, a digital shadow of the product and supply chain, maybe build upon distributed-ledger technology. Yet, for the organizational, structural, and procedural design of the supply chain and its IT support, there is still research necessary.

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Scenario Analysis of Online Food Supply Chains

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Purpose: *For a long time, online food retail, especially in Germany, lagged strongly behind other e-commerce industries. The COVID-19 pandemic gave this market an unforeseen boost in demand. Nevertheless, numerous problems still exist in the industry, such as lack of profitability, staff shortages, and product returns. Identifying possible future developments can help to design meaningful strategies for the fulfillment within online food supply chains.*

Methodology: *The scenarios are built using Porter's Five Forces in combination with a STEPE analysis examining socio-cultural, technological, economic, political, and ecological factors. The findings are validated and ranked by four interviews with experts working in the online food retail industry.*

Findings: *The literature research and the assessment of the experts show that above all socio-cultural (e.g., customers' price sensitivity) and technological factors (e.g., warehouse automation) will be decisive for the future development of the industry. These are combined to form three scenarios (best-case, worst-case, focus on shelf-stable food). Implications for online food retailers are given for each scenario.*

Originality: *This paper applies methods of trend and future research to the areas of online food retail and logistics and supply chain management research. In this area only little original scientific research exists.*

First received: 14. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

For a long time, online food retail, especially in Germany, lagged strongly behind other e-commerce industries. In most other industries, e.g., “Fashion & Accessories”, “Consumer Electronics” or “Home & Living”, the share of e-commerce sales makes up a significant portion of total turnover, namely between 10 and 25 percent (IFH Institut für Handelsforschung GmbH, 2017). In contrast, the share of online food retail in Germany was stagnating at under one percent with a share of slightly over 1 billion euros online versus a total food market share of 123.1 billion euros (Statista, 2020).

However, the demand for food ordered on the Internet changed abruptly in early 2020 with the outbreak of the COVID-19 pandemic in Germany. Consumers' fear of the virus led to enormous growth rates for online food retailers. GetNow, for example, recorded an increase in the number of new customers of over 500 percent in some cities. Picnic stated that the demand for their service more than doubled in March of 2020. Similar experiences were made by other online food retailers such as Rewe and Amazon Fresh (Reimann, 2020).

It seems that food retail, especially online food retail, is one of the big winners of the COVID-19 crisis, almost doubling the sales comparing the last quarter of 2019 with the last quarter of 2020 (Reimann, 2021). Despite this encouraging development, the enormous surge in demand also on one hand caused problems. The retailers had to extend their delivery time from usually 1-3 days to 14 days, some even had to ban new customers from registration for a certain time (Reimann, 2020). On the other hand, already existing problems were highlighted, such as lack of profitability, shortage of staff, and product returns.

The aim of this paper is to glimpse into potential future developments of online food retail in Germany. Identifying possible scenarios can help to design meaningful strategies for the business model of online food retailers, especially on the supply chain and logistics aspects of fulfilling customer orders.

Following this introduction, the theoretical background for the paper is presented. This includes a definition of the online food retail industry, an overview of the German online

food retail market and a characterization of the different business models with a logistics and supply chain focus. Next, the research design is presented, which comprises the data collection and analysis of primary (four expert interviews) and secondary data (case studies and literature). Subsequently, we list our research findings resulting from each research method. This includes an internal (Porter's Five Forces) and external (STEPE) analysis of the German online food retail market as well as three future scenarios (best-case, worst-case, focus on shelf-stable food) and their implications. The paper finishes with a short conclusion and the limitations of our research.

2 Theoretical background

Before describing the German online food retail market and characterizing the different business models, we first need to give a definition of what we refer to as online food retail. In this paper, only companies that deliver food in a narrower sense of the word are considered, i.e., retailers selling goods to end customers which are meant for eating or drinking, which are part of the daily needs of life. This excludes catering services and online delivery services such as Deliveroo or Delivery Hero (Foodora) because they deliver prepared meals from restaurants.

The companies included in this definition can be distinguished into three major groups:

(1) The first group are online supermarkets offering a full range of products typically found in a supermarket, i.e., frozen food, chilled food, fruits, and vegetables, packaged food articles, beverages packed in crates as well as non-food articles like toiletries (Beckmann et al., 2020). The largest online food retailer in Germany in terms of sales and delivery locations is Rewe. Other companies with a smaller number of delivery locations are Bringmeister (formerly Edeka, in March 2021 sale to the Czech investment group Rockaway was announced (Kausch, 2021)), Picnic (a Dutch company with participation of Edeka) and Amazon Fresh. The market is subject to strong change. For example, the online delivery service of supermarkt.de (Ortmann, 2013) and Kaufland (Pieringer, 2017) were discontinued after only about a year. GetNow had to file for insolvency in October 2020 (Gassmann, 2020). Nevertheless, new companies are constantly entering the

market, most recently instant delivery services such as Gorillas and Flick, and the Czech company Rholik (knuspr.de).

(2) In contrast to the first group, niche providers focus on a specific product or product range. They only offer an excerpt of a typical supermarket assortment (Beckmann et al., 2020). There seems to be an infinite number of companies in this group. For almost every possible food item an online food retailer can be found. Table 1 gives an overview of food categories with company examples. The food categories are an excerpt of the categories used by HDE in their retail report food 2018 (IFH Institut für Handelsforschung GmbH, 2018b).

Table 1: Examples for niche providers by food category

Food category	Niche provider
Canned/prepared/fixed products	dm, Netto Marken-Discount
Dairy products	Hemme Milch, Käsewelten, Käse Willie, kaeseversand24.de, Käs Hütte Fischen, Milchbubie.de, okäse.de
Ice cream	Florida Eis, Gelato Vannella, O-Mochi
Delicatessen/Spices/Convenience	Bremer Gewürzhandel, Gewürzland, Gewürz Mayer, Just spices, Spicebar
Fruit and vegetables	Freshorado, Fruchtknall, Gesunde Tüte, Obstkorb
Confectionery/Pastries	Candy and more, Candyhouse.de, Sugafari, sweets-online.com, torten.de, World of sweets

Food category	Niche provider
Alcoholic beverages	Alkoport, Belvini, Jacques', Hawesko, weinlieferservice.net
Non-alcoholic beverages	Durst.de, Flaschenpost, Getränke.jetzt, getraenkedienst.com
Frozen food	Bofrost, Eismann

(3) Vendors of cooking boxes or meal kits make up the third group of companies in the online food retail market. They sell food pre-packaged according to the ingredients for a specific recipe. Customers can order the box and cook dinner without having to worry about the necessary amounts. In 2010, seven such companies started in Germany of which three are still in the market in 2021: HelloFresh, Marley Spoon and Kochhaus, although the latter had to file for insolvency, suggesting that this business model is a niche in which only a few players can operate profitably (Beckmann et al., 2020).

Several authors highlight the importance of logistics and supply chain management for e-commerce as an integral part of the business model (i.a., Beckmann et al., 2020; Seidel et al., 2016; Grant et al. 2014). Beckmann et al. (2020) summarize their findings in a morphological box detailing the current business model characteristics and fulfillment concepts used in the food online retail market in Germany. We updated the morphological box by updating the 23 case studies used originally and adding five case studies of new companies in the market. Figure 1 shows the adjusted morphological box. The changes made are highlighted with a light grey background.

The first column presents the categories in which the business model is broken down. Each row includes the expressions the categories can take on. For example, there are three basic types of delivery cost models: (1) a monthly or yearly flat rate, (2) a fixed delivery fee, and (3) a dynamic delivery fee, which can depend on factors such as delivery date and time window or minimum order value (Beckmann et al., 2020).

Type of provider	Start-up			Online retailer			Food retailer	
Cooperation partner	Food retailer	Food wholesaler		Small shops	Food producers		E-commerce platform	None
Type of distribution	Outsourcing to LSP (DHL, Hermes, DPD or others)				Own delivery service			
Distribution center	Own existing DC (multi-channel)		Own DC "dark store" (only online food retail)		Bricks-and-mortar store		Urban mini distribution hub	
Depth of product range	≤ Ø supermarket (10.000 SKU)		2-3x Ø supermarket (20-30.000 SKU)		5-10x Ø supermarket (50-100.000 SKU)		> 100.000 SKU	
Delivery area	Nationwide		Many regions, but not nationwide		Some cities and surrounding area (3-10)		Few cities and surrounding area (2-3)	
Delivery location	Home (adress)			Click-and-collect (store)			Pick-up station or store	
Delivery options	Same-day within < 1h	Same-day within 1-4h	Same-day evening (> 4h delivery time)	Day with <1h window	Day with 1-2h window	Day with halfday window	1 day	2-3 days
Delivery cost model	Flatrate			Fixed delivery fee			Dynamic delivery fee	
Min. order value	No min. order value		Min. order value < 40 €		Min. order value 40-50 €		Min. order value >50 €	
Free shipping	No	Min. order value < 40 €		Min. order value 40-50 €	Min. order value 50-100 €		Min. order value >100 €	
Surcharges	None		Beverage crates		Fresh goods		Frozen goods	
Cold chain	Active cooling (delivery vehicle)			Passive cooling (packaging)			None	

Figure 1: Morphological box of fulfillment concepts

3 Research design

This study is based on the research published by Beckmann et al. (2020), who used secondary multiple case studies according to the example of Herden and Bunzel (2018) and analyzed the case studies using qualitative content analysis. We extend these findings. Primary data was collected by semi-structured interviews with experts working for online food retailers. Secondary data, namely industry reports, news articles and research papers, were used to establish the status quo of the online food retail market in Germany and to complement the information gained in the interviews.

3.1 Data collection

Four semi-structured interviews were conducted with experts working for online food retailers between November 2019 and March 2020. The experts represent different positions and companies from different groups of the online food retail market. The experts were asked to assess the status quo of the industry. They were also presented with the morphological box from Figure 1. Further, they were asked to state whether this reflected the market for them and whether they would add anything. Then the factors of the STEPE analysis were discussed, and the experts were asked to evaluate them regarding the importance of the market. Finally, existing problems of the market, their possible solutions and market developments were discussed. The interviews were subsequently transcribed. The experts were asked to validate the transcripts. Any comments made were adopted accordingly.

3.2 Data analysis

The data is structured and analyzed using Porter's Five Forces, STEPE analysis and scenario analysis.

Porter's Five Forces Framework is a method to analyze the competition of a business with the help of five forces, namely (1) threat of new entrants, (2) threat of substitutes, (3) bargaining power of customers, (4) bargaining power of suppliers, and (5) competitive rivalry. They determine the competitive intensity and attractiveness of an industry and are referred to as the microenvironment of the business (Porter, 1979).

The macroenvironment can be characterized using the STEPE analysis. STEEP and PESTE are other abbreviations commonly used for this variant of the PEST framework. STEPE is an acronym formed by the following factors: (1) socio-cultural, (2) technological, (3) economic, (4) political and (5) ecological. STEPE analysis is used as a strategic tool for understanding a market's potential for growth or risk of decline as well as the general business position (Richardson, 2017). Table 2 lists more detailed factors for each category of the STEPE analysis (Bensoussan and Fleisher, 2008).

Table 2: Factors of the STEPE analysis

STEPE analysis category	Factors
Socio-cultural	Age distribution, income, working hours, price sensitivity, convenience, urbanization
Technological	Automation, rate of technological change, technological shifts
Economic	Economic growth, inflation rate, interest rate
Political	Tax policy, labor law, trade restrictions, tariffs, political stability
Ecological	Weather and climate, waste, CO2 emissions

3.2.1 Scenario analysis

In the literature and in practical applications, the terms scenario technique and scenario method are used synonymously for scenario analysis. There is no comprehensive or even uniform theoretical-methodical foundation for scenario analysis in the scientific literature. (Kosow et al., 2008). For this work, we apply scenario analysis following a five-step process as described in the following:

(1) Scenario environment definition: The scenario environment is defined by employing the Porter's Five Forces Framework on the online food retail market.

(2) Key factor identification: The key factors are provided by the STEPE analysis and narrowed down by interviews with industry experts.

(3) Key factor analysis: For the third step of the process, we generate expressions for those factors which the experts see as most important for the development of the market.

(4) Scenario generation: The so-called funnel model (Figure 2) serves to illustrate a set of alternatively imaginable scenarios. Here it is shown that developments in the near future are largely determined by the conditions of the present. The further into the future the forecast is to be made, the less influence the current situation has and the wider the spectrum of possibilities opens, like a funnel.

From today's perspective, several future constellations are conceivable. In practical application, it has proven useful to develop a few scenarios. As a rule, the edge points of the funnel are chosen, so-called extreme scenarios, since this completely spans the funnel, and all other scenarios move between the extreme with particularly favorable (best-case scenario) and the extreme with particularly unfavorable (worst-case scenario) assumptions.

Accordingly, the generated expressions from the third step are combined in a way to form a best-case and a worst-case scenario.

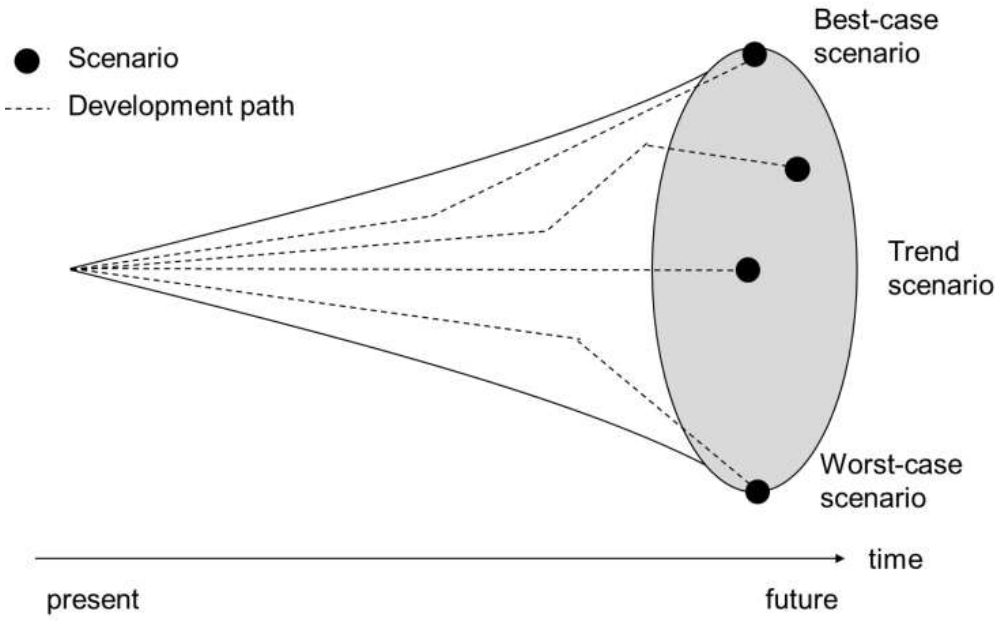


Figure 2: Funnel model

(5) Scenario transfer: The last step is to discuss implications for online food retailers resulting from the different scenarios.

4 Review of results

The analysis of the collected data gives a comprehensive picture of the micro- and macroenvironment of the German online food retail market.

4.1 Microenvironment (Porter's Five Forces

Firstly, we present the results for the microenvironment of the market. This also serves as a description of the status quo for the scenario analysis. Figure 3 summarizes the findings of the Porter's Five Forces Analysis.

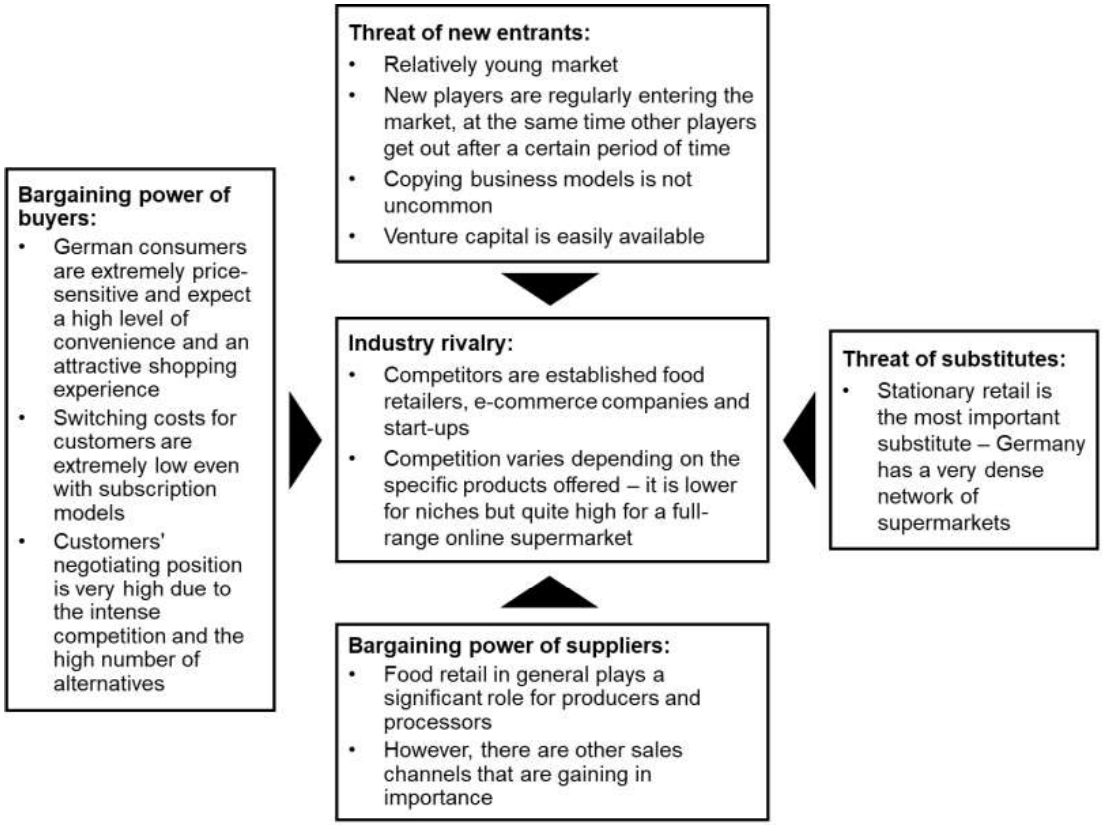


Figure 3: Porter's Five Forces analysis of the online food retail market in Germany

4.1.1 Industry rivalry

The market is characterized by many different companies, with only a few retailers offering a full range of products. Market players here are, on the one hand, established food retailers (Edeka formerly with Bringmeister now in cooperation with Picnic, Rewe, Real). There are also online retailers that have previously traded in other product groups and are now expanding their product range into this area (primarily Amazon with Amazon Fresh). On the other hand, there are numerous start-ups that want to revolutionize traditional grocery shopping (e.g., Allyouneedfresh.de, GetNow, Gorillas, Rholik).

Most companies focus on specific product groups, with both pure player concepts and omnichannel concepts. The focus on exclusive food products, such as the business model of gourmondo.de, seems to be particularly worthwhile to achieve profitability.

Finally, a sub-market of companies that ship so-called cooking boxes has formed. Subscription users receive recipes and the exact ingredients to go with them delivered directly to their homes and are supposed to be able to prepare a fresh meal within about 30 minutes. The convenience for users is that they do not have to search for recipes themselves or shop for the appropriate ingredients. In addition, the precise combination of ingredients means that there are no leftovers that need to be recycled. Depending on the provider, the number of people, the delivery days offered, and the type of recipes can differ. However, the concept is basically very similar, which is why significant consolidation has already been observed in the cooking box market. Of ten providers on the German market, only three are still active after just under 10 years, namely HelloFresh, Marley Spoon and Kochhaus.

Overall, competition within the sector varies greatly. In the full-range segment, it appears to be high, while the sub-market for cooking boxes has already consolidated and competition has therefore decreased. The more companies focus on a specific product group and the more specific the target group, the less competition a provider will face.

4.1.2 Threat of new entrants

The German online food retail market is a relatively young market, compared to other countries like Great Britain, France, or the USA. It is characterized by companies trying out the online supermarket concept (e.g., Kaufland and supermarkt.de) and then leaving after a certain period of time due to it being a loss-making business or even having to file for insolvency (e.g., GetNow). At the same time, new players are regularly entering the market, such as Amazon Fresh in 2017, Picnic in 2018, Gorillas and Flink in 2020, as well as Crisp and knuspr.de (Rholik) in 2021. It is interesting to note that - in contrast to the offline market - with Picnic and Rholik, foreign companies are also venturing into the German market. In general, therefore, there is a high risk from new competitors, as these are usually also endowed with large amounts of venture capital. Additionally, it is not uncommon in e-commerce to copy successful business models (Deges, 2019). HelloFresh

copying the model of Middagsfried and the very similar business models of Gorillas and Flink can be seen as examples.

4.1.3 Bargaining power of suppliers

Similar to traditional food retail, online food retail suppliers include food producers, processors, and wholesalers. Food retail in general plays an important role for food producers and processers. However, the food industry has numerous alternatives for selling their products outside the food retail (offline or online), e.g., hotels, restaurants, catering, export abroad, which are gaining in importance. Another option is direct marketing to the consumer, which bypasses retailers through vertical integration (IFH Institut für Handelsforschung GmbH, 2018a). Thus, the bargaining power of suppliers can be described as medium.

4.1.4 Bargaining power of buyers

The most important target groups for online grocery shopping are young professionals, families with young children, and so-called silver surfers, i.e., older people who are confident in their use of the Internet. For these people, shopping in brick-and-mortar stores often does not offer a special experience or fun factor. More important are the time aspect and certain stress factors, such as searching for products, products that may be out of stock, distracting products at the checkout, and the heavy weight of purchases (Seitz, 2013). Single people are seldom the focus for online grocery shopping, as it is difficult for them to achieve the necessary minimum order quantities or amounts.

According to Suhr (2020), 30 percent of Germans have already ordered food online. In the case of online supermarkets, this figure has risen to 19 percent since the COVID-19 pandemic, compared with only 7 percent previously (Suhr, 2020). However, customers still cite concerns about the quality and freshness of the goods as the biggest barrier, especially in the case of fruit and vegetables. Insufficient trust and a higher price level are further reasons for not buying groceries online (Ahrens, 2021; Grant et al., 2014).

Generally, it can be said that German consumers are extremely price-sensitive when it comes to food and expect a high level of convenience (Seitz, 2013) and an attractive

shopping experience (Ahrens, 2020; Yeao et al., 2017). They also want to have individual wishes realized online, such as bananas with a certain degree of ripeness or sausage cut into particularly thin slices.

It should also be noted that e-commerce places the focus on customer needs so that processes are designed to be as simple and convenient as possible. However, this leads to low switching costs for customers from one provider to another. Some retailers are trying to counter this with monthly or annual subscription models (e.g., Rewe). It saves customers delivery costs and keeps them loyal to a retailer for longer.

In conclusion, the customers' negotiating position is high due to the great competition and the large number of alternatives. Customers decide to buy on the Internet when they see a major benefit for themselves. Heavy products such as cans or beverage cartons are therefore successful.

4.1.5 Threat of substitutes

The most important substitute for online food retail is stationary retail. Germany is characterized by a very dense network of supermarkets and is therefore quite different from, for example, France and the USA (Ahrens, 2020; Seidel et al., 2016). In total, there are just short of 38.000 grocery stores in Germany with a retail space of 36,2 million square meters (IFH Institut für Handelsforschung GmbH, 2018a).

The biggest disadvantage for online retailers compared to brick-and-mortar stores is delivery fees. Due to the low prices in the German grocery market, retailers calculate tightly, and the margins are low compared to other countries (Seitz, 2013). Therefore, in most cases, the delivery fees cannot be covered by the margins. At the same time, many consumers find the delivery charges too high.

The biggest advantage lies in offering a wide range of products. An average supermarket, for example, offers between 2,000 and 20,000 different items (Nitsche and Figiel, 2016). Online grocery retailers can offer assortments ranging from 30,000 to over 100,000 items in some cases (so called long-tail effect).

The chance of replacing the normal weekly shopping trip to the supermarket with an online order for a significant proportion of the population can be regarded as low in

Germany. However, as a supplement to traditional shopping with an additional channel for certain products or occasions, online food retailing certainly has its justification.

4.2 Macroenvironment (STEPE analysis

Comparing the answers given by the four experts regarding the different factors of the STEPE analysis, the following results could be derived (cf. Table 3).

All one of the experts describe socio-cultural factors as highly relevant or medium relevant. The customer's wish for convenience and their price sensitivity are named by several experts as key factors. German customers are regularly described as particularly price sensitive. Also, a trend to focus more on convenience can be found in the literature (Yeo et al., 2017; Saarijärvi et al., 2014).

Again, the industry experts agree on the relevance of technological factors to be highly important. They state that an automation of the processes is necessary to achieve the profitability of the business model for online food retail. In their opinion, an automation of the warehouse processes will be likely, citing Ocado in Great Britain as an example, on the one hand. On the other hand, however, they believe that an automation of the delivery processes is unlikely.

Regarding the economic factors, no specific relevance is identified. The interviewees believe that a good economic environment might speed up the market development and that an economic crisis might slow the development down. However, economic factors will not influence the path of development.

Political factors will only play a little role in the development of the online food retail market according to the experts. They agree that the political system in Germany is stable. Antitrust laws and minimum wage are mentioned as factors with a certain relevance for the industry.

Ecological factors are assessed with medium to high relevance. Important topics in this are waste (food and packaging) and CO2 emissions. The fleet electrification of delivery vehicles is stated as an important development and a solution for the reduction of emissions, which coincides with different studies (Nitsche and Figiel, 2016).

Table 3: Factors of the STEPE analysis ranked by the experts

STEPE analysis category	Expert A	Expert B	Expert C	Expert D
Socio-cultural	+++	+++	+++	++
Technological	+++	+++	+++	+++
Economic	+	0	0	0
Political	++	0	+	+
Ecological	+++	++	++	++

+++ high relevance ++ medium relevance + little relevance 0 no relevance

In summary, it can be stated that the experts are in accordance that social-cultural and technological factors will have the most relevance for the future development of the industry.

4.3 Scenarios

Following the identification of the relevant factors, expressions are formulated for each of the key factors. The results of this step are given in Table 4.

Table 4: Possible key factor manifestations

STEPE analysis category	Key factor	Possible manifestations
Socio-cultural	(1) Price sensitivity of consumers	(1a) Price sensitivity decreases, customers are willing to spend a higher percentage of their income on food. (1b) Price sensitivity stays the same.
	(2) Need for convenience of consumers	(2a) Convenience becomes very important to German consumers. (2b) The need for convenience stays at the current level.
	(3) Experiencing look and feel of products	(3a) Consumers trust in retailers to pick their products even for fresh foods. (3b) Most consumers still want to examine their fresh foods themselves and experience the look and feel firsthand before the purchase.
Technological	(4) Automation	(4a) Warehouse automation is profitable, so companies invest into automation technologies like picking robots. (4b) Automation of warehouse or delivery are not profitable. Processes stay mostly manual.
Political	(5) Minimum wage	(5a) The minimum wage stays at its current level.

STEPE analysis category	Key factor	Possible manifestations
		(5b) The minimum wage for untrained workers is increased significantly.
Ecological	(6) Waste avoidance	(6a) Political requirements for waste avoidance stay the same, also consumer awareness of the issue is unchanged. (6b) Legal requirements for packaging and food waste avoidance are stricter.
	(7) CO2 emissions	(7a) Legal requirements for CO2 emissions stay at the current level. (7b) Legal requirements for CO2 emissions become stricter. Companies have to undertake greater efforts to save CO2 emissions and become carbon neutral.

The fourth step is the scenario generation. The manifestations of the factors are now combined in a way that extreme scenarios form which open the scenario funnel. We also decided to create a third scenario with a specific property based on findings from the literature. The combinations of possible manifestations are presented in Table 5.

Table 5: Scenarios generated

Scenario generated	Combination of key factor manifestations

Best-case scenario	(1a), (2a), (3a), (4a), (5a), (6a), (7a)
Worst-case scenario	(1b), (2b), (3b), (4b), (5b), (6b), (7b)
Scenario with focus on shelf-stable food	(1a), (2a), (3b), (4a), 5-7 not relevant

(1) Best-case scenario: Many consumers had positive experiences ordering food online during the COVID-19 pandemic, which can be seen as a wildcard event breaking with the trend. Their price sensitivity has weakened somewhat, and they attach great importance to convenience. The larger order volume makes warehouse automation feasible for retailers. Despite political requirements for a minimum wage and the use of electric vehicles and waste avoidance, profitable business models can be developed in this way.

The share of online retail in the overall food trade is increasing, as is already the case in other countries.

(2) Worst-case scenario: The positive development during the COVID-19 pandemic cannot be continued. Sales figures fall back to the level before 2020. The price sensitivity of customers remains high. It is also extremely important to most customers to assess the touch and feel of fresh produce for themselves (Seitz, 2013). Automation in the warehouse or for delivery remains unprofitable. Political requirements such as the increase in the minimum wage and ecological requirements to avoid waste and reduce CO2 emissions are putting retailers under further pressure.

Start-ups do not receive renewed financial injections after a few years. All companies in the online food retail market that offer a typical supermarket product range continue to make losses. One by one, retailers are discontinuing their online business or filing for insolvency. Larger retailers may succeed in converting their online business to profitable niches. Most niches are served by only one monopolist (e.g., cooking boxes by HelloFresh).

(3) Scenario with focus on shelf-stable food: The creation of this scenario was considered for three reasons. Firstly, studies show that preferably shelf-stable foods are bought online (PWC, 2018). Secondly, supply chain and delivery processes are less complex for

non-refrigerated and more durable products. Finally, some big German retailers offer online services only for products of this kind (e.g., dm and netto).

Consumers have had positive experiences with ordering food online. However, it is important to them to choose fresh products such as fruits and vegetables themselves. As a trend, it can be deduced that mainly heavy and long-life foods are ordered online. Online retailers are adjusting their product ranges and fulfillment concepts. Not having to handle fresh and delicate products makes automation easier and cheaper. The increase in online retailing for shelf-stable products is having an impact on traditional supermarkets. They are focusing on fresh products in their stores. Long-life products, which customers do not want to examine on site, can be ordered in advance and then picked up on site (click-and-collect) if fresh products are also purchased from the retailer.

The online share of total business will increase in the coming years but will not reach the same level as in other industries or countries.

5 Conclusion

In this paper, we investigate the future development of the German online food retail market with the help of a scenario analysis. Socio-cultural and technological factors have the highest relevance for the online food retail market. Three different scenarios are developed based on different manifestations of the factors price sensitivity, need for convenience, automation of the fulfillment processes, as well as minimum wage, waste avoidance and CO2 emission reduction:

(1) Best-case scenario: Online food retail establishes itself in Germany due to changing consumer preferences that enable profitable business models. In the long term, the online share will rise to a double-digit percentage, as in other industries and countries. However, the market is also consolidating, so that only a few retailers compete.

(2) Worst-case scenario: Online food retail is not successful in Germany except in special niches. These are mostly occupied by monopolists. Retailers who do not serve a niche continue to make losses, so they either leave the market or change their offer fit a niche.

(3) Scenario with focus on shelf-stable food: Online food retail is successful for long shelf-life food. However, consumers prefer to buy fresh products on site. Online retailers adjust their business models accordingly, which also leads to traditional supermarkets changing their approach. They become multi-channel retailers offering click-and-collect fulfillment options for shelf-stable food and focusing the product presentation on site on fresh products and produce.

6 Limitations

The research results presented are on the one hand based on four interviews with industry experts. Due to the fast pace of the online food retail market, some insights gained may already be outdated. For further investigation, more interviews with a broader variety of experts should be conducted to validate the results obtained.

On the other hand, further data was collected by studying industry and media reports using a secondary case study analysis. Here we were dependent on those reports being publicly available at the time of the survey, which may skew the results.

Acknowledgements

The author would like to acknowledge the support of the Technische Universität Berlin and the Chair of Logistics for this project. The author would furthermore like to acknowledge the work of Beckmann et al., 2020, which was presented at HICL 2020 and published as part of the Proceedings, as a foundation for the research presented in this paper.

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Logistics Platform Strategies for Freight Technology-enabled Smart Services

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Purpose: *In this paper, the authors investigate logistics platform strategies in the road freight market through the analysis of business models of logistics service providers (LSPs) and freight technology providers (FTPs). The purpose of this paper is to gain knowledge of emerging freight technologies and to explore logistics platform strategies between LSPs and FTPs enabling smart services.*

Methodology: *This paper follows an empirical analysis approach to study business models using the concept of Business Model DNA. To this end, the business models of 25 LSPs and 15 FTPs are investigated according to 55 business model patterns (BMPs). Subsequently, the authors conceptualize four logistics platform models to demonstrate how LSPs can manage nascent freight technologies.*

Findings: *The authors argue that freight technology-enabled smart services can promote digital forwarding by logistics platform strategies. LSPs can make use of complementary service capabilities while FTPs can benefit from profound customer access and physical logistics resources.*

Originality: *To the best of the authors' knowledge, no empirical research exists that consistently focuses on logistics platform strategies for freight technology-enabled smart services. The obtained insights in this study lead to the first contribution of digital platform strategies for road freight transportation in the sphere of digital logistics.*

First received: 16. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Due to its cross-function between industries, the road freight market represents a vital element for global economies. While transportation costs account for a value of EUR 513 billion p. a. in Europe, EUR 246 billion account for road transportation by trucks (Schwemmer, 2019, p. 41 and p. 57). Despite its economical contribution, the forwarding business is yet characterized by the use of heterogeneous and proprietary information systems (IS) within a fragmented trucking sector (Backhaus et al., 2017). In lights of the digital transformation, logistics service providers (LSPs) have to manage a vast number of customized systems and operational information and communication technologies meet the digital requirements of their customers to remain competitive in an increasingly data-driven market (Wurst, 2021; Seifert, 2017).

At the same time, "smart" logistics platforms have been recently recognized as a key enabler to realize digital forwarding and achieve efficiency by integrated and connected road freight operations (Sucky and Asdecker, 2019) towards data-driven transport management (Heinbach et al., 2021). To achieve real-time transparency and enable data exchange within a fragmented industry with siloed data, the emergence of digital platforms driven by start-ups appear disruptively in the form of electronic marketplaces, digital freight exchanges, and digital freight forwarders (Göpfert and Seeßle, 2019; Elbert and Gleser, 2019; Mikl et al., 2020). Hence, digital business models are driven by venture capital investment in global transport and logistics that has increased remarkably from 3.5 USD billion to 13.8 USD billion between 2017 and 2019 (Oliver Wyman, 2020).

For instance, innovative logistics start-ups such as Cargonexx and RIO Cloud operate as a digital intermediary to aggregate and enrich data from transport orders and physical assets (e.g., trucks). Beyond, the providers develop data-driven services to enhance the order flow between shippers and carriers, support operational decision-making, increase visibility, and automate processes in both a vertical and a horizontal direction. The appearance of specialized enterprises focusing digital technologies in the forwarding industry is discussed in practice as "Freight Technologies" (Roland Berger GmbH, 2020) and addresses the phenomenon of freight technology providers (FTPs), which disrupt the traditional forwarding business through their cloud-based digital service capabilities in

the road freight industry (Baron et al., 2017; Ortwein and Kuchinke, 2021). Thus, platform-enabled "smart" services from operational data by FTPs reveal new business opportunities to optimize road freight efficiency, to facilitate forwarding processes between stakeholders, and to promote collaboration by the utilization of siloed data within transport ecosystems in the digital age.

Against this backdrop, it becomes obvious that traditional logistics service providers (LSPs) risk becoming increasingly obsolete in light of FTP developments in the future (Kille, 2018) due to scalable transport platforms concepts fostering connected and automated platform ecosystems (Wagner et al., 2020). Hence, we raise the question of how LSPs can address freight technologies to extend their established business models and to develop data-based (smart) services in the digital platform age for transport stakeholders? To answer this question, this paper assumes the following options for LSPs to make use of freight technology-enabled smart services: (1) join an existing logistics platform, or (2) collaborate with existing FTPs. To explore the strategic options of relevant logistics platform strategies (FPSs) between LSPs and FTPs we aim at an analysis of their business models to identify the individual elements and to understand the benefits of freight technologies for LSPs. Our approach is the first contribution to the best of our knowledge, which strives for the conceptualization of FTPs in the road freight industry to guide practitioners and scholars towards platform strategies and future research.

Following this line of thinking, we apply the concept of Business Model DNA (Böhm et al., 2017) in this study to identify business model elements from LSPs and FTPs, which are further specified by the consideration of data-driven transport management. In addition, we derive four logistics platform strategies for freight technology-enabled smart services and further suggest a procedure to establish the logistics platform between LSPs and FTPs enabling digital forwarding.

2 Fundamentals

2.1 Logistics Platforms in Freight Forwarding

Logistics platforms in the road freight forwarding market have a tradition and can be determined as a digital marketplace between shippers, freight forwarders, and carriers (Bierwirth et al., 2002) to enable matchmaking of freight shipments and truckload capacities (Graser et al., 2017). Other platforms concepts exist that support the process of freight procurement (Wurst, 2020) and digital order management (Dietrich and Fiege, 2017). Beyond, logistics platforms for freight transportation realize connectivity of IT systems to facilitate end-to-end visibility (Riedl et al., 2018), as well as the service intermediation between shippers and carriers (Hentschel et al., 2019) to improve freight asset utilization and avoid empty runs of trucks (Hofmann and Osterwalder, 2017). A particular digital platform phenomenon has emerged in recent years and is discussed by scholars as “Digital Forwarder” or “Digital Freight Forwarder” (Elbert and Gleser, 2019; Göpfert, 2019, p. 267). Digital forwarders act as an intermediary between shippers and carriers and their unique selling proposition against other logistics platforms is the liability character in combination with fixed freight rates for shippers (Hentschel et al., 2019).

In essence, the new form of creating value from data by logistics platforms is founded on multi-sided marketplaces that allow interactions and transactions between several market participants (Hagiu and Wright, 2015). While providers facilitate platform-based transactions, the platform appearance in the road freight industry can be divided into three different types (Evans and Gawer, 2016): transaction platforms (e.g., Timocom), data-focusing platforms (e.g., Cargonexx), and integration platforms (e.g., RIO Cloud).

2.2 Freight Technology Providers

The road freight service industry is a fragmented market and composed by a variety of small and medium-sized transport operators (e.g., carriers). Since road carriers’ operational environment is characterized by limited resources, low margins, and missing standards, software vendors, enterprises with an IT-focus, and start-ups have noticed the

vast potential to establish new digital platform concepts years ago. Based on the idea of "Uberization", IT and software vendors particularly succeed in the digital forwarding industry since they use platform and data technologies as the primary resource to realize service innovations for advanced transport management (Heinbach et al., 2021). In addition, technology providers remain a flexible and cost-competitive resource for traditional road freight providers (Roy and Fellenberg, 2020). The platform-based freight services by providers are discussed as "Freight Technology" (short FreightTech) in practice and promise a digital forwarding business towards intelligence, automation, and integration of freight transportation (Roland Berger GmbH, 2020). Thus, in this paper, we define freight technology providers (FTPs) by two attributes: (1) FTPs represent organizations from the software and IT sector, which make use of advanced (digital) technologies, and (2) FTPs realize smart services based on data from transport orders and assets to support digital forwarding. In essence, FTPs enable direct interactions between shippers and carriers based on "as-a-Service" offerings towards digital transport management (Figure 1).

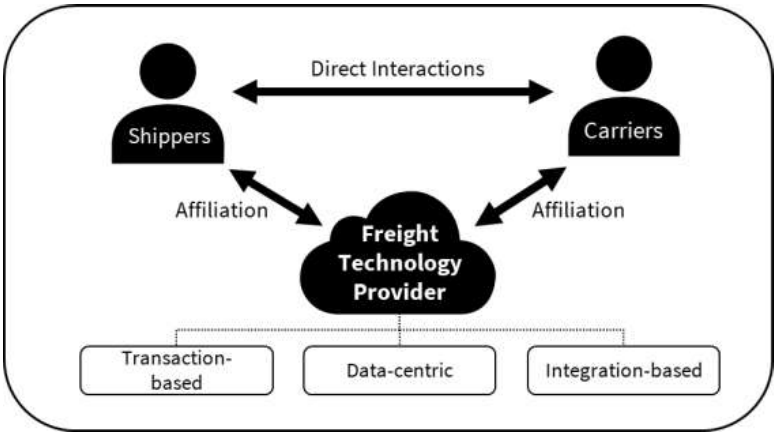


Figure 1: Concept of Platform-based Freight Technology Providers based on Evans and Gawer (2016)

The digitization of transport management activities allows FTPs to move established transport processes into the cloud-based environment (Dietrich and Fiege, 2017; Kille and Wagner, 2017). As a consequence, traditional LSPs risk losing their role as the former intermediary in the transport value chain (Kille, 2018). For this reason, we explore

logistics platform strategies for LSPs to facilitate smart services in road freight transportation by FTPs.

2.3 Smart Services in Road Freight Transportation

Smart services have emerged significantly in the context of "Industry 4.0" and "Logistics 4.0" since they refer to individual services based on data that are mainly developed and offered by the use of internet-based communication and information technologies (acatech, 2015). Various benefits arise from data-driven services in contrast to traditional services. For instance, remote services enable product accompanying services for a remote-controlled output, such as repair (Remote Repair), diagnosis (Remote Diagnosis), or maintenance (Remote Maintenance) of assigned machinery across distances (Wünderlich and Wangenheim, 2007; Kammler et al., 2019). Consequently, smart services reveal various business opportunities in the logistics industry specifically for logistics service providers due to the cost-saving effects through the integration of data-based services and the adaption of their existing business model (e.g., Thomas et al., 2015).

Since the internet represents an open and standardized transport ecosystem, smart services can increase the efficiency of logistics chains and realize new business models through real-time processing of orders, improved decision-support from analyzed data, collaboration with transport resources, and the exploitation of innovative value creation potentials (Zsifkovits and Woschank, 2019). Due to the fragmented forwarding industry, the cloud indicates particular opportunities for the harmonization of IT applications and the development of smart services associated with digital business models leading to "smart forwarding" (Heinbach et al., 2020). For this reason, LSPs such as DB Schenker or Emons Gruppe should contemplate emerging freight technologies from innovative platform providers such as Freightos or Pamyra to realize smart services (e.g., ETA, real-time freight rate management) in a growingly digital and competitive business environment. In this context, we study logistics platform strategies of freight technology-enabled smart services to support the decision process collaboratively addressing both FTPs and LSPs. The methodology to answer our research questions will be presented in the following section.

3 Research Method and Data Collection

3.1 Research Method

A systematic literature review is a recommended method to summarize existing knowledge and to identify research gaps related to our topic. Although our topic represents an emerging research field that is a nascent phenomenon, we conducted literature research according to Vom Brocke et al. (2009). We defined the review scope of the last five years and established keywords, such as "logistics platforms", "digital forwarding", "business models", in combination with "freight technology". Subsequently, we queried scientific databases (EBSCO host, Springer Link, Emerald, Google Scholar) to search relevant literature. Surprisingly, no contribution we have identified does address freight technologies and smart service in the forwarding sector towards platform strategies indicating that our study presents the first contribution in this topic.

To investigate the structure of business models of existing LSPs and FTPs in the road freight transport sector, we apply the concept of Business Model DNA suggested by Böhm et al. (2017). The concept is based on the St. Gallen Business Model Navigator and covers 55 patterns, which represent 90 percent of the business models existing today (Gassmann et al., 2013). We aim to identify the business model structure and to understand the strengths and weaknesses from both perspectives of the traditional logistics market as well as the new digital logistics market. Furthermore, we seek to find complementary business model aspects between LSPs and FTPs to understand freight technology-enabled platform capabilities. Thus, we build the Business Model DNA according to the 55 patterns developed by Gassmann et al. (2013) and assign binary variables for each business model pattern (BMP), which indicates whether it is available or not (Figure 2).

Provider \ Pattern	**1**	**2**	**3**	**4**	**5**	**6**		**49**	**50**	**51**	**52**	**53**	**54**	**55**
LSP name 1	1	0	1	1	0	0		0	1	1	0	1	0	1
...	...						...	...						
FTP name 1	0	1	1	0	1	0		1	0	1	1	0	0	1
...	...							...						

Figure 2: Exemplary Business Model DNA adapted from Böhm et al. (2017)

3.2 Data Collection

To collect the data for the conduction of the Business Model DNA analysis, a selection of LSPs was made based on the work »TOP 100 in European Transport and Logistics Services« according to the English version of Schwemmer (2019). This comprehensive work represents the top-ranked logistics service providers across all multimodal business segments operating in Europe. We selected LSPs by two criteria to ensure our focus on road freight transport services. First, we selected LSPs providing Full Truck Load (FTL) services. Second, we refined our selection by selecting LSPs providing Less Than Truckload (LTL) services in addition. From the selection process, 25 LSPs were identified for further analysis in this study.

FTPs have been selected in the form of logistics start-ups from a database, which has been established by Schwemmer et al. (2021). The database was established starting in 2017 and contains start-ups and other new ventures that are active in logistics by providing logistics services, supporting logistics service providers, or establishing themselves as intermediaries between LSP and their customers from the industry and retail sectors. 15 companies were extracted by keyword search for the keyword platform in the database. The keyword could be found in several database entries in string variables with information about the companies' offerings. The final selection contains companies dubbed as platform providers, which remained active in Europe.

We collected the data by describing the business model of LSPs and FTPs and searching the web. Additional information sources included providers' websites, press reports, and interviews with founders or CEOs that were publicly available. This task was performed by the authors independently and separately for either LSPs or FTPs because of their professional experience and specific knowledge focus. After the assignment of the binary variable to the BMPs, the results from the empirical analysis were clustered and presented in network graphs to assess the networks of LSPs and FTPs. Based on the results, the authors derive freight technology-enabled smart services and further conceptualize logistics platform strategies for LSPs.

4 Analysis of Business Models and Smart Services in Road Freight Transportation

4.1 Business Model Cluster

The following data assessments were carried out with Gephi (Ver. 0.9.2) (Bastian et al., 2009), a software that enables network analyses. The software allows to draw network graphs and assess those networks in an explorative manner in terms of network density, the nodes, and their connections, and clusters within those networks. According to the aim of the assessments to identify clusters of LSPs and FTPs depending on their BMP, the following two visualizations contain two types of nodes. One type shows the companies assessed in the network. The other nodes depict the BMP that got assigned during the assessment phase of the project. Their labels are introduced with a hashtag symbol (#). The edges of the graph show the connections from each company node to the assigned BMP. Company nodes are not connected to each other.

The first visualization contains the network that represents the established field of LSP active in Europe (Figure 3). The network contains more than 500 edges that connect LSPs to the assigned BMP. From the 55 BMP a count of 33 could get assigned to the assessed 25 LSP. 11 BMP are matching the business models of all assessed LSPs and are appropriate to describe a general forwarding service. Plausibly, the most diverse among the assessed players got assigned to the highest numbers of BMP, i.e. 26 or more BMP were matched to the business models of Deutsche Post DHL, Deutsche Bahn AG, Dachser SE, DB Schenker (considered as part of Deutsche Bahn DB and assessed additionally), Kuehne + Nagel and Rhenus SE. These build a cluster in the center of the network graph with the most differentiated service offerings.

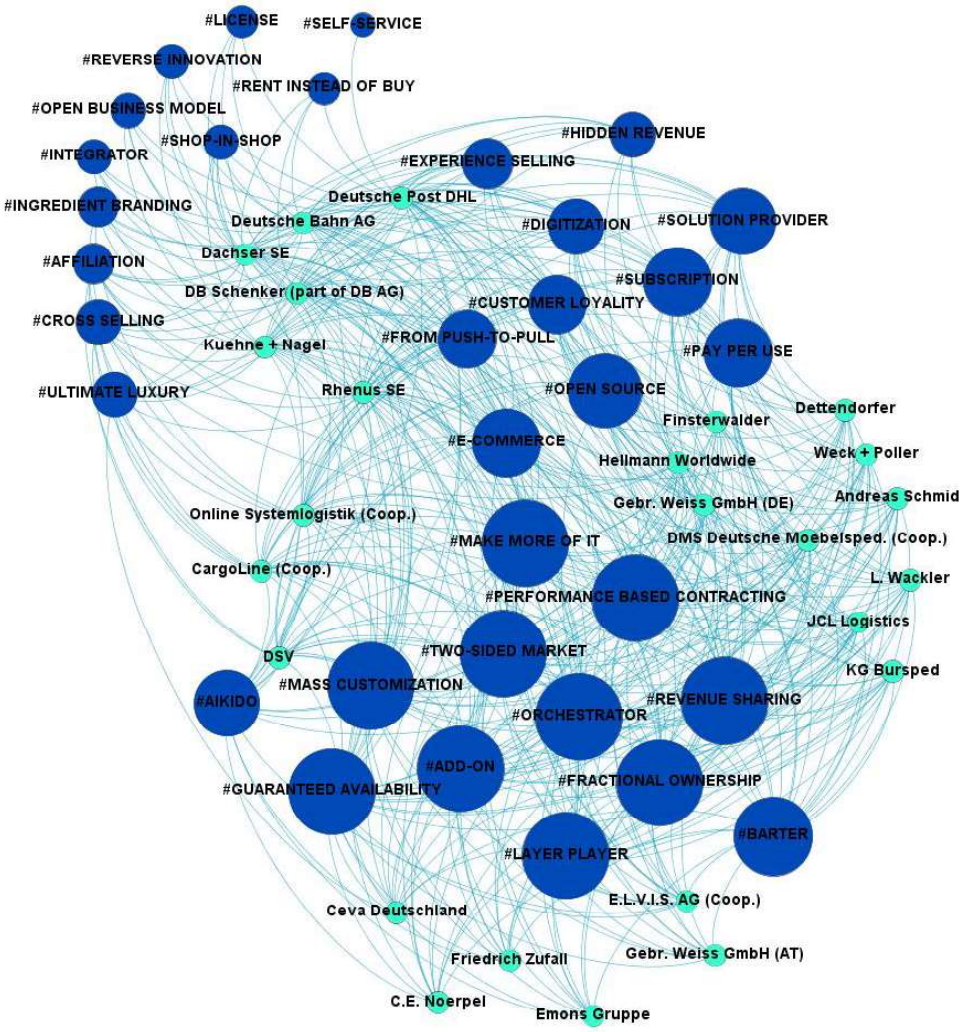


Figure 3: LSP Network graph

A second cluster contains LSPs that are connected to a mediocre number of 16 to 21 BMP in the right corner. A third cluster at the bottom of the graph contains LSPs offering more standardized services and are therefore connected to up to 15 BMPs. Three additional LSPs do not form a clear cluster in terms of how many BMPs are matching their business models. The assessment of the LSP-BMP-networks suggests that the more diversified and larger those LSPs are, the more differentiated are their business model compositions.

The second visualization shows the network that represents the result of the data assessment for logistics platforms operated by FTPs (Figure 4). 10 of the 55 BMP got assigned to those platforms. Compared to the assessed LSPs, the number of assigned BMP is lower by a palpable amount. For instance, the platform providers seem more focused.

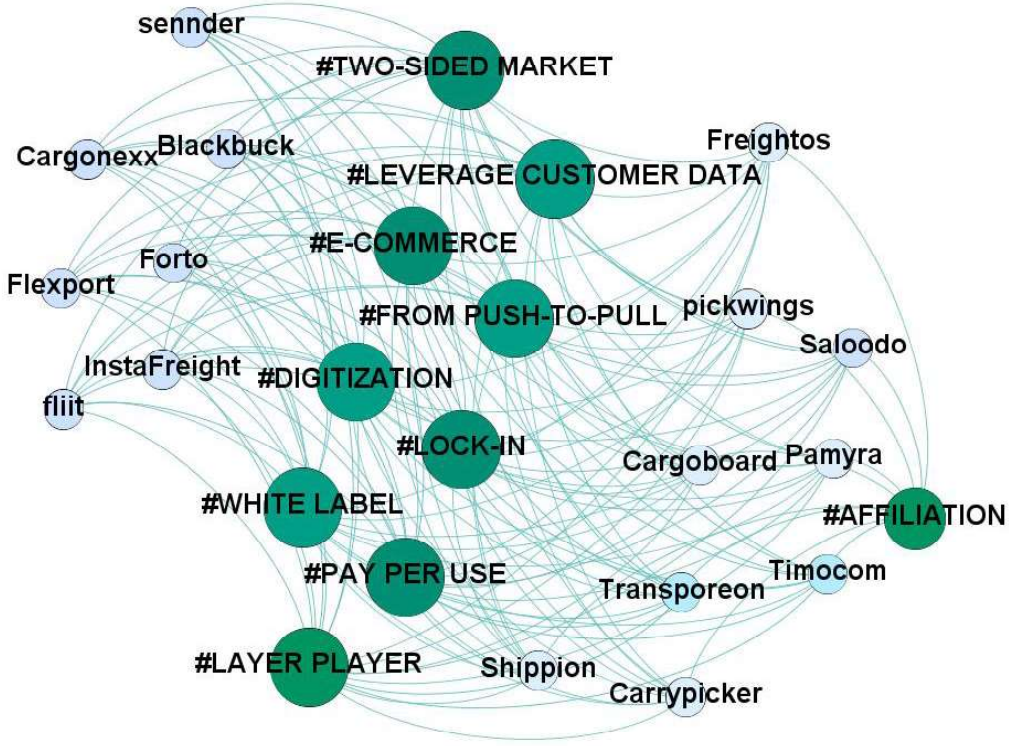


Figure 4: FTP Network graph

Located in the middle of the graph are those BMP that match the business models of all the included platforms. The companies in the graph are divided into two clusters. The BMP "affiliation" divides these clusters. In those cases that are connected to this BMP "…the focus lies in supporting others to successfully sell products and directly benefit from successful transactions." (Gassmann et al., 2013, p. 9). This BMP got assigned to those platforms that do not carry out transportation as a legal entity but connect customers to logistics service providers. The companies that did not get assigned to the "affiliation" node carry out logistics services as digital freight forwarders. These

companies become legal partners of customers and do not only connect other parties of the logistics market. Digital freight forwarders also become competitors of the above-assessed LSPs, while the other clusters play a role in supporting established LSPs in their respective fields of activity.

For both of the assessed company types (LSP and FTP), Table 1 presents the BMPs that are assigned to our comprehensive sets of LSPs and FTPs as the least common multiple or backbone of the respective business models. The comparison in Table 1 indicates that the business models of the two company types differ vastly from each other. FTPs are by far more focused and therefore are more similar to each other in terms of their Business Model DNA.

Table 1: Comparison of Business Model Patterns: LSPs vs. FTPs

BMP Title	Explanation of BMP (Gassmann et al., 2013)	LSP	FTP
Add-on	Additional services are offered to a basic offer	x	
Barter	Goods exchange without immediate money transaction	x	
Fractional Ownership	…of a certain asset class	x	
Guaranteed Availability	…of the service provided	x	
Make more of it	Know-how and assets get shared with customers	x	
Mass Customization	Individualization of transportation services	x	
Orchestrator	…of transportation services, also with subcontractors	x	

BMP Title	Explanation of BMP (Gassmann et al., 2013)	LSP	FTP
Performance Based Contracting	According to individual service levels for customers	x	
Revenue Sharing	Strongly pronounced cooperation with competitors as partners or subcontractors	x	
Layer Player	Providing a special value adding-step (transport)	x	x
Two-Sided Market	Shippers are connected to freight service providers	x	x
Digitization	…of former physical products/services to digital variants		x
E-Commerce	…of transportation services		x
From Push-to-pull	High flexibility to respond to customer needs		x
Leverage Customer Data	…for value-adding		x
Lock-in	…to the service providers service realm		x
Pay Per Use	Payment based on what is consumed effectively		x
White Label	Customers are enabled to offer the companies service under their own brand		x

4.2 Freight Technology-enabled Smart Services

During our analysis, we have identified a variety of smart services from FTPs that support the process of road freight transport management. These services have shown an alignment to Transport Management Systems (TMSs) representing a standardized

software for order handling, shipment execution, and administration of transports. Hence, we found that platform participants (e.g., shippers, carriers, forwarders) make use of freight technology-enabled smart services beyond their TMSs to enhance the order flow, support operational decision-making, increase visibility, and automate processes. In Figure 5 we illustrate examples of smart services assigned to the types of logistics platforms already introduced in section 2.1. The services are assigned to the dimensions of road freight transport management as the second level of systematization. Our findings are based on the results of Roy and Fellenberg (2020) as well as Heinbach et al. (2021) and provide a range of freight technology-enabled smart services throughout the road freight order lifecycle.

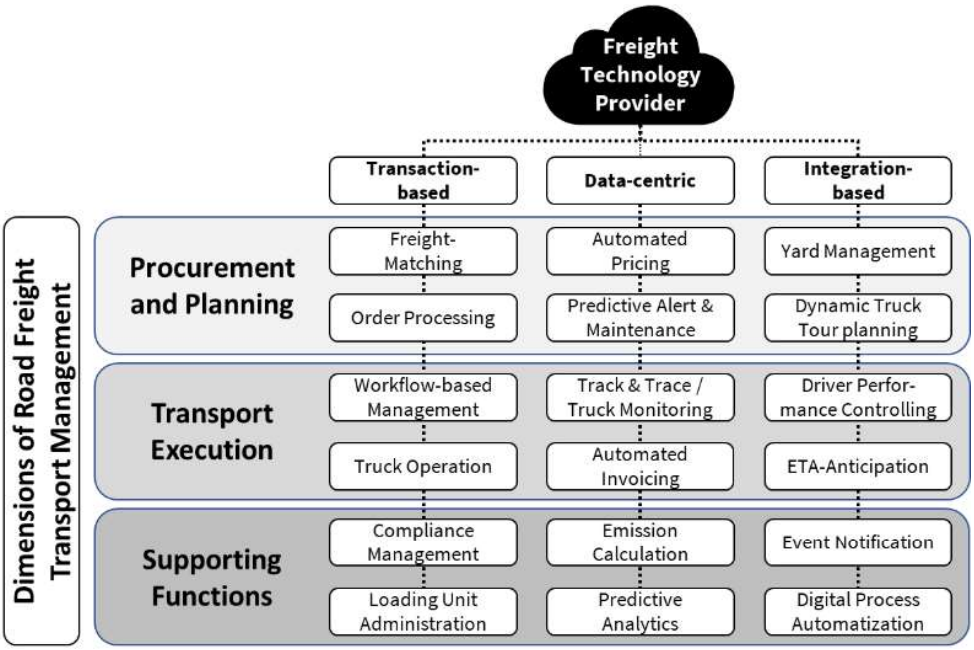


Figure 5: Examples of Freight Technology-enabled Smart Services based on Roy and Fellenberg (2020) and Heinbach et al. (2021)

5 Conceptualization of Freight Technology-enabled Logistics Platform Strategies

5.1 Objective

According to our analysis, FTPs provide complementary services for LSPs by realizing digital forwarding services for improved transport management. At the same time, FTPs are growingly in competition with traditional LSPs due to their digital bypass capabilities as the new intermediary between shippers and carriers (Kille, 2018). Their agile and flexible qualities to create data-based value employing logistics platforms represent unique selling propositions with disruptive potential in the fragmented road freight market. To decide on the position of LSPs in light of the new freight technology innovations for smart service realization, conceptual options provide systematic guidance for both LSPs and FTPs. For this reason, we propose logistics platform strategies aiming at the following objectives:

- Give orientation for the establishment of platform strategies for the integration of additional transport stakeholders
- Provide guidance for the allocation of duties within transport chains
- Increase transparency of FTP capabilities within LSP organizations towards digital business models
- Create a starting point for scholars and practitioners for further exploration or adaptions of logistics platform strategies

5.2 Logistics Platform Strategies

To address the logistics platform objectives based on the findings in this study, we propose four logistics platform strategies in this paper. For the first strategic option (Figure 6), LSPs can employ FTPs founded on multi-sided marketplaces that allow interactions and transactions between several market participants (Hagiu and Wright, 2015). For instance, the matchmaking of freight resources and related orders does increase asset utilization and optimize customer service levels. LSPs can make use of multiple logistics platforms to increase the matching results known as “multihoming” (Seiter et al., 2019). However, LSPs and FTPs operate separately according to their selling

propositions and maintain individual business models. An FTP example for this strategic concept is presented by the enterprise Timocom.

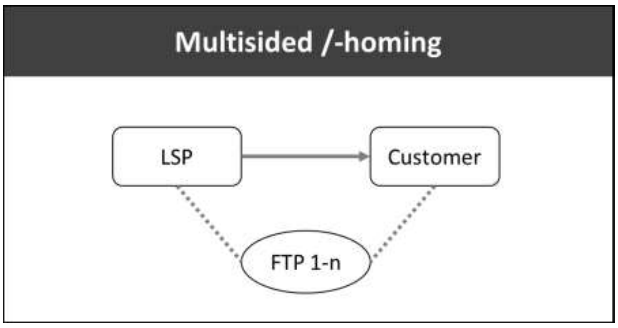


Figure 6: Proposed "Multisided / -homing" Logistics Platform Strategy

A second strategic option for LSPs and FTPs arrives through the collaboration of LSPs and FTPs by specific agreements leading to a "Smart Forwarding Provider" towards customers (Figure 7). This concept supports collaborative digital business models by a unified service provider through partnership programs. Accordingly, LSPs obtain exclusive smart service capabilities and the generated revenue is shared between LSPs and FTPs. Beyond, LSPs can use this option to increase their innovation competence and develop future road freight services based on data together with FTPs. For example, if LSPs organize full truckloads within complex transport networks, freight technologies are used to deliver ETA and manage yard operations for advanced transport efficiency collaboratively. The enterprise Pamyra is found as a corresponding example.

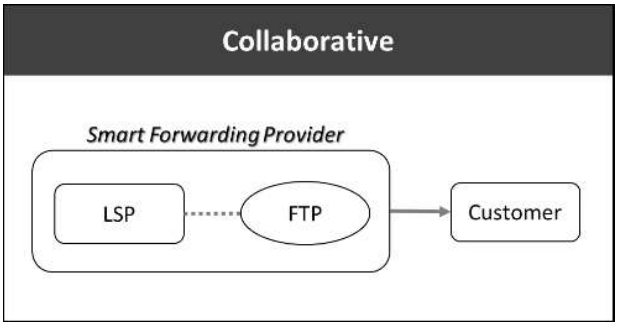


Figure 7: Proposed "Collaborative" Logistics Platform Strategy

The third proposed option refers to a modular-integrated logistics platform strategy (Figure 8). This concept engages data technology providers (e.g., provider of truck

telematics systems) from an FTP perspective additionally to aggregate and streamline data offered to LSPs (e.g., transport operators managing their asset). As a result, LSPs are transformed into a "Smart Managed Fleet Provider" due to the enrichment of asset-based data for digital transport management. The newly generated services lead to the adoption of existing business models. To give an example, position and performance data from transport means can be used in real-time across mixed fleets to support ETA and the monitoring of fuel consumed for advanced emission tracking services for customers. Herein, we found Forto as a corresponding example in practice.

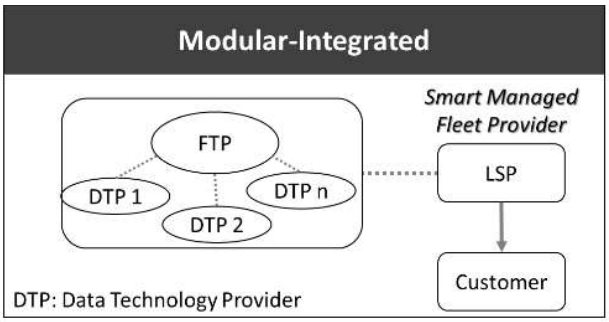


Figure 8: Proposed "Modular-integrated" Logistics Platform Strategy

In the fourth strategic option, a platform concept is formed by LSPs, which incorporate FTPs within their organizational business scope to promote advanced smart service innovations (Figure 9). This concept is founded particularly by start-ups that are acquired by medium-sized and large enterprises leading to a "Smart Freight Service Provider" due to the smart service capabilities beyond the transport activities. For instance, start-ups that develop technologies based on artificial intelligence can be of strategic importance for LSPs since the technology can be used for dynamic route planning in the transport field and warehouse management at the same time to predict capacity constraints and support planning activities jointly. Thus, incorporation of FTPs is considered as an effort with significant monetary investment for LSPs while the generated business model contributes to digital service innovations in logistics. A corresponding example for this platform strategy is found by Salodoo (DHL).

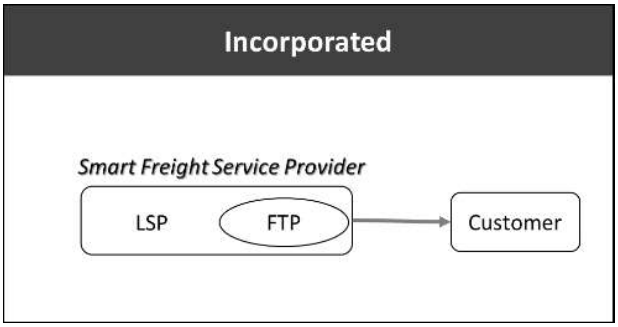


Figure 9: Proposed "Incorporated" Logistics Platform Strategy

5.3 Procedure to Establish Logistics Platform Strategies

The proposed logistics platform strategies reflect the paradigm of digital and connected freight transport systems and stress the traditional forwarding concept. This development is discussed in the context of supply chain visibility in theory and practice since freight technologies promote transparency while fostering the control of logistics chains (Möller et al., 2020; Roland Berger GmbH, 2020). Beyond, the value of data for road freight operations is not limited to digital platforms and marketplaces but rather provide further opportunities in the context of logistics ecosystems by integrating other relevant logistics stakeholder that can benefit from smart services, such as insurance companies or maintenance providers for trucks. Consequently, we see a high relevance for the proposed platform strategies in practice to facilitate technological collaboration in a complex industry. To achieve our objectives presented in this section, we suggest a four-step procedure and present actions for the establishment of logistics platform strategies between LSPs and FTPs (Figure 10). The procedure marks a starting point and logistics players receive orientation and guidance to develop their individual platform strategy.

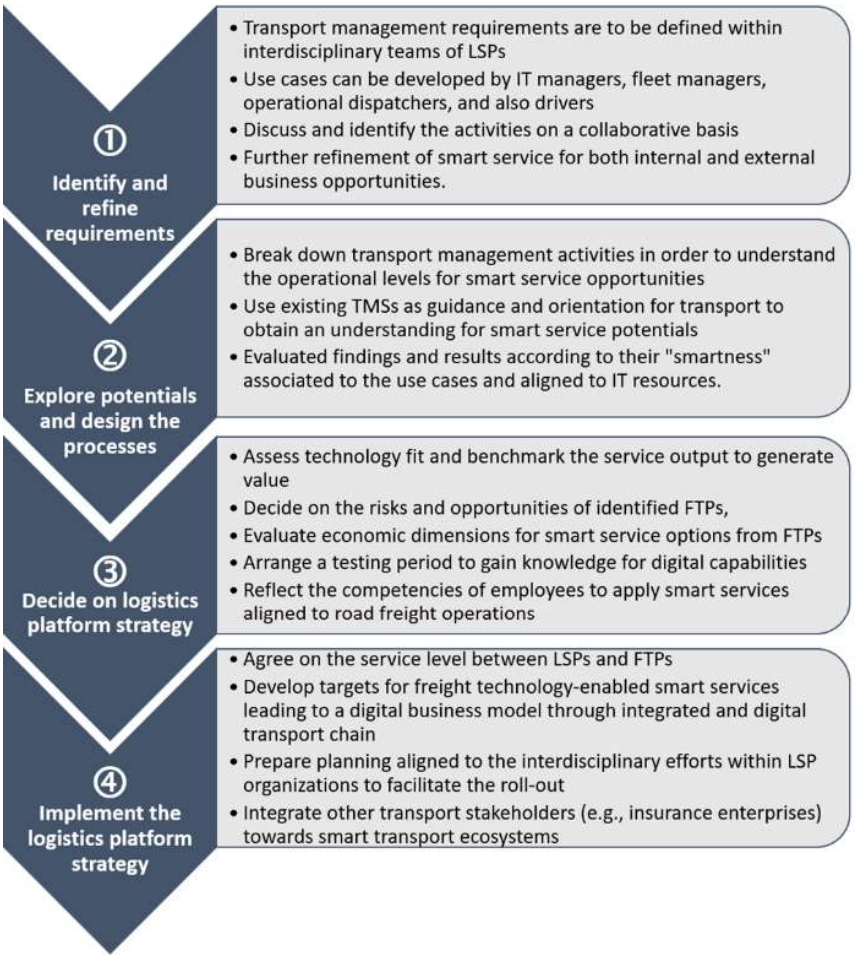


Figure 10: Suggested Procedure to establish Logistics Platform Strategies

The procedure constituted above suggests initial tasks to manage the proposed logistics platform strategies. The strategic concepts are based on freight technology-enabled smart services which operate within a cloud infrastructure supporting interconnected smart transport ecosystems.

6 Discussion and Limitations

Logistics platforms operate as the digital enabler to facilitate smart services within the fragmented road freight industry (Kille and Wagner, 2017). To this end, freight technology providers (FTPs) maintain cloud-based services along the process of road freight

transport management while logistics service providers (LSPs) recognize the emerging trend of freight technologies towards the achievement of unique selling propositions.

Our study explores a new market of logistics platforms in a specific business context and we are convinced that it can also contribute to the broader picture of understanding digital transformation in logistics. FTPs use data as the primary resource to offer customers services (El Sawy and Pereira, 2013) based on the facilitation of transactions and the integration of IS between shippers, carriers, and forwarders. Particularly, our analysis of business models has shown the opportunities of complementary services by FTPs to digitize road freight lifecycle. The four platform strategies we have derived from the business models of LSPs and FTPs represent a blueprint for further development towards platform-based and collaborative "smart forwarding" (Heinbach et al., 2020). LSPs and FTPs in the digital age are guided to establish a common strategic ground for new joint business opportunities to strengthen road freight collaboration towards integrated freight operations by intelligent digital platforms (Yang et al., 2017). Hence, our investigation opens new research avenues for scholars to further explore the phenomenon of freight technologies in the realm of digital logistics. Managerial contributions arise in the context of TMSs for operational transport management since managers gain strategic knowledge of freight technologies and receive orientation for developing smart services in a yet complex road freight market.

The investigation has both practical and scientific value despite some limitations that are naturally given. First, our exploration is founded in data from 25 LSPs and 15 FTPs only. Even we considered a broad range of data, our coverage is neither comprehensive nor representative for LSPs and FTPs in the logistics sector in general. Additional providers to be involved might uncover further business model paradigms and smart services. Second, our examination is related to the road freight market and the consideration of other modes of transports may reveal other business specifications. Third, our conceptualization of logistics platform strategies remains simplified compared to the real-world environment since we draw the concepts on an abstracted level. Fourth, the four concepts are derived by individual interpretation from authors with professional experience related to the business sector. However, other researchers may have concluded other findings with minor differences to our results.

7 Conclusion and Outlook

Road freight transportation is increasingly transformed into a digital business through the emergence of freight technology-enabled smart services. In this paper, we study logistics platform strategies between logistics service providers (LSPs) and freight technology providers (FTPs) according to their business model structures. To this end, we apply the concept of Business Model DNA to evaluate 55 patterns for business models for 25 LSPs and 15 FTPs to cluster the aggregated structures. We present the results in network graphs, demonstrate relevant smart services assigned to the dimensions of transport management, and further derive four platform concepts.

The findings in this study serve as a starting point in an emerging digitally transformed business field with fruitful research opportunities. Further research should investigate the success factors and platform governance of the proposed platform strategies in more detail. Beyond, we see the opportunity to study the phenomenon of freight technology beyond visibility and optimization towards intelligent and automated transport ecosystems that may, at least to some extent, act autonomously in the future. More data is required to provide more evidence on Business Model DNA, smart services, and platform strategies within a fragmented business sector. Business models in the digital freight forwarding age should be investigated rigorously to engage the field of service engineering, platform design, and digital transport ecosystems in the technology-driven domain. These initiatives are beneficial for LSPs to navigate in the era of digital transformation and illuminate the ongoing evolution of digital ecosystems in a challenging business environment. We hope to motivate other scholars by our contribution to further study digital platform capabilities and data ecosystems in the sphere of digitalization that helps to enhance the understanding of smart service innovations through the use of freight technologies.

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Logistics Innovation and Integration: Impact on Supply Chain Adaptability

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Purpose: *This study investigates the relationships among innovation by logistics services provider (LSP), user's supply chain (SC) adaptability, and the level of the user-provider relationship integration. Using low integrated, standard contractual relationships as a reference group, this study assesses how moderately integrated partnerships and highly integrated strategic relationships moderate the impact of LSP's innovation on the user's SC adaptability.*

Methodology: *Moderated partial least squares structural equation modeling (PLS-SEM) was performed on survey data collected from 48 Sudanese companies.*

Findings: *The findings revealed that innovation by LSPs had the greatest positive impact on SC adaptability in firms maintaining a moderate level of logistics integration. Interestingly, firms highly integrated with their LSPs witnessed a reduced effect of logistics innovation on their SC adaptability. In other words, while user-provider partnerships reinforced the impact of LSPs' innovation on user's SC adaptability, strategic relationships weakened this impact.*

Originality: *Extant literature advocates fully integrating with LSPs to build a responsive, efficient SC. Nevertheless, the complexities of managing a highly integrated relationship with LSPs may pose challenges that exceed the expected benefits of such relationships. This study provides empirical evidence that moderate, rather than full, integration with LSPs may yield greater benefits for the users of logistics services.*

First received: 19. Apr 2021 *Revised: 02. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Fueled by population urbanization and the increasing prevalence of e-commerce, the demand for logistics services is exploding (Amling and Daugherty, 2018), placing tremendous pressure on logistics services providers (LSPs) to enhance their processes and become as competitive as never before. Broadly defined as all helpful services that are new in the eye of the beholder (Flint et al., 2005), logistics innovation is therefore becoming an imperative in the new economy in order to improve the bottom-lines of LSPs and win customers loyalty (Chapman, Soosay and Kandampully, 2002; Flint et al., 2005; Grawe, Chen and Daugherty, 2009; Wallenburg, 2009; Wagner and Sutter, 2012; Asian et al., 2019).

Over the past decade, logistics services user-provider relationships have witnessed a remarkable shift away from the traditional short-term transactions toward relationships that are strategic in nature (Premkumar, Gopinath and Mateen, 2020). Such integration is emerging as an innovative approach in inter-firm relationship management (Yang and Zhao, 2016) since standard contractual logistics relationships are not expected to foster innovation (Chen, Jin and Huo, 2020). Due to their short-term and adversarial nature (Cox, 1996; Halldórsson and Skjøtt-Larsen, 2004), firms now strive to go beyond such “arm's length” relationships with a minimum of information interchange (Skjoett-Larsen, 2000) to build closer relationships with competent LSPs to reap the benefits of their competence (Bhatnagar and Viswanathan, 2000).

With an accelerated pace of change in the business landscape, building efficient supply chains (SCs) is no longer sufficient (Christopher and Holweg, 2011). SC adaptability is therefore considered a prerequisite for sustaining competitive advantage (Eckstein et al., 2015; Feizabadi, Gligor and Alibakhshi Motlagh, 2019; Gligor et al., 2020). The purpose of this study is to examine how SC adaptability is affected by LSP’s innovation and integration. Specifically, this study investigates the effect of LSPs innovation on SC adaptability at moderate and high levels of user-provider relationship integration, compared to low level of integration.

The remaining of this study is organized as follows. First, the theoretical underpinnings and subsequent hypotheses development are presented. Next, the methodology of the

study is explained, followed by presentation of the findings and their discussion. Finally, the managerial implications, limitations and future research directions are provided.

2 Theory and Hypotheses

To enable greater focus on core competencies and service improvement, firms outsource their logistics function (Maloni and Carter, 2006). Having some or all of the logistics activiteis managed and executed by LSPs makes the users increasingly dependent on their LSPs as their entire SC perfromance is affected by the quality of LSPs‘ services (Giri and Sarker, 2017). Following a Resource Denedepnce perspective (Pfeffer and Salancik, 1978), integraion is therefore proposed as an effective strategy to manage inter-organizational relationships and mitigate adverse consequences of asymmetric power/dependencies and uncertainties in a SC (Zhang and Huo, 2013; Huo et al., 2015; Perdana, Ciptono and Setiawan, 2019).

2.1 Logistics Services User-Provider Relationships

A common understanding in literature is that logistics services user-provider relationships are placed on a continuous scale ranging from single transactions to integrated service agreements, and that the degree of logistics integration, including the level of formalization and mutual obligations, is proportional to the level of required skills and the associated asset specificity (Bowersox, 1990; Cox, 1996; Hertz and Alfredsson, 2003; Halldórsson and Skjøtt-Larsen, 2004; Hsiao et al., 2010; König, Caldwell and Ghadge, 2019).

The lowest level of user-provider relationships is the contractual relationships. These merely transactional arrangements offer standardized services and are characterized by short-term orientation and low asset specificity, targeting mainly cost reductions (Cox, 1996; Halldórsson and Skjøtt-Larsen, 2004). User-provider partnerships represent a higher level of logistics relationships. Offering customized services selected from a broad range of standard services, this type of relationships typically targets access to complementary skills, and usually involves low/medium asset specificity since the

services can easily be adjusted to other clients (Halldórsson and Skjøtt-Larsen, 2004; Hsiao et al., 2010). The highest level of user-provider relationships are the strategic relationships. Unlike previous engagements, the logistics solutions provided in this relationship are unique and jointly developed. The two parties invest in long-term oriented specific assets often involving human as well as physical assets. The innovation capabilities are "essential" in this type of relationships, and both parties are willing to share information, coordinate processes, and solve problems jointly (Halldórsson and Skjøtt-Larsen, 2004; Hsiao et al., 2010; König, Caldwell and Ghadge, 2019).

2.2 Innovation in Logistics Services User-Provider Relationships

Firms innovate to face the accelerating change and competition in today's turbulent environment. A provider of logistics services is no exception (Grawe, Chen and Daugherty, 2009), as it strives to design superior solutions that "exceed those of its competitors and of the customer itself [to] survive the selection process" (Wallenburg, 2009, p.77). Logistics innovation refers to everything that is different from a company's current practice, and is used for improving logistics operations (Flint et al., 2005; Grawe, 2009; Daugherty, Chen and Ferrin, 2011). This includes ideas, technology, and services, as well as procedures, processes, and practices (Flint et al., 2005; Grawe, 2009). The advantages of logistics innovation are numerous, as it can improve LSPs' relationships with its customers (Flint et al., 2005), promote customer satisfaction and loyalty (Asian et al., 2019), and help LSPs expand their businesses and achieve higher profitability (Wagner and Sutter, 2012).

The mere reaction to expressed customer demands was prevalent in the logistics industry (Flint et al., 2005; Wagner, 2008). This conduct is no longer sufficient in logistics services user-provider relationships, as users increasingly expect new and innovative solutions from their LSPs (Langley and Infosys, 2020, 2021). Improvements specified to customer requirements help LSPs maintain a stronger user-provider relationship and an overall better performance (Large, Kramer and Hartmann, 2011), especially when initiated by the LSPs (Deepen et al., 2008). This type of proactive innovation that occurs in an ongoing user-provider relationship is a special type of LSP's innovation

(Wallenburg, 2009). Unlike "pure" innovation targeting operational efficiency of the LSPs themselves, or "market" innovation intended to increase the competitiveness of the LSPs, this relationship-specific innovation directly impacts a single customer and is directed towards the improvement of logistics solutions without prior request from the customer (Wallenburg, 2009). Proactive innovation in logistics relationships does not only lead to the achievement of goals, but it also result in benefits exceeding the main targets (Deepen et al., 2008), resulting in increased customer loyalty (Wallenburg, 2009).

Logistics Innovation and SC Adaptability

The logistics outsourcing decision was previously driven by efficiency targets and better resource allocation (Skjoett-Larsen, 2000). Today's driving forces are more strategic in nature, and are directed towards facing increasing SC complexity (Hsiao et al., 2010) and improving flexibility towards the changing market conditions (Langley and Infosys, 2019). LSP's innovation capability enables it to incorporate logistics innovation to solve problems and adapt in such fluctuating SC environment (Wang et al., 2020). LSPs can utilize unique and innovative solutions to achieve the targeted adaptability without sacrificing their bottom-lines (Amling and Daugherty, 2018). The use of Open E-Logistics Standards (OELS), for example, were proposed as an "effective boundary-spanning mechanism" to integrate various SC activities and leverage process adaptability (Pu, Wang and Chan, 2020). Another example is the technology-based, on-demand pick-up locations that enable highly adaptable networks (Amling and Daugherty, 2018).

As discussed above, general innovation is expected to improve the logistics outsourcing performance. This study investigates the effect of proactive innovation on a specific aspect of the user's performance, i.e., its SC adaptability. This study thus proposes the following hypothesis:

H1. LSP's proactive innovation is positively associated with the user's SC adaptability

2.3 The Role of Logistics Integration

Integration is the essence of supply chain management (SCM) (Perdana, Ciptono and Setiawan, 2019). It can be described as the collaborative management of independent value-adding processes both inside and outside firms' boundaries (Flynn, Huo and Zhao,

2010). Firms integrate, i.e., create linkages and share knowledge and resources, internally among different departments as well as externally with their suppliers, customers, and logistics service providers (Flynn, Huo and Zhao, 2010).

Driven by volatility of the business environment and the increasing demands of customers, the development of strategic orientation is taking root in logistics services user-provider relationships (Yang and Zhao, 2016; Premkumar, Gopinath and Mateen, 2020). Users of logistics services invest in relationship specific assets with their LSPs to face uncertainties of demand and supply (Huo et al., 2018). Coupled with a high level of integration, this recipe is expected to trigger innovation is logistics services user-provider relationships (Wagner and Sutter, 2012; Pedrosa, Blazevic and Jasmand, 2015). Thus, a logistics services user can boost its operational performance when integrating with its LSPs (Hofer, Smith and Murphy, 2014). From an LSPs perspective, integration improves operational performance (Hemstrom, 2014) and financial performance (Huo et al., 2017). Offering integrated logistics solutions also enables LSPs to negotiate a higher price for their services (König, Caldwell and Ghadge, 2019). Ultimately, integration will bring benefits for both the user and provider of logistics services.

Since integrated logistics relationships put the user-provider relationship "at the center of a firm's strategic and operational thinking" (Panayides and So, 2005), this study proposes that when firms advance their relationship with LSPs into higher levels of integration, i.e., engage into partnerships or strategic relationships, the positive impact of LSPs innovation on users' SC adaptability will be strengthened. More specifically, the following hypotheses are proposed:

- H2a. The relationship between LSP's proactive innovation and user's SC adaptability is stronger for firms engaging in user-provider partnerships compared to contractual relationships.
- H2b. The relationship between LSP's proactive innovation and user's SC adaptability is stronger for firms engaging in strategic user-provider relationships compared to contractual relationships.

The figure below (Figure 1) illustrates the conceptual framework of the study.

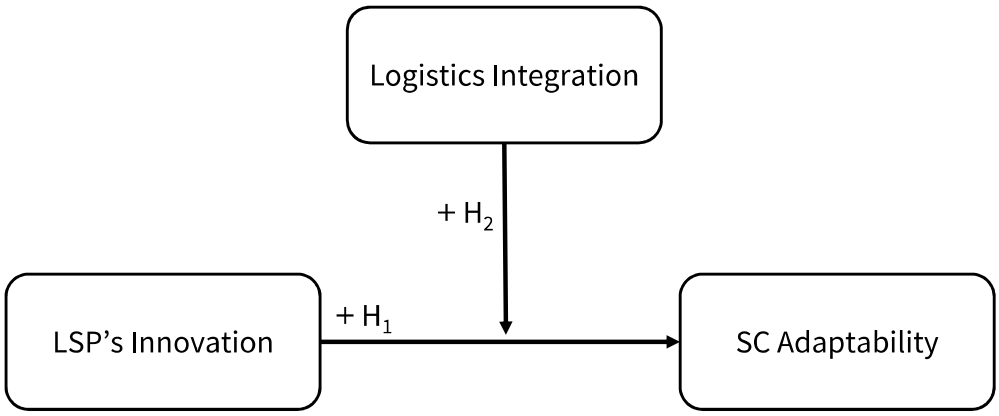


Figure 1: Conceptual framework

3 Methodology

3.1 Sample and Data Collection

The data was collected from a sample of Sudanese companies via a survey instrument. The city of Khartoum was the target for data collection. Questionnaires were hand-delivered to 146 managers from 66 firms. A total of 134 questionnaires were retrieved. Six questionnaires were discarded due to incompleteness, yielding a response rate of 88 percent. Since the unit of analysis for this study is the firm, responses from the same firm were reduced to one using the criteria of 'the middle manager with the longest experience', resulting in 64 responses. Out of the 64 remaining firms, 16 firms did not use logistics outsourcing, so they were also excluded from the analysis. The final sample of Sudanese companies included 48 companies.

The analysis of the sample demographics showed that a quarter of the firms were from the Food and Beverages industry, and another quarter were from the Petroleum, Chemical, and Medical industries. The sampled firms were relatively new, as 57 percent of them were founded after the year 2000. Finally, the majority of firms (63%) were of medium size (100 – 999 employees). Table 1 provides the details of the sample demographics.

Table 1: Sample Demographics

Industry	N	%	Firm size	N	%
Food and Beverages	12	25.0	Less than 100	6	12.5
Petroleum, Chemical, and Medical Products	12	25.0	100 – 999	30	62.5
Nonmetallic Products	1	2.1	More than 1000	8	16.7
Electrical and Electronic Products	1	2.1	Missing	4	8.3
Metal Products and Machinery	2	4.2	Total	48	100.0
Finance and Insurance	3	6.3	Firm age	N	%
Wholesale and Retail	2	4.2	1951 – 2000	17	35.4
Telecommunication	7	14.6	2000 ~	25	52.1
Others	8	16.7	Missing	6	12.5
Total	48	100.0	Total	48	100.0

3.2 Measurement

Pre-validated measures were used in this study. Construct items were measured using a 7-points Likert scale (1 = strongly disagree/much worse, 7 = strongly agree/much better). SC adaptability (SCAdpt) was measured a three-item reflective construct. The items were adapted from Pu, Wang and Chan (2020). Respondents were asked to compare to their closest competitor(s) their firms' ability to adapt its SC relationships, business priorities, and activities to respond to different changes in the market and the external environment. Logistics innovation (LSPInn) was measured using a four-item reflective

construct. The items were adapted from Deepen et al. (2008). Respondents were asked to indicate their level of agreement with statements reflecting the innovativeness and proactive improvements made by their LSPs. Logistics Integration was measured using a categorical/factor variable developed based on previous literature (Hsiao et al., 2010; Liu et al., 2015; Halldórsson and Skjøtt-Larsen, 2004). Respondents were asked to choose one out of three statements describing the relationship with their LSPs, including the type(s) and nature of used services, and the major target for the engagement in the relationship. The statements correspond to three levels of integration: low integrated contractual relationships using standard services with a focus on efficiency (reference group), moderately integrated partnerships using customized services with a focus on access to complementary resources (PRTNship), and highly integrated strategic relationships using advanced services with a focus on flexibility (STREship). Firms' sizes (number of employees) and industry (Manufacturing = 1, non-manufacturing = 0) were included as control variables. Table 2 presents the descriptive statistics and correlations among the variables of the study.

Table 2: Descriptive Statistics and Correlations

	Mean	SD	1	2	3	4	5
1. Size	658.06	1272.54	1.000				
2. Industry	n.a	n.a	0.237**	1.000			
3. SCAdpt	5.278	1.153	-0.145	-0.037	1.000		
4. LSPInn	5.255	1.063	-0.101	-0.088	0.480**	1.000	
5. PRTNship	n.a	n.a	0.181	0.184	-0.022	-0.045	1.000
6. STREship	n.a	n.a	-0.189**	-0.108	0.181	0.255**	-0.475**

n = 48, **p<0.05

4 Analysis and Results

Partial least squares structural equation modelling (PLS-SEM) using SmartPLS (Ringle, Wende and Will, 2005) was used for the analysis of this study. PLS-SEM is a popular and powerful method in the Marketing and Management research (Hair et al., 2014) with the ability to handle small sample sizes (Hair, Ringle and Sarstedt, 2011; Hair et al., 2014, 2019). For these reasons, it was chosen as the analysis method in this study.

Since the data was collected from single informants, the presence of common method bias must be checked. The occurrence of a VIF greater than 3.3 is proposed as an indication that a model may be contaminated by common method bias (Kock, 2015). The highest VIF score among constructs was 1.25, indicating that the model is free of common method bias.

4.1 The Measurement Model Assessment

The indicator loadings of the two constructs, SCAdpt and LSPInn, ranged from 0.73 to 0.96, above the recommended level of 0.708 (Hair et al., 2019). Cronbach's alfa (α) and composite reliability (CR) scores were good, as they exceeded the recommended level of 0.70 and are below the level of 0.95, indicating internal consistency reliability (Hair et al., 2019). The convergent validity of the constructs was established as average variance extracted (AVE) scores exceeded 0.50 (Hair et al., 2019). Finally, the heterotrait-monotrait (HTMT) ratio of the correlations was 0.55, far below the threshold of 0.90 (Henseler, Ringle and Sarstedt, 2015) indicating discriminant validity. According to these results (see Table 3), the measurement model meets all the required criteria (Hair et al., 2019).

Table 3: Measurement Model Assessment

Constructs and Items	Loadings
LSPInn (α = 0.87, CR = 0.81, AVE = 0.64)	

Constructs and Items	Loadings
LSPInn1	0.78
LSPInn2	0.73
LSPInn3	0.89
LSPInn4	0.78
SCAdpt (α = 0.91, CR = 0.94, AVE = 0.85)	
SCAdpt1	0.96
SCAdpt2	0.92
SCAdpt3	0.88

4.2 The Structural Model Assessment

Before proceeding to the structural model assessment, the collinearity of indicators and constructs were examined using variance inflation factor (VIF) scores. Since none of the VIF scores exceeded 5 (Hair et al., 2019), no collinearity issue was detected.

To test the study's hypotheses, three models were developed (see Table 4). In all models, no effects of control variables (size and industry) were detected. In the Model 1, the direct effect of the independent variable, LSPInn, and the two moderators (PRTNship and STREship) on the dependent variable, SCAdpt were examined. The results presented in Table 4 show that LSPInn positively impacts SCAdpt (β = 0.459, p-value = 0.000) and explains about 20 percent of the variance in SCAdpt (R^2 = 0.242, adjusted R^2 = 0.191), providing support for the first hypothesis (H1). The two moderators show no effect on the dependent variable, SCAdpt.

In Model 2, the effect of LSP's innovation on user's SC adaptability at a moderate level of integration, i.e., the moderating effect of user-provider partnerships was tested. As

shown in Figure 2 and Table 4, the interaction term LSPInn*PRTNship was positive (β = 0.363, p-value = 0.004), indicating that the relationship between LSPInn and SCAdpt is strengthened in logistics services user-provider partnerships. The percentage of the explained variance in the dependent variable (SCAdpt) increased to almost 30 percent (R^2 = 0.369, adjusted R^2 = 0.294). This positive moderating effect renders the second hypothesis (H2a) acceptable.

In Model 3 (see Figure 3 and Table 4), the effect of LSP's innovation on user's SC adaptability at a high level of integration, i.e., the moderating effect of strategic user-provider relationships was tested. The interaction term LSPInn*STREship was, surprisingly, negative (β = -0.352, p-value = 0.004) with an improved percentage of explained variance from the original 20 percent in Model 1 (R^2 = 0.335, adjusted R^2 = 0.256). This result provides support for the exact opposite of the third hypothesis (H2b), meaning that the relationship between LSPInn and SCAdpt is weakened, rather than enforced, for firms engaging in strategic user-provider relationships compared to contractual relationships. Thus, H2b is not supported.

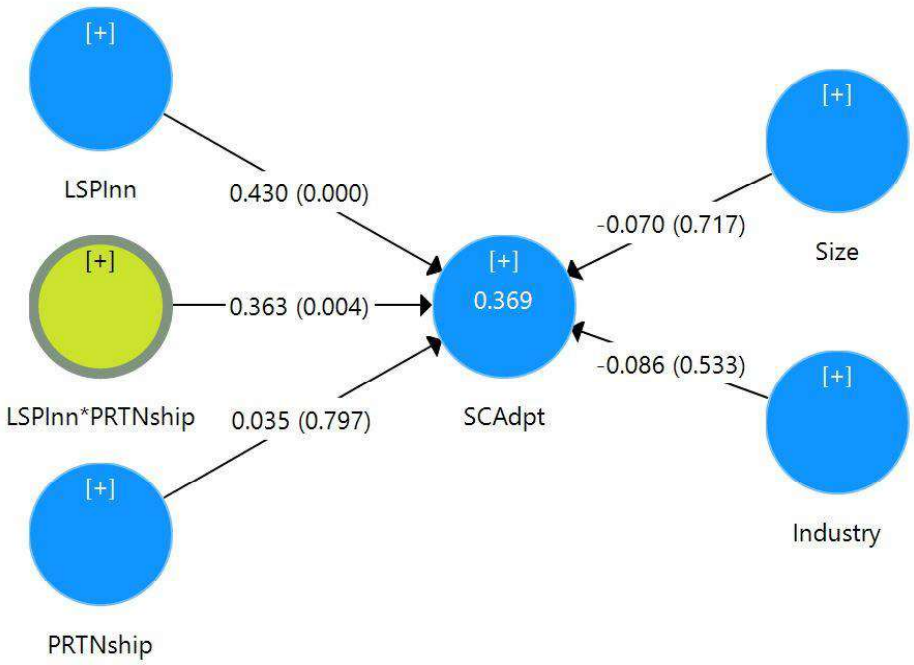


Figure 2: The effect of LSP's innovation on SC adaptability at a moderate level of integration

Table 4: Analysis Results

Path	Model 1	Model 2	Model 3
LSPInn→ SCAdpt	0.459***	0.430***	0.425***
PRTNship → SCAdpt	0.045	0.035	
STREship → SCAdpt	0.069		0.133
LSPInn*PRTNship → SCAdpt		0.363***	
LSPInn*STREship → SCAdpt			-0.352***

** p<0.05, ***p<0.01

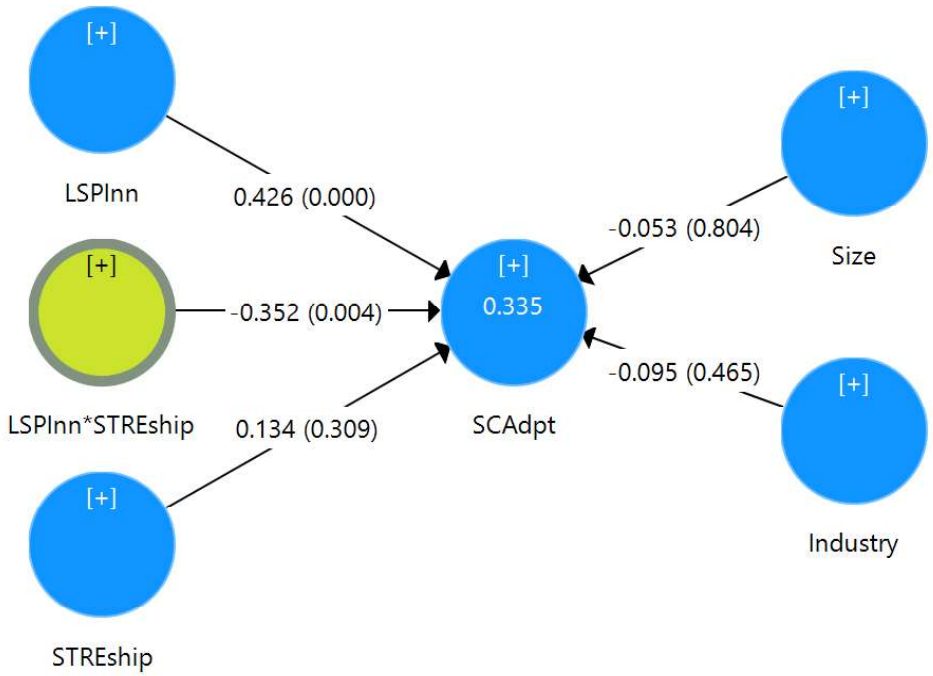


Figure 3: The effect of LSP's innovation on user's SC adaptability at a high level of integration

5 Discussion

Users of logistics services rely on LSPs' competencies, including their innovativeness, to enhance their own competitive positioning (Bhatnagar and Viswanathan, 2000). In strategic logistics relationships, such reliance is greater as users expect LSPs to drive innovation and continuously improve logistics solutions (Flint et al., 2005; Langley and Infosys, 2020, 2021).

This study investigated the impact of proactive innovation by LSPs on SC adaptability. The findings support previous research (e.g., Amling and Daugherty, 2018; Wang et al., 2020) that LSPs innovation drives higher capabilities, including adaptability. This study contributes to the literature by providing empirical evidence that such impact of LSP's innovation on SC adaptability is moderated by the depth of the relationship between the user and the provider of logistics services.

As suggested by the findings, a moderate, rather than high, level of logistics integration provides the highest benefit for the user in terms of SC adaptability. More specifically, logistics services user-provider partnerships characterized by a moderate level of integration reinforced the positive impact of LSPs innovation on SC adaptability.

Contrary to the proposed hypothesis, strategic user-provider relationships weakened the innovation-adaptability relationship. Although it may be puzzling at first glance, some explanations could be suggested to understand such unexpected finding.

From a context perspective, the findings were based on a sample from the Sudanese business environment, which is characterized by many sources of political and economic complexities (The World Bank, 2021). These traits may justify why the management of strategic, long-term relationships could be demanding and thus bring more challenges than benefits for the user. This conclusion is consistent with evidence found in the literature (e.g., Yang and Zhao, 2016) associating market volatility and uncertainty with decreased integration in logistics outsourcing relationships.

Additionally, the success of outsourcing advanced logistics services is contingent upon the availability of proper outsourcing management processes (Zhu et al., 2017). Basic logistics services, however, can provide benefits for the user in terms of cost reduction

and delivery performance without such management processes (Zhu et al., 2017). It is possible that users upgrading their relationships with LSPs from contractual to strategic relationships underestimate the need for appropriate selection, performance measurement and control processes based on their previous experiences with basic logistics services, leading to failure in achieving the required efficiency and flexibility targets when outsourcing advanced logistics services.

Furthermore, strategic user-provider relationships may prevent users from switching to other viable providers when necessary due to the creation of a "lock-in" effect (Schmitz, Schweiger and Daft, 2016), leading to reduced flexibility and adaptability to market changes. Based on the previous discussion of the study findings, we can conclude that, ironically, strategic relationships targeting flexibility do not only fail to achieve this target, but they also reduce logistics innovation's contribution.

6 Conclusion

The aim of this study was to investigate the impact of LSP's proactive innovation on SC adaptability, and to assess this impact on various levels of logistics services user-provider relationships. The findings confirmed the positive effect of LSP's innovation on SC adaptability, and revealed that this effect is strengthened in user-provider partnership characterized by a moderate level of logistics integration. An interesting finding was that, contrarily to the expectation of an even stronger positive effect, the relationship between LSP's innovation and SC adaptability was weakened at strategic relationships with LSPs, indicating a negative moderating effect of high logistics integration.

7 Practical Implications

User of logistics services usually extend their relationships with LSPs in order to flexibly gain complementary resources and improve their SC adaptability to various changes in the environment. However, as indicated by the findings of this study, these advantages may not always be attained. In managing logistics services user-provider relationships, users must pay attention to possible drawbacks of a strategic, long-term relationship

with an LSP and carefully balance these with the expected advantages. In a turbulent business environment such as what we witness nowadays, SC managers could be advised to engage in moderate integration with SC partners, including LSP's, in order to mitigate the adverse consequences associated with strategic long-term commitments.

8 Limitations and Future Research Directions

The limitations of this study can be used to direct future research. The results of this study were based on a single-country sample, imposing limitations to possible generalizability. Moreover, cross-sectional data used in the study may, by their very nature, prevent the exploration of longer-term effects. Also, the classification of logistics integration levels in this study was based on three distinct categories, i.e., contractual relationships, partnerships, and strategic relationships. In practice, however, such distinction is not as clear since "intermediate forms are often difficult to classify" (Skjoett-Larsen, 2000) and service providers' types can overlap (König, Caldwell and Ghadge, 2019). Future research can address these issues by conducting longitudinal studies that include samples from several business environments.

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Bus driver's technology acceptance for driving assistants

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Purpose: *According to recent studies, many road accidents could be avoided using driving assistance systems. However, the introduction of increased levels of technology in workplaces is often met with opposition. The paper, therefore, analyzes the bus drivers' acceptance of assistance systems and provides recommendations for increasing acceptance.*

Methodology: *Using a mixed-method research approach of conducting interviews (N = 8) and an online survey among professional bus drivers (N = 81), we test a theoretical framework based on the Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT) with qualitative content analysis and multiple regression analyses.*

Findings: *The interview findings suggest that TAM and IDT provide a suitable theoretical grounding for analyzing the bus driver's acceptance. The quantitative results confirm a positive attitude towards digital transformation processes at the bus driver's cab while, among others, the functionality and perceived usefulness experienced by the drivers can facilitate acceptance.*

Originality: *The paper analyzes the use of assistance systems in the workplace of professional bus drivers from various perspectives. Concerning technology acceptance, the present study contributes to a better understanding of underlying acceptance mechanisms in professional bus driving.*

First received: 20. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

New technologies offer opportunities for innovation in the logistics and transportation industry. In this context, the use of assistance systems by bus drivers not only plays a vital role in the prevention of traffic accidents and has an overall positive effect on occupational health and safety (Mokarami, Alizadeh, Pordanjani, & Varmazyar, 2019), but also helps to recruit and retain skilled workers. Extant literature found evidence that assistant systems mitigate CO_2 emissions while the related security also increases driver's well-being (Zarkadoula, Zoidis, & Tritopoulou, 2007). However, assistance systems are not yet widely used and are sometimes rejected by drivers (Gruchmann, Demtschenko, & Salzmann, 2021). Besides economic and regulatory reasons, drivers' negative attitudes toward them might be based on the mental and emotional stress levels generated by their use and the fact that the technology is not universally reliable (Tse, Flin, & Mearns, 2006). To gain more insights into the bus driver's technology acceptance, the following research question guided our research: *Which factors significantly affect the bus drivers' attitudes towards using assistance systems?*

To systematically test factors influencing the acceptance of assistance systems, the present study proposes a theoretical model integrating Innovation Diffusion Theory (IDT) (cf. Roger, 1995) and the Technology Acceptance Model (TAM) (cf. Davis, Bagozzi, & Warshaw, 1989). The TAM is specifically designed to model user acceptance of technologies and information systems and has been widely used in information systems research, often in conjunction with social psychology questions. Also, IDT is a popular theory in a wide range of disciplines to study how people in a social system react to innovations and the processes that result from them. In this context, innovations are understood as various forms such as messages, objects, modern processes, and technical advances (Rogers, 1995). The fundamental question of the IDT is thereby why people make decisions for or against an innovation based on their convictions. For the present research context, an integrated research model of these two fundamental theories, TAM and IDT, is used. The constructs of the extended IDT (compatibility, demonstrability of results, and triability) can be found along with the two main dimensions of TAM (perceived ease of use, perceived usefulness, perceived behavioral

control) as mediators for the intention to use or reject the technology (Yuen, Cai, Qi, & Wang, 2020).

Based on qualitative interviews (N = 8) and a quantitative questionnaire (N = 81) being administered in Germany, the factors influencing the use of legally mandatory assistance systems (e.g., emergency brake assist) and voluntary assistance systems (e.g., adaptive cruise control, turn-off assistant) are examined. These included, among others, the technical functionality and reliability of the systems. As a result, we found functionality and perceived usefulness as the strongest predictors for the intention to use assistance systems. Accordingly, technological innovations with assistance systems constitute an essential cornerstone for increased safety and job attractiveness (Gruchmann, Demtschenko, & Salzmann, 2021). Our study thereby contributes to improving the working conditions in the transportation sector, as well as the driver's perception and appreciation of the activities related to their occupational profile.

The remainder is structured as follows: Section 2 provides a brief literature background, while Section 3 describes the theoretical lens of IDT and TAM and related hypotheses. Section 4 describes the applied research design. Next, sections 5 and 6 present the findings of the qualitative and quantitative investigations. Finally, section 7 discusses the results against previous research, the limitations, managerial implications, and recommendations for future research.

2 Literature Background

Some important research has been published in recent years with a direct reference to bus drivers. In 2006, for example, a report by Tse, Flin, and Mearns (2006) summarized over 50 years of research on the health of bus drivers. Their report found that the most significant stressors for drivers today are the increased volume of traffic, aggressive and potentially violent passengers, and increasingly tight schedules. The studies also indicated that appropriate training, longer breaks, consistent and regular allocation of shifts, and appropriate assistance in road traffic (including assistance systems) could improve bus drivers' well-being as well as driver's and passengers' safety (Tse, Flin, &

Mearns, 2006). Supporting these results, an Australian study by Salmon, Young, and Regan (2011) found similar stressors and reasons for distraction.

A Greek project in 2007 investigated how bus drivers on Athens city routes could be trained to use more efficient driving styles and hence promote environmentally-friendly driving. In several phases, three bus drivers were trained by a Dutch training company and were taught how to drive more efficiently, thereby also using modern assistance systems. After completing the training, the bus drivers used 4.35% less diesel when driving in the city than before. In addition, they noticed that they could drive more economically without slowing down and hence did not risk running behind schedule. The findings showed that even in urban traffic, there need not be any time-related disadvantages for bus drivers when relying on assistance systems as long as appropriate training is provided.

More recently, Mokarami, Alizadeh, Pordanjani, and Varmazyar (2019) studied the relationship between organizational safety culture and unsafe driving behaviors. They particularly found that strategies for improving safety culture can reduce the number of accidents among bus drivers. Similar results were found by Nævestad, Phillips, Laiou, Bjørnskau, and Yannis (2019) for Norwegian and Greek bus drivers. Further, Miller, Filtness, Anund, Maynard, and Pilkington-Cheney (2020) found several factors contributing to sleepiness among London bus drivers. Assistance systems thereby can be seen as a potential means to positively influence safety culture and decrease accidents based on driver sleepiness.

More broadly integrating assisted and autonomous driving technologies into the socio-technical context, the study by Yuen, Cai, Qi, and Wang (2020) examined the decisions made for or against automated vehicles. They found that an integrated model combining the TAM and the IDT is very well suited to carry out further research in this context. According to their study, the advantages of non-automated vehicles and providing targeted training for drivers are factors for the successful adoption of this innovation.

3 Theoretical Background

The TAM was initially developed by Fred Davis and published in 1989 (Davis, Bagozzi, & Warshaw, 1989). The TAM includes two specific constructs: "Perceived Usefulness" and "Perceived Ease of Use." Both dimensions directly influence an individual's attitude towards using a system and are determined by external variables such as demographic factors and personality traits. Attitudes, accordingly, directly influence the behavioral intention to use, which influences the actual system use (Davis, Bagozzi, & Warshaw, 1989). Considering the study's context, we can formulate the following hypotheses:

1. **H1a:** Perceived usefulness of assistance systems positively affects the intention to use.
2. **H1b:** Perceived ease of use of assistance systems positively affects the intention to use.
3. **H1c:** The intention to use assistance systems positively affects the actual usage.
4. **H1d:** The functionality of assistance systems positively affects the actual usage.

The TAM formulates the hypothesis that the potential users' mental assessment about how well work goals correspond to the results of carrying out a work task with the help of the technology serves as a basis for the development of assessments of the usefulness of the system (Venkatesh & Davis, 2000). In addition, subjective norms, following the basic idea that individuals are influenced by the ideas and attitudes of important people, were added as direct determinants of behavior (Venkatesh, Morris, Davis, & Davis, 2003). If personal norms and subjective norms do not match, people will be reluctant to engage with the technology. Davis and Venkatesh (2000, p. 187) explain this as follows: *"People may choose to perform a behavior, even if they are not themselves favorable toward the behavior or its consequences if they believe one or more important referents think they should, and they are sufficiently motivated to comply with the referents."* Regarding the use of assistance systems, we can formulate the following hypotheses:

5. **H2a:** Subjective norms positively affect the intention to use assistance systems.
6. **H2b:** Subjective norms positively affect the perceived usefulness of assistance systems.

7. **H2c:** Technology commitment positively affects the perceived usefulness of assistance systems.

In addition to the TAM, the IDT shall be considered. According to IDT theory, the decision-making process depends on five characteristics of the innovation: relative advantage, compatibility, complexity, experimentability, and observability (Poong, Eze, & Talha, 2009). In addition, the characteristic of observability can be divided into the two characteristics of demonstrability of results and visibility. Finally, the characteristic of voluntariness is introduced in conjunction with triability (Moore & Benbasat, 1991). Therefore, we formulate the following hypotheses:

8. **H3a:** Result demonstrability positively affects the perceived ease of use of assistance systems.
9. **H3b:** Triability positively affects the perceived ease of use of assistance systems.
10. **H3c:** Compatibility positively affects the perceived ease of use of assistance systems.

Figure 1 shows the theoretical framework to be tested.

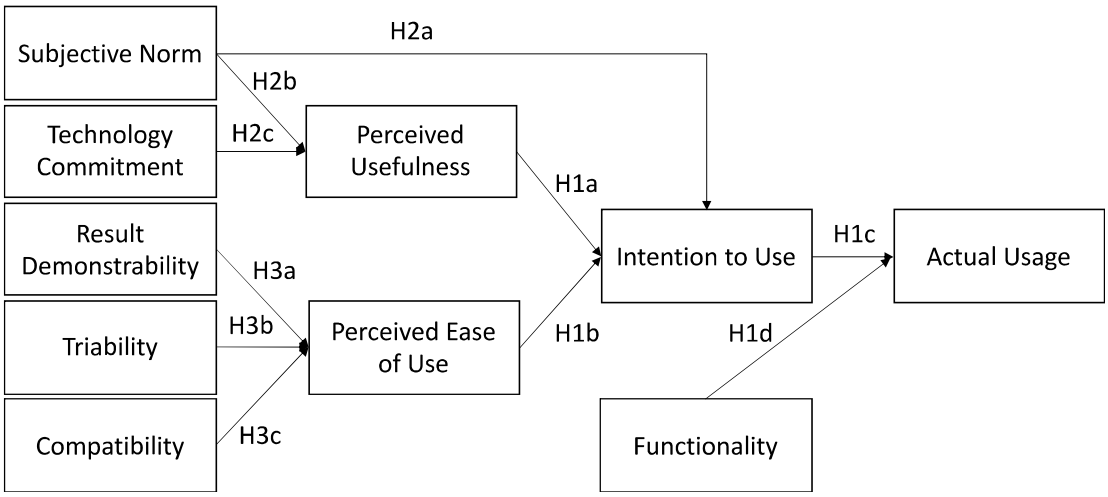


Figure 1: Integrated Theoretical Framework

4 Research Design

To answer the proposed research question, we applied a mixed-method research approach. A quantitative approach was conducted as an online survey among professional bus drivers in Germany (N = 81) to test factors influencing the acceptance of assistance systems statistically. To gain deeper and more exploratory insights into the bus drivers' personal perspectives and opinions with respect to assisted driving we additionally conducted qualitative interviews (N = 8). Mixed-method research designs are widely applied in logistics research, also including the blue-collar worker's perspective on workplace transformations (cf. Gruchmann, Mies, Neukirchen, & Gold, 2020).

4.1 Qualitative Interview Approach

To generate sound qualitative data, guided interviews with experts are particularly productive as a data collection method for identifying bus drivers' personal perspectives and opinions on a case-by-case basis (Riege, 2003). The interviewee selection is deliberately designed to ensure the heterogeneity of the research field under investigation by choosing interviewees from different areas of the industry. Thus, a sample of eight experts was compiled for the research process (see Table 1). An interview topic guide was used. All the interviews were recorded since this increases the accuracy of subsequent analyses and allows the researcher to refer to specific quotes from interviewees. Before the recording, the interviewees were informed that the interviews are recorded, transcribed, and analyzed anonymously.

The analysis of the interviews was carried out in two steps, first the transcription of the audio files and second, the evaluation of the data using qualitative content analysis (Mayring, 2015). First, the transcription process was carried out with f4transcript, a transcription software program. Any details subject to data protection were anonymized within the transcription process. The second step involved the process of evaluating the material obtained with qualitative content analysis. This evaluation process helps to structure the data via a systematic formation of main categories. By defining categories, it is possible to assign text passages to categories that match the content. The categories used were exclusively created by deductive means based on the underlying theoretical

constructs of the TAM and IDT. According to the integrated model by Yuen, Cai, Qi, and Wang (2020), the theoretical dimensions that matched the content were applied as subcategories in the coding process. The entire coding process was carried out using the program f4analysis. It served as a database for the entire text material, allowing to list the main categories and subcategories and organize the coding process.

Table 1: Interviewees

Interviewee	Acronym	Length
Team bus driver for a premier league soccer team	B1	17 minutes
Bus driver for touristic coach travels and shuttle transport	B2	28 minutes
Public bus driver for scheduled bus services	B3	12 minutes
Bus driver for touristic coach travels and long-distance bus services	B4	31 minutes
Bus driver for school shuttle services	B5	22 minutes
Public bus driver for scheduled bus services	B6	42 minutes
Public bus driver for scheduled bus services	B7	32 minutes

Interviewee	Acronym	Length
Fleet manager for public bus operations	B8	22 minutes

4.2 Quantitative Survey Approach

Survey data were collected through a self-administered questionnaire based on the integrated theoretical framework (see Figure 1). The constructs of the questionnaire are displayed in Table 2. Table 2 also shows the measures used together with the descriptive data (mean value and standard deviation) and the code for each item. The participants (N = 81) for this survey were recruited through the Federal Association of German Bus Operators (BDO). The participants were mainly male (N = 73) and had an average age of 52.23 years (SD = 10.44). The majority of the companies employing the respondents can be categorized as small- to medium-sized. All constructs of the questionnaire were measured on a 5-point Likert scale with values from 1 to 5 (ranging from either "never" to "always" or from "strongly disagree" to "strongly agree"). All scales were already applied in other publications and altered for the context of bus driving assistants (e.g., Neyer, Felber, & Gebhardt, 2012). The questionnaire was administered in German. The translation of the questionnaire into English was done through the back-translation technique; the questions were accordingly translated and then retranslated.

Table 2: Constructs and Items

Constructs	Items	Code	Mean	SD
Actual Use	I use the emergency brake assistant	AU1	3.25	1.71
	I use the turning assistant	AU2	2.52	1.77

Constructs	Items	Code	Mean	SD
	I use the lane-keeping assistant	AU3	3.46	1.43
	I use the adaptive cruise control	AU4	3.60	1.37
	In the past, I deactivated assistant systems.	AU5	1.81	0.95
Functionality	In the past, the emergency brake assistant worked error-free.	FC1	3.79	1.23
	In the past, the emergency brake assistant technically fulfilled its purpose.	FC2	4.05	1.09
	In the past, adaptive cruise control worked error-free.	FC3	4.02	1.22
	In the past, adaptive cruise control technically fulfilled its purpose.	FC4	4.15	1.23
Intention to Use	I wish assistance systems will be used more often.	IU1	4.21	1.03
	I plan to use the existing assistance systems in the next months.	IU2	4.21	1.13
	As long as assistance systems are not legally mandatory, they should remain switched off.	IU3	1.35	0.88
Perceived Usefulness	The use of assistance systems avoids accidents.	PU1	4.47	0.84
	The use of assistance systems increases safety.	PU2	4.54	0.67

Constructs	Items	Code	Mean	SD
	The use of assistance systems increases job attractiveness.	PU3	3.30	1.34
	The use of assistance systems improves my work performance.	PU4	3.54	1.21
	I consider assistance systems useful for my work.	PU5	4.21	0.95
	Assistance systems make my work easier.	PU6	3.99	1.16
	Assistance systems make me inattentive.	PU7	2.31	1.22
	In general, the signals from assistance systems offer me an added value.	PU8	3.93	0.96
	The handling of assistance systems is clear and understandable for me.	PE1	4.22	0.82
Perceived Ease of Use	Dealing with assistance systems does not require great mental effort from me.	PE2	4.17	0.97
	I find assistance systems easy to use.	PE3	4.1	0.89
	The system does what I want without any problems.	PE4	3.74	1.06
Subjective Norm	My company supports the use of assistance systems.	SN1	4.47	0.937
	Colleagues who are important to me recommend the use of assistance systems.	SN2	3.57	1.31

Constructs	Items	Code	Mean	SD
	Supervisors who influence my actions think that I should use assistance systems.	SN3	4.15	1.23
	I have the resources (time, nerves, attention, etc.) to be able to use assistance systems.	SN4	4.26	1.05
Technology Commitment	I am very curious about new technological developments.	TC1	4.59	0.67
	I enjoy new technical developments.	TC2	4.22	0.87
	I am always interested in using the latest technical equipment.	TC3	3.98	1.07
	If I had the opportunity, I would use technical products much more often than I do now.	TC4	3.84	1.08

To test the internal consistency of each scale, Cronbach's alpha measure of reliability was employed. In a meta-analysis on the Cronbach's alpha coefficient, Peterson (1994) provided evidence that a value below 0.60 is unacceptable, 0.60-0.70 is low, 0.80–0.90 is moderate to high, and above 0.90 is high. The results of the reliability analysis are shown in Table 3. If the α for a specific scale was found to be less than 0.60, correlation matrix analyses were done to identify and remove the item(s) contributing to low reliability.

Table 3: Cronbach's Alpha

Construct	Alpha	No.of Items
Actual Use	.675	3

Functionality	.804	4
Intention to Use	.717	3
Perceived Usefulness	.878	7
Perceived Ease of Use	.853	4
Subjective Norm	.827	4
Technology Commitment	.866	4

All items of the different constructs were entered into a principal component analysis (PCA) with orthogonal rotation (varimax). The Kaiser-Meyer-Olkin (KMO) measure verified the sample size adequacy for the analysis (KMO = 0.819). According to Field (2009), this is a "great" value for the overall KMO and well above the given limit of 0.50 for the individual items. Bartlett's test of sphericity yielded an approx. $\chi 2$ = 1648.06, $p < 0.001$, and showed that correlations between items were sufficiently large for PCA. The analysis showed inflections that would justify retaining eight components with an Eigenvalue above 1.0, explaining 75.42 percent of the variance. The results of the factor loadings after rotation are reported in Table 4. Therefore, the TAM, as elaborated by Venkatesh and Davis (2000), was only partly confirmed by the PCA.

Table 4: Rotated Component Matrix (values above .3 displayed)

Construct	Item	1	2	3	4	5	6	7	8
	AU1							.387	.592
Actual Use	AU3								.836
	AU4					.745			.359

Construct	Item	1	2	3	4	5	6	7	8
Functionality	FC3					.888			
	FC4					.789			
	FC1							.859	
	FC2							.830	
Intention to Use	IU1	.449	.334	.583					
	IU2	.303		.524				.458	
	IU3			.707					
Perceived Usefulness	PU1			.802					
	PU2			.793					
	PU3	.639					.366		
	PU4	.731					.306		
	PU5	.711		.383					
	PU6	.790							
	PU8	.718	.336						
Perceived Ease of Use	PE1		.413		.642				.307
	PE2				.780				
	PE3				.784				

Construct	Item	1	2	3	4	5	6	7	8
	PE4				.714				
Subjective Norm	SN1						.687		
	SN2	.370					.528		
	SN3						.853		
	SN4	.399	.306				.524		
Technology Commitment	TC1		.823						
	TC2		.818						
	TC3		.672						
	TC4	.341	.690						

5 Findings of the Qualitative Content Analysis

In the following subsections, we qualitatively analyzed the effect of triability, compatibility, and result demonstrability on the perceived ease to use and perceived usefulness. Due to a lack of survey data, we could not test the relationships statistically. Nevertheless, a qualitative approach is well suited for a more exploratory analysis also considering bus drivers' perceptions and opinions. We found qualitative evidence that the IDT provides a suitable theoretical grounding for analyzing the bus driver's acceptance. Based on the qualitative data, we confirm the positive relationships between triability, compatibility, result demonstrability, and the perceived ease to use as hypothesized with the hypotheses H3a-H3c.

5.1 Triability

The bus drivers stated they enjoy testing out the systems. In addition to the training, there was enough time on the road to get to know the systems and learn how to use them efficiently (B3). In this context, person B5 mentioned that after a few hours of driving with the systems, a typical driver would have *"gotten used to"* them (B5). According to person B6, due to the triability, after some time, the problems with and reservations about the systems were *"no longer an issue"* among colleagues (B6). Persons B7 and B8 also stated that the drivers could learn how to use the systems well while on the job. After a few trips, *"at some point routine sets in"* (B7; B8). Person B5 sums up the drivers' comments with the following quote: *"And sure, you basically have to learn it, but you just do that, you know, step by step and try things out. And then you learn it if you're on the road day in and day out, then it's, I would say, like a day's training."* (B5)

5.2 Compatibility

The compatibility of the assistance systems refers to the extent to which the systems are compatible with the drivers' working environment and their everyday working lives. Here, the interviews illustrated that although the systems have many advantages, there are still a few situations in which the systems are not compatible with the working environment. For example, person B1 reported that the emergency brake assist would sometimes break when *"it was not necessary at all"* (B1). Person B4 added that there were situations in which it was unnecessary to use a particular assistance system. For example, he stated that there was no need to switch on cruise control in inner-city areas (B4). The main reason why assistance systems are compatible with the bus drivers' work goals and work environment is reflected in the following quote: "*The buses have an automatic transmission, after all, which means gear shifting is no longer necessary today, and this cruise control of course also reduces fuel, that is, diesel consumption, because it makes sure that the system always uses the ideal amount of fuel, so to speak."* (B2)

5.3 Result Demonstrability

The demonstrability of the results of the assistance systems, i.e., the direct results that arise from the use and activation of the systems, was a subject on which the respondents answered unanimously. They stated that it was clear that if the systems were used consistently and in combination with defensive driving, it was possible to avoid accidents and achieve considerable fuel savings, thus clearly demonstrating the usefulness of assistance systems (B4; B5; B6). Person B4 explains the bus drivers' perspective on the results of using the systems: *"And that's because of the cruise control – with the first cruise control, I don't remember exactly, but I would say at least ten percent, more like ten percent definitely. That was the reason why he had them put in everywhere after that – because you didn't need 33 liters anymore, but 30 liters or 29 liters."* (B4)

5.4 Perceived Ease of Use

Concerning the ease of using the most commonly used systems, the responses were mainly formulated quite unequivocally. Person B1, for example, did not think that "*you have to study it for 20 days"* (B1) to understand and handle the systems. He stated that there were not more systems installed in buses than in modern passenger cars (B1). Person B3 also stated that the systems are *"actually self-explanatory"* (B3), but he also pointed out that the drivers have to *"study them and try them out a bit"* (B3) to be able to use the systems to their advantage, especially if a driver is not very technically minded (B3). However, since most drivers had no problems with the systems, the following quote is a typical example of drivers' attitudes toward the ease of use of assistance systems: *"Everyone can grasp it right away. The systems are also pre-configured, which means I simply notice when I drive over into the wrong lane. I notice when I'm doing a hundred, and the, uh, and the bus slows down because, uh, 200 meters in front of me there's a vehicle, that, that's something I notice right away and so, it doesn't take long to get used to it."* (B2)

5.5 Perceived Usefulness

The respondents expressed their views on the usefulness of the installed systems very openly. Person B4, for example, said he was "*much more relaxed"* when using the

assistance systems at work (B4). They also mentioned that the assistance systems, when used correctly, significantly reduce fuel consumption (B4; B5). According to persons B6 and B7, the systems additionally serve as an attention booster and prevent accidents, which in turn *"help the driver with his work"* both physically and mentally (B6; B7). Person B1 sums up the usefulness of the assistance systems from the driver's point of view: *"I mean there is a reason why they develop them. They are supposed to make the driver's job a little bit easier, which they actually do."* (B1)

6 Findings of the Quantitative Analyses

In the following subsections, we analyze the hypothesized relationships concerning the hypotheses H1a-H1d and H2a-H2c. As explained above H3a-H3c were analyzed by qualitative means only due to a lack of survey data. Except for hypothesis H2a, we found statistically significant results within the regression analyses, supporting the proposed theoretical framework. The quantitative results also support the mainly positive attitude towards using assistance systems.

6.1 Correlation Analysis

A multiple regression analysis was performed to analyze the relationships proposed by the TAM and IDT. Table 5 shows the intercorrelations among the measured constructs. Weak to strong correlations were evident between each of the variables. All constructs were positively correlated and significant. Technology commitment ($r = 0.592$, $p < 0.001$) and intention to use ($r = 0.750$, $p < 0.001$) were the most strongly correlated with perceived usefulness. Perceived usefulness and perceived ease of use were significantly ($p < 0.001$) and moderately correlated with the intention to use and the actual usage. Functionality was the most weakly associated with intentions to use ($r = 0.392$, $p < 0.001$) and perceived usefulness ($r = 0.357$, $p < 0.001$). Subjective norm, in general, had moderate to high correlation coefficients with the other constructs. As hypothesized by Venkatesh and Davis (2000), subjective norms were more strongly correlated with perceived usefulness ($r = 0.607$, $p > 0.001$) than with intention to use ($r = 0.435$, $p < 0.001$).

Table 5: Correlation Coefficients for the Measured Constructs

Item	1.	2.	3.	4.	5.	6.	7.
1. Actual Usage	--						
2. Functionality	.523**	--					
3. Technology Commitment	.204	.454**	--				
4. Intention to Use	.407**	.392**	.456**	--			
5. Perceived Usefulness	.394**	.357**	.592**	.750**	--		
6. Perceived ease of use	.460**	.525**	.438**	.509**	.489**	--	
7. Subjective norm	.456**	.600*	.566**	.435**	.609**	.537**	--

** Pearson correlation is significant at 0.01 level (2-tailed).

6.2 Regression Analysis

To predict actual usage, the intention to use and functionality variables were entered in the regression analysis. The results are shown in Table 6. The predictor variables explained 32.2 percent of the variance in the actual use. Intention to use and functionality had significant beta weights in the regression equation ($\beta = 0.239$, $p < 0.05$ and $\beta = 0.429$, $p < 0.001$, respectively).

Table 6: Regression Analysis to Predict Actual Usage

Variables	R2	R2 change	B	SE B	β
	.322	.322***			

Variables	R2	R2 change	B	SE B	β
Intention to use			.346	.146	.239*
Functionality			.532	.126	.429***

* p < 0.05; ** p < 0.01; *** p < 0.001.

In a stepwise regression analysis to predict intention to use, the perceived usefulness and perceived ease of use variables were entered first, followed by the subjective norm construct. The regression analysis results are shown in Table 7. The predictor variables explained 59.7 percent of the variance in the intention to use. Perceived usefulness and perceived ease of use had significant beta weights in the regression equation ($\beta = 0.713$, $p < 0.001$ and $\beta = 0.225$, $p < 0.05$, respectively). Subjective norm was not significant and had a much smaller, negative effect.

In the regression analysis to predict perceived usefulness, the subjective norm and technology commitment variables were entered. The regression analysis results are shown in Table 8. The predictor variables explained 46.1 percent of the variance in perceived usefulness. Subjective norm and technology commitment had significant beta weights in the regression equation ($\beta = 0.403$, $p < 0.001$ and $\beta = 0.364$, $p < 0.001$, respectively). Figure 2 gives an overview of the tested relationships.

Table 7: Regression Analysis to Predict Intention to Use

Step	Variables	R2	R2 change	B	SE B	β
1		.589	.589***			
	Perceived Usefulness			.680	.086	.658***
	Perceived ease of use			.195	.087	.187*

Step	Variables	R2	R2 change	B	SE B	β
2		.597	.597***			
	Perceived Usefulness			.737	.097	.713***
	Perceived ease of use			.234	.092	.225*
	Subjective norm			-.106	.086	-.120

* p < 0.05; ** p < 0.01; *** p < 0.001.

Table 8: Regression Analysis to Predict Perceived Usefulness

Variables	R2	R2 change	B	SE B	β
	.461	.461***			
Subjective Norm			.344	.086	.403***
Technology commitment			.362	.100	.364***

* p < 0.05; ** p < 0.01; *** p < 0.001.

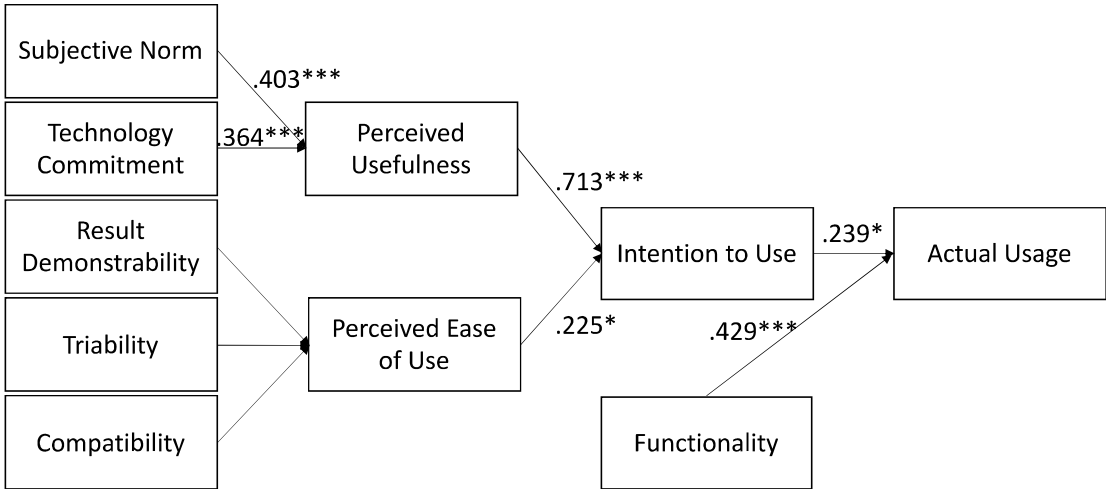


Figure 2: Significant Beta Weights of the Tested Theoretical Framework

7 Discussion and Conclusion

By comparing the qualitative and quantitative results with the integrated model of the TAM and the IDT, as shown in Figures 1 and 2, it becomes evident that the theoretical dimensions do indeed impact driver acceptance of the assistance systems. For example, the results indicate that the perceived usefulness of the assistance systems plays a significant role in implementing and accepting driving with assistive technology ($\beta = 0.713$). The collected data thereby confirms the TAM for the context of bus driving assistants except for hypothesis H2a. Further, the demonstrability of the results of the assistance systems can be seen as essential for their success following IDT. For example, bus drivers are much more open to using assistive technology if they do not only have "perceived" advantages from using the systems but can equally experience the benefits of using the systems on a measurable level. Here, the measurable advantages of saving fuel and reducing traffic accidents are most important.

The compatibility and triability of the assistance systems also impact drivers' attitudes toward the assistance systems. Triability is very important for drivers, as it allows them to gradually adapt to using assistive technology while at the same time developing a driving style that is environmentally friendly as well as comfortable for the passengers. On the other hand, many drivers still see compatibility as a weakness of current

assistance systems. The drivers acknowledge problems in the interaction of the assistance systems with new phenomena, such as the increasingly heavy and aggressive traffic on the roads (Nævestad, Phillips, Laiou, Bjørnskau, & Yannis, 2019). Under optimal driving conditions (empty roads, for example), compatibility is valued positively (e.g., through fuel savings). Under less-than-optimal driving conditions (e.g., busy roads), this dimension can still be seen as an obstacle to successful interaction.

Despite these contributions, this study is not free from limitations. First, the analysis is restricted to evaluating prior defined or assumed relationships by testing hypotheses rather than discovering unexpected patterns. Although the qualitative approach applied is more exploratory, the categories used were exclusively created by deductive means based on the underlying theoretical constructs of the TAM and IDT. Future work might use inductive means to discover new patterns with respect to acceptance of assistant driving. Furthermore, the sample size could be enlarged. The data collected is based on one country (Germany) only and thus, could be extended to other countries, hence also taking into account cultural factors influencing the acceptance of driving assistants.

In the following, the findings of this study will be discussed against previous research and recommendations for future research will be provided. In contrast to the study by Banks, Eriksson, O'Donoghue, and Stanton (2018), who found that drivers of automated vehicles tend to rely on the technology overly, the findings of the present study suggest that this is not the case for bus drivers. While bus drivers trust the assistance systems' operational capability and technical functionality, they are also convinced that drivers should not have blind faith in the systems. The bus drivers believe that the systems should only be perceived as a form of support and should continue to alert them. The difference in results may, to some extent, be explained by the fact that drivers in the study by Banks, Eriksson, O'Donoghue, and Stanton (2018) referred to driving in their private vehicles during leisure time, while the current study is focused on bus drivers in their work context. Hence, an increase in the drivers' perceived responsibility may lead to a change in their willingness to rely upon assistive technology versus staying in control themselves. Comparing our results with the studies by Hoff and Bashir (2014), which states that people's trust in machines develops similarly to their trust in people, could explain why bus drivers do not immediately fully embrace new forms of assistive

technology. Similar to trust between people, it has to grow and flourish over time. The role of trust and how it can be developed with respect to human-machine interaction in the context of bus driving assistants might be a future research question to explore.

In line with the research results of Tse, Flin, and Mearns (2006), we were able to confirm the stress factors of an increased volume of traffic and the associated disadvantages. In contrast to their study, however, the bus drivers we interviewed report that the assistance systems were of little help in these situations and, in some cases, even entirely useless. This adds a further indicator that increased traffic volume can become an obstacle to using assistant systems. However, some bus drivers felt significantly calmer and more relaxed at work due to using the systems, which again supports the study's findings. Future research might hence explore the conditions under which driving assistants are considered a support or an obstacle when traffic volume increases.

The results of this study also provide guidance for managers in the process of prioritizing measures to generate acceptance and improvements in performance with respect to bus driving assistance systems: Our research shows that efficient training and an extended time frame when implementing the assistance systems are essential factors for technology acceptance. The drivers interviewed were able to confirm that appropriate training and consistent use of specific assistance systems such as cruise control (in combination with an appropriate driving style) will lead to significant fuel savings benefitting the environment as well as improving driving quality for passengers. This is in line with the results of the study conducted by Zarkadoula, Zoidis, and Tritopoulou (2007). The quantitative results confirm a positive attitude towards digital transformation processes while, amongst others, the functionality and perceived usefulness experienced by the drivers can facilitate acceptance and should hence be taken into consideration for managerial measures.

In conclusion it can be stated that the paper analyzed the use of assistance systems in the workplace of professional bus drivers from various perspectives, hence contributing to a better understanding of underlying acceptance mechanisms in professional bus driving. The qualitative findings suggest that TAM and IDT provide a suitable theoretical grounding for analyzing bus drivers’ acceptance, while the quantitative results confirm a positive attitude of bus drivers towards digital transformation processes. Thereby,

among others, especially the functionality and perceived usefulness experienced by the drivers can facilitate acceptance.

Acknowledgements

We like to express our sincere gratitude to Gunther Mörl, former managing director of the BDO, and Vincent Beul from FOM University of Applied Sciences for supporting the data collection and analysis.

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Development of a Procurement-4.0-PMS using the Balanced Scorecard

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Purpose: *Performance measurement systems (PMS) are multidimensional, indicator-based systems that form the basis for performance evaluation and management. In management research and in corporate practice, the Balanced Scorecard (BSC) is the most established PMS. In principle, the BSC can also be used in Procurement, but there is a lack of studies on its suitability or adaptation in digitalized Procurement 4.0. To close this gap, this paper develops an initial concept of a PMS geared to Procurement 4.0 with help of the BSC.*

Methodology: *For data collection, a systematic literature review is conducted according to Durach et al. (2017). The results will be systematized in the development of a general Procurement-BSC and taken into account in the adaptation of the model to Procurement 4.0. Subsequently, the model will be validated by expert interviews.*

Findings: *The results show that the holistic performance evaluation of Procurement 4.0 will become even more important in the future. As part of its new understanding, the BSC supports the development of Procurement into a value and strategy driver of the organization.*

Originality: *To the best of the authors' knowledge, this is the first study of its kind. As such, it represents the starting point for further research.*

First received: 23. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

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1 Introduction

Procurement 4.0 is considered as a fundamental conceptual element of Industry 4.0, as it connects the various partners in the supply chain and enables dynamic and rapid collaboration and coordination across organizational boundaries (Glas and Kleeman, 2016, p. 56). However, the evaluation of the performance in procurement 4.0 has not yet been sufficiently investigated, thus this is the starting point for this paper. The Balanced Scorecard (BSC) is used as the methodological framework for performance measurement. In particular, the following research question is addressed:

> *What are the implications of the conceptual vision of procurement 4.0 for the performance measurement based on the BSC?*

2 Theoretical Background

2.1 Performance Measurement

The criticism of traditional performance measurement systems (PMS) that emerged in the 1980s led to the development of a new generation of performance measurement systems, especially in the following decade (Eccles, 1991, p. 131; Bourne, et al., 2000, p. 754; Parida, et al., 2015, p. 9). Such PMS have used major deficits of traditional KPI systems as starting points for the further development towards a holistic performance measurement (Gleich, Quitt and Görner, 2011, p. 11). Deficiencies addressed by PMS were, for example, the past orientation and the strong financial orientation (Kaplan and Norton, 1997, p. 22) the cost-side view and the associated dysfunctional behavior in favor of a short-term view, the division-related achievement of suboptima (Bititci, 1994, p. 17; Neely, et al., 1997, p. 1131), the missing relation to strategic planning (Bititci, 1994, p. 16) and the disregard of important stakeholders such as customers, suppliers or employees (Greiling, 2009, p. 92). The most appropriate definition of performance measurement is formulated by Gleich et al. who understand performance measurement as the "construction and application of usually several key figures of different dimensions (e.g. costs, time, quality, innovation capability, customer satisfaction), which are used to

measure and evaluate the effectiveness and efficiency of the performance and the performance potential of a wide range of objects in the company, so-called performance levels (e.g. organizational units of different sizes, employees, processes)" (Gleich, Quitt and Görner, 2011, p. 17).

2.2 Balanced Scorecard

Since the criticism of traditional performance measurement systems, a variety of different PMS has been developed. For example, Parida et al. list 27 PMS published between 1977 and 2012 (Parida, et al., 2015, p. 10 f.) Of the well-known PMS, however, the BSC has emerged as the dominant PMS in general management research and in corporate practice (Neely, 2005, p. 1274; Gleich and Quitt, 2015, p. 12). Especially the continuous improvement of Kaplan and Norton's concept, first published in 1992, and the related broad treatment in studies in the 2000s and 2010s has created a wide acceptance of the BSC in practice (Singh and Sethi, 2017, p. 24 f.) Moreover, due to its generic approach, the BSC is suitable for a wide range of industries and has therefore already been implemented in many cases (Kaplan and Norton, 1993, p. 2).

The development of a BSC starts with the definition of a mission, a vision and values of the company. Subsequently, the corporate strategy is derived (Kaplan and Norton, 2008, p. 64). According to Kaplan and Norton, the corporate strategy consists of several hypotheses about causes and effects, their relationships can be made explicit in the BSC, so that they become manageable and validatable (Kaplan and Norton, 1996, p. 65). These relationships can always be perceived in four perspectives: the financial perspective, the customer perspective, the internal process perspective, and the learning and growth perspective. Such a holistic view of the company then enables decision-makers to control it in a similar way to an airplane cockpit (Kaplan and Norton, 1992, p. 72). Accordingly, in the causal logic, the BSC shows what knowledge, skills and systems employees need (learning and growth) to innovate and build the right strategic capabilities and efficiencies (internal processes) that deliver specific value to the market (customers). This in return leads finally to a higher shareholder value (finances). For the representation of causal paths, the strategy map is an established framework from BSC research (see Figure 1). It provides a visual framework that embeds the various elements

and the four perspectives of the BSC in a cause-and-effect chain. This links the desired outcomes and goals to the drivers of those outcomes (Kaplan and Norton, 2000, p. 3).

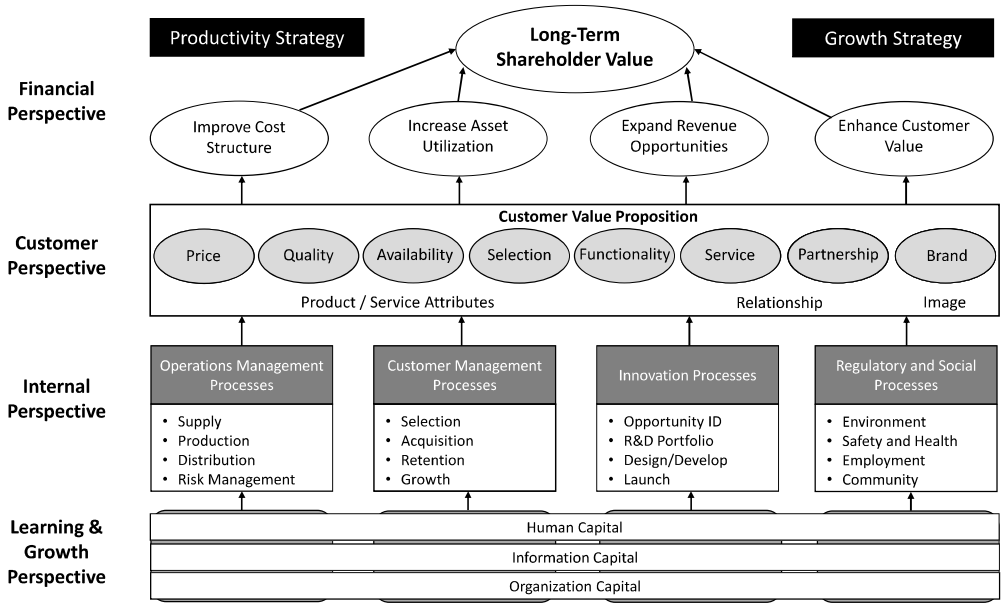


Figure 1: Strategy Map (Kaplan and Norton, 2004, p. 12)

After a strategy map is developed, Kaplan and Norton propose the derivation of the associated BSC with its key performance indicators (Kaplan and Norton, 2008, p. 68). At its core, the BSC represents the translation of strategy into a comprehensive set of key performance indicators that form the strategic measurement and control system (Kaplan, 1996, p. 18). The balanced consideration of the strategically relevant key figures of the four perspectives and their preceding goals, objectives and the derivation of strategic actions leads to the balanced BSC target system (Horváth & Partners, 2004, p. 3). The BSC is shown in Figure 2.

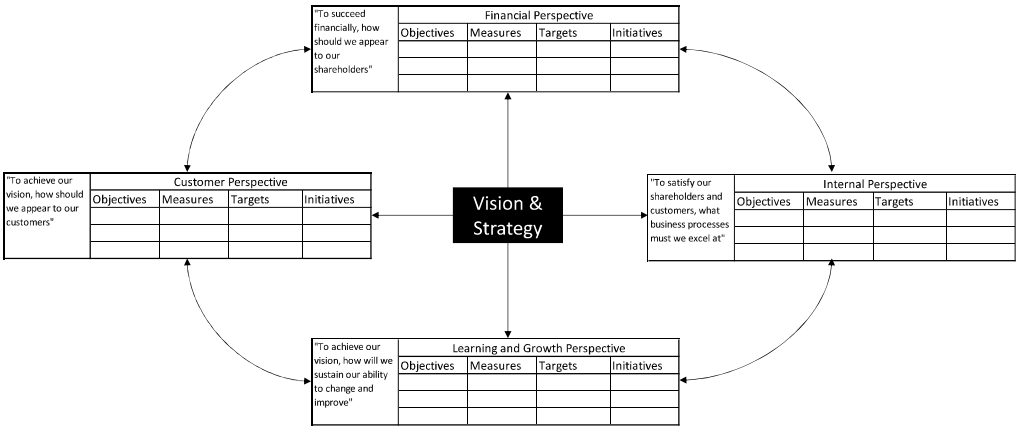


Figure 2: Balanced Scorecard (Kaplan, 1996, p. 54)

2.3 Procurement and Procurement 4.0

In many industries, especially in retail and manufacturing, procurement has an eminent influence on the overall value creation. This is mainly caused by the fact that cost optimizations in procurement have a major impact on the company's earnings (Large, 2013, p. 6; Schentler, et al., 2014, p. 304). Procurement is becoming even more important as a result of the increasing focus on core competencies, an increased proportion of externally sourced materials and services, and the associated reduction in vertical integration (Hug and Weber, 2011, p. 7; Bräkling and Oidtmann, 2012, p. 6). In addition to cost potentials, procurement is increasingly influencing profit by achieving revenue potentials. Procurement identifies supplier innovations and influences the factors of time, speed and flexibility with the selection of suitable suppliers. Procurement also plays an important role in the perception of the product benefits and quality, as it has a significant influence on the quality of the supplier services and thus on the final product (Hug and Weber, 2011, p. 18; Bräkling and Oidtmann, 2012, p. 8 ff.; Large, 2013, p. 5 f.). The activities in procurement can be summarized in the procurement process model according to van Weele and Essig (see Figure 3).

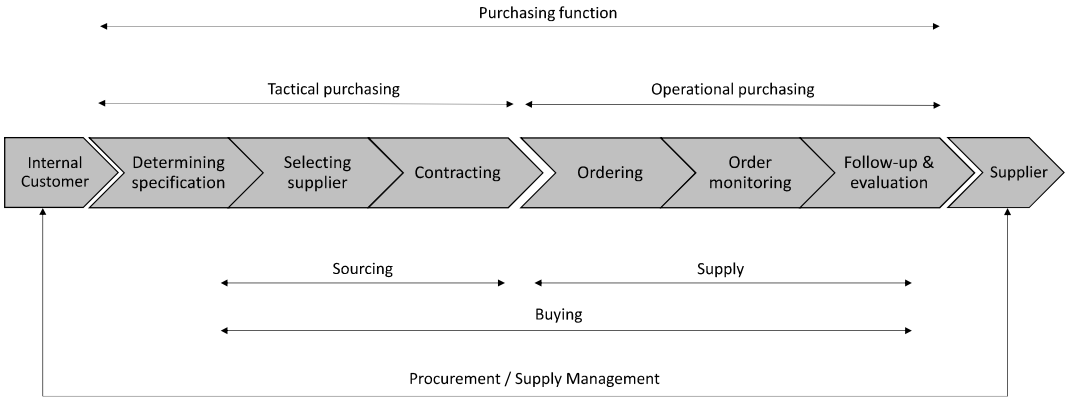


Figure 3:Procurement Process (van Weele and Essig, 2017, p. 22)

Considering the developments of Industry 4.0, these activities play an essential role in the implementation of digitalization due to their interface function (Henke and Feldmann, 2016, p. 25; Nicoletti, 2018, p. 190; Kleeman and Glas, 2020, p. 5). This expands the traditional task of procurement. On the one hand, in procurement 4.0, the progress of systems with which the manual work in procurement tasks is reduced and automated will continuously advance; on the other hand, the degree of cross-organizational and functional integration will increase (Nicoletti, 2018, p. 210). In this way, procurement will be able to exert qualitatively driven impacts on new business models and ecosystems, significantly influencing growth, scope change, and the organizational transformation of processes (Seyedghorban, Samson and Tahernejad, 2020, p. 1689).

3 Methodology

This paper presents a Procurement 4.0-BSC (P4.0-BSC) in order to be able to evaluate the performance provided by Procurement 4.0. The conception of the P4.0-BSC follows a three-step procedure (see Figure 4). In the first step, BSC concepts related to procurement are identified. These concepts are then used to develop a generic Procurement-BSC (P-BSC). With the help of the identified perspectives of the P-BSC, an analysis of the literature on Procurement 4.0 is carried out, followed by validation and complementation of the resulting model in the third step. For the data collection of the

first two steps, the Systematic Literature Review (SLR) according to Durach et al. is carried out, as it is particularly suitable in Supply Chain Management (SCM) (Durach, Kembro and Wieland, 2017, p. 71 ff.). Furthermore, four expert interviews are conducted to validate and complement the P4.0-BSC using a qualitative content analysis approach following Mayring (Mayring, 2015, p. 62 ff.). The analysis was done through MAXQDA.

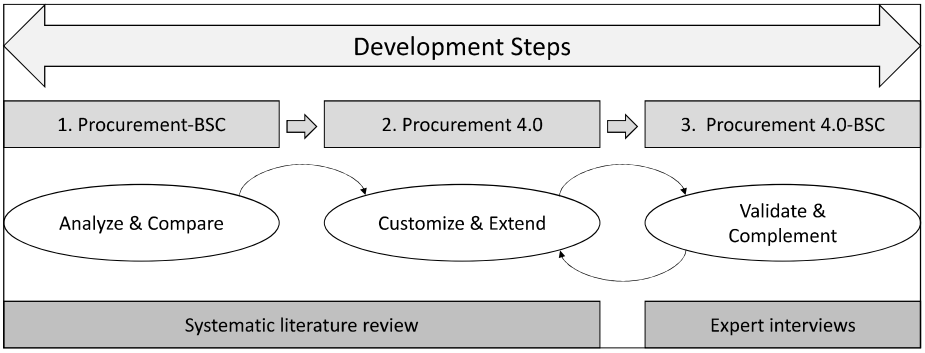


Figure 4: Methodology

To conduct the SLR, six phases proposed by Durach et al. are followed. In the **first phase**, the theoretical framework and the research objectives are defined. These research objectives then resulted in the central research question from the introductory section. In the **second phase**, the procedure provides for the definition of characteristics of the SLR that determine a comprehensive search in a delimited scope of investigation (see Table 1). Then, in the **third phase**, search procedures are defined and samples are queried. To obtain an initial scope of investigation, the databases were searched using the terms "Procurement 4.0 Balanced Scorecard", "Purchasing 4.0 Balanced Scorecard", "Einkauf 4.0 Balanced Scorecard", "Beschaffung 4.0 Balanced Scorecard" and "Supply Management 4.0 Balanced Scorecard". For all compound terms, the hit search was unsuccessful. Thereupon, two further searches were conducted to address this research gap. Thus, the second search investigated which existing BSC concepts exist in purchasing and the third search investigated how Procurement 4.0 has already been defined. This resulted in the following key words for the second search: "Procurement Balanced Scorecard", "Purchasing Balanced Scorecard", "Supply Management Balanced

Scorecard", "Beschaffung Balanced Scorecard" and "Einkauf Balanced Scorecard". Similarly, the key words of the third search were "Procurement 4.0", "Purchasing 4.0", "Supply Management 4.0", "Beschaffung 4.0" and "Einkauf 4.0". A search using cross-references was not performed. However, this search procedure was carried out at an earlier stage of the unstructured review as part of the process of setting up the theoretical framework. Thus, this type of search represents a fourth search, of which the results have also been taken into account.

Table 1: Characteristics of SLR

Study context	Study type	Language	Type of publication	Databases
Supply Management, Performance Measurement	Quantitative, Qualitative	German, English	Journal, conference paper, university publication, research report, company publication	Scopus, Web of Science, TEMA, EconBiz, EBSCO, Google, Google Scholar, DNB, Catalog TU Dortmund

In the **fourth phase**, relevant literature is selected with the help of a relevance check. Thus, in the case of hit numbers, it is checked whether the title, abstract, key words, table of contents and then the content with reference to the research question are relevant. As a result, a total of 40 papers are identified. Of these, 16 relate to existing BSCs in Procurement and 24 to the topic of Procurement 4.0 (see Figure 5). For a better overview, a synthesis of the literature is carried out in the **fifth phase** using a coding scheme so that similar works can be identified. The **sixth phase** of the SLR involves reporting the results, which is done in the next chapter as part of the development of the P-BSC and P4.0-BSC.

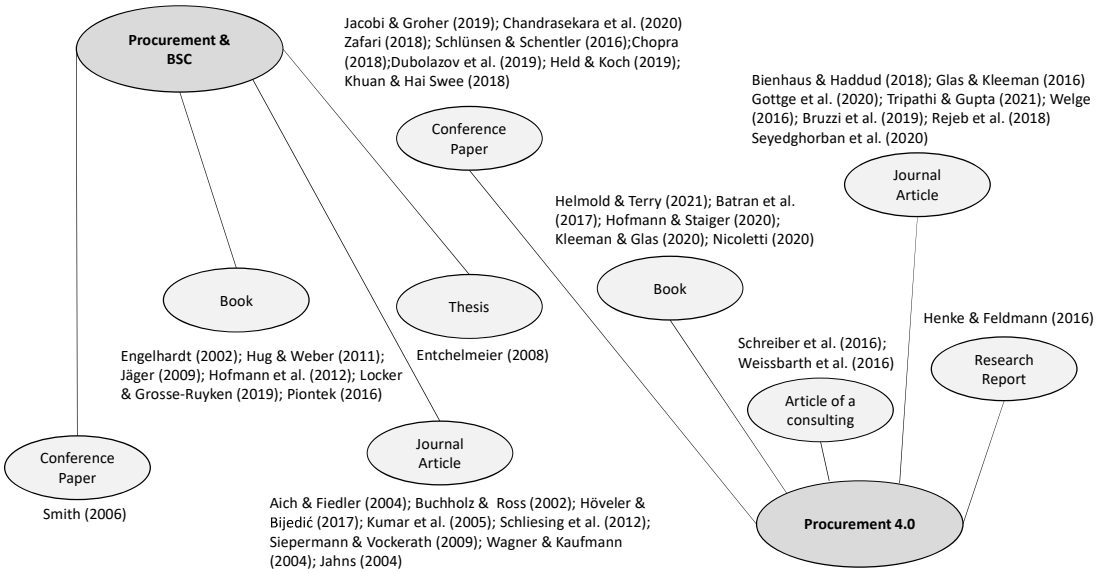


Figure 5: Results of the SLR

4 Findings

4.1 Development of the P-BSC

A majority of authors confirm that the formulation of a procurement vision and a purchasing strategy is at the heart of BSC development (Engelhardt, 2002, p. 33; Aich and Fiedler, 2004, p. 41; Entchelmeier, 2008, p. 71; Hofmann, et al., 2012, p. 146; Piontek, 2016, p. 227). A methodical procedure, which is described for example by Smith (Smith, 2006, p. 907 ff.), is suitable for developing a procurement strategy. In practical BSC-projects, it has also been shown that the additional formulation of a mission can play a role for successful implementation (Smith, 2006, p. 914 f.; Schliesing, Krampf and Schlüchtermann, 2012, p. 411 f.). In particular, Jahns emphasizes that supply manager behavior and supply management reporting do not change with a newly introduced supply strategy as long as it is not broken down into concrete supply management actions and goals using the BSC (Jahns, 2004, p. 278). With regard to the general BSC, it is noticeable that some authors have added an additional supplier perspective (Entchelmeier, 2008, p. 72; Hug and Weber, 2011, p. 76; Schliesing, Krampf and

Schlüchtermann, 2012, p. 413; Piontek, 2016, p. 234; Locker and Grosse-Ruyken, 2019, p. 67). In addition, the P-BSC differs from the general BSC in the customer perspective, as the customer promise primarily addresses internal customers. A further adjustment of the perspectives becomes clear with the renaming of the financial perspective to value perspective (Aich and Fiedler, 2004, p. 41).

When analyzing the publications, it became apparent that the strategic objectives mentioned, including their cause-effect relationships and the strategy maps, are very similar. Based on this, a strategy map that tracks the most important objectives in procurement and relates them via causal relationships (arrows) was developed. The development of the generic P-BSC strategy map took three aspects into account. First, the original concept of Kaplan and Norton served as a general template (see Figure 3). Second, insights from literature-specific examples were used to create comprehensive strategy maps. And third, the E-BSC strategy map was guided by the cause-effect relationships presented in the literature. This results in the following:

In the **value perspective**, the goal of improved cost structure became the goal of *substantial savings*, since in procurement the well-known savings present a common goal. In addition, the goal of increasing customer value has been replaced by *reducing supply chain risk* as a financial measure of customer value more specific to procurement. The goals of *increasing asset utilization* and *helping to increase sales* are also specific goals in procurement literature. In the **internal customer perspective**, the analysis of the literature also showed that *customer satisfaction* of internal customers is a high strategic goal. The *service* that procurement provides along the way was identified as a success factor. This service can be expressed, for example, in short response times, the early involvement of departments in the procurement processes. Relevant processes in the **process perspective** are innovation processes and procurement processes. Relevant goals in the procurement processes are the *increase of the efficiency and effectiveness* of processes as well as the *standardization*. With the innovation processes the meaning of the purchase lies predominantly on the sighting of *market chances*, in order to be thus a driver of innovations and bringing these into the enterprise. Furthermore, the supplier management processes are in line with the **supplier perspective**. The goals in this perspective relate to *improving supplier selection processes*, *increasing supplier*

performance and *increasing supplier integration*. In this context, the goals of the supplier management processes were identified as success factors for the goals of the procurement execution processes and the innovation processes, since exploiting supplier potential can influence the effectiveness and efficiency of procurement activities and the search for innovative procurement solutions. In the **learning and development perspective**, the human, information, and organizational capital can be found, which in turn has been translated into employees (people), information (technology), and organization. As intangible assets, these represent the original success factors of the higher-level goals. One goal regarding suppliers is to *increase employer attractiveness* in order to establish the procurement organization as an attractive business partner for suppliers. In addition, the establishment of a technological infrastructure is necessary to *improve the exchange of information* with suppliers, as well as the goal of establishing a *lean, differentiated and global supplier base*. This last mentioned goal is necessary to be able to purchase at the best conditions. Furthermore, a category regarding general process improvements was identified, in which an *increase in employee competence*, the *optimization of systems and technologies* (purchasing tools) and the *establishment of an efficiently designed corporate network* are defined as general goals. In the last category, an *increase in employee satisfaction* and *improved knowledge management* were defined as strategic goals. Overall, the success factors mentioned target three potentials. These are cooperation with suppliers, continuous process improvements and the further development of procurement in the company as a whole. The interrelationships described are shown in the strategy map below (Figure 6).

The next step in the development of the P-BSC is to derive key performance indicators (KPIs). The topic of KPIs is treated as an essential component of the BSC by three quarters of the 16 publications. When analyzing the key figures, it becomes clear that the majority of them do not provide a differentiated description in the form of a definition, collection method or differentiation between result or performance key figures. An assignment of the key figures mentioned in the literature to the respective strategic goals of the strategy map was made in Figure 7. It is noticeable that the key figures are very similar in essence.

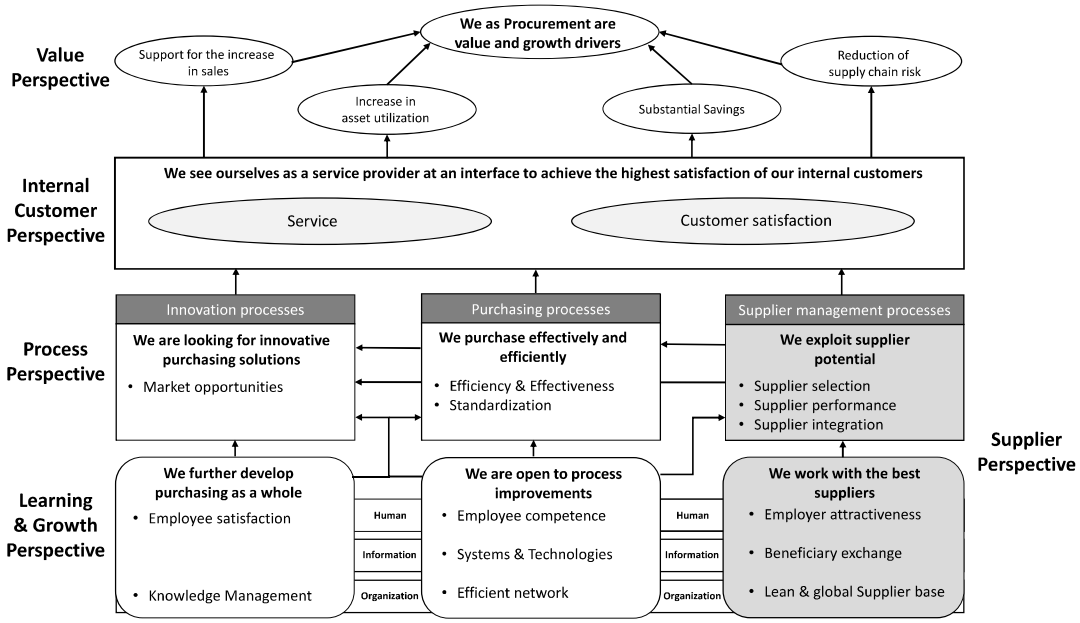


Figure 6: Strategy Map of the P-BSC

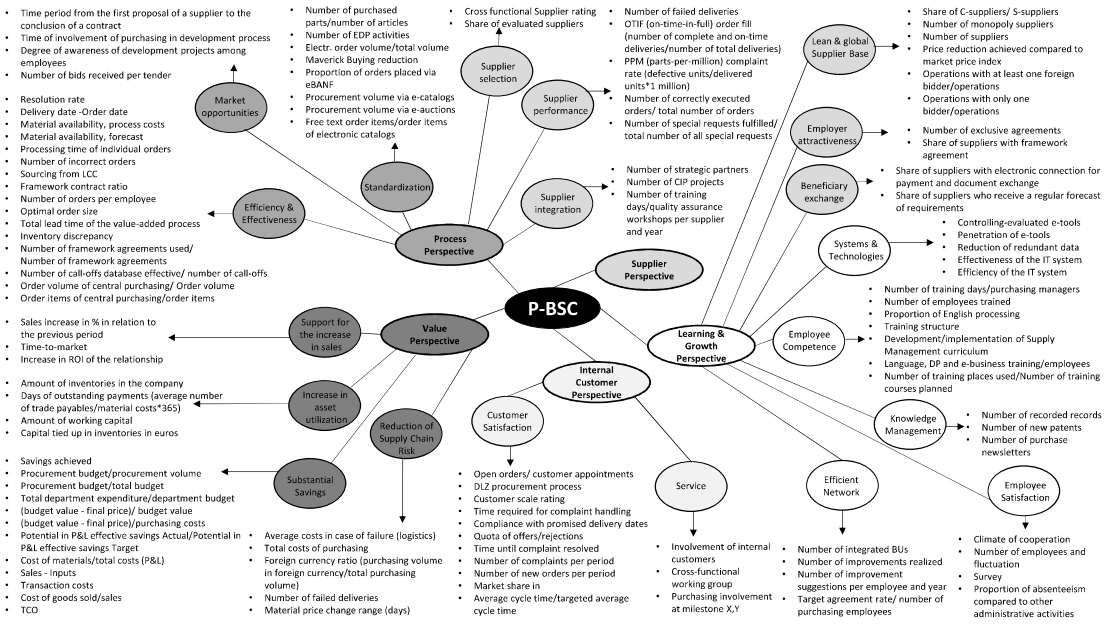


Figure 7: KPI collection of the P-BSC

In the final step of the development of the P-BSC, success factors are identified. These are named either explicitly or implicitly in the form of challenges and barriers. Key success factors relate to the involvement of all procurement employees in the development and implementation of the P-BSC. That way the knowledge of the employees is used in generating the causal relationships and commitment to the key performance indicators and targets is achieved. Furthermore, intensive communication of the introduction process supports avoiding misunderstandings regarding participation and feedback possibilities (Schliesing, Krampf and Schlüchtermann, 2012, p. 417). Therefore, a structured project approach should accompany the BSC project phases (Buchholz and Ross, 2002, p. 56 ff.; Engelhardt, 2002, p. 79; Piontek, 2016, p. 228; Locker and Grosse-Ruyken, 2019, p. 66). Moreover, it is necessary that professional support for developing the P-BSC is provided by trained personnel, that support is provided by top management, and that the P-BSC is aligned with the corporate strategy (Wagner and Kaufmann, 2004, p. 273 ff.). In addition, it makes sense to establish an institutional body to enable the objective and verifiable collection of KPIs with a broad-based IT infrastructure (Schliesing, Krampf and Schlüchtermann, 2012, p. 417).

4.2 Adoption of the P-BSC towards Procurement 4.0

The analysis of the 24 publications identified in the SLR on Procurement 4.0 was conducted via the five perspectives of the P-BSC. The results can be summarized as follows:

From a cost-side, savings are realized in the **value perspective** primarily through an optimized procurement 4.0 process. This provides, for example, better insight into corporate spending and budgets and therefore allowing better contracts to be negotiated (Chandrasekara, Vidanagamachchi and Wickramarachchi, 2020, p. 1098). Costs due to supplier failures will also decrease, as these are mitigated by real-time visibility and information availability. Furthermore, automated information flow saves coordination costs (Glas and Kleeman, 2016, p. 59). From a value side, procurement, as the primary owner of the supplier interface, will increase its distinctive value proposition within the enterprise by participating in the development of new business models. This is possible because procurement has deep expertise and strategic know-how about

suppliers, their markets, goods, services and alternatives offered, including new innovations. These insights and values can be offered not only internally but also externally. In this way, additional revenue potential can be generated by selling such field application and customer usage data to suppliers. Subsequently, suppliers can in turn use this additional information about their products to generate targeted specifications and applications. This in turn will lead to the development of more cost effective and functional products (Weissbarth, Geissbauer and Wetzstein, 2016, p. 1 ff.). Thus, some authors conclude, that Procurement 4.0 could increase its distinct value proposition from a cost center to a profit center (Khuan and Hai Swee, 2018, p. 53).

From the **internal customer perspective**, Procurement 4.0 is expected to proactively participate in the implementation of digitalization. Through this, it can help to develop a clear understanding of the challenges ahead (Kleeman and Glas, 2020, p. 28). This is expressed on the one hand in a leading role in networking with supply chain partners, and on the other hand in the digitization of procurement processes, which is being driven forward by the company itself (Hofman and Staiger, 2020, p. 95). Through its own automation, Procurement 4.0 is expected to contribute to classical goals like the reduction of procurement cycle time or resource optimization. Furthermore, the customer promise of Procurement 4.0 is also expressed in the fact that it creates trust when sharing data. In particular, it must succeed in promoting visibility and transparency, and thus trust in the buyer-supplier relationship (Tripathi and Gupta, 2021, p. 452 f.). The procurement of digital categories and services will also lead to new business requirements, which will be reflected in new requirements for procurement (Weissbarth, Geissbauer and Wetzstein, 2016, p. 3; Bruzzi, Genco and Balbi, 2019, p. 111).

Within the **process perspective**, the authors predict a high degree of automation in the in the operational tasks of procurement (Henke and Feldmann, 2016, p. 21; Welge, 2016, p. 60; Batran, et al., 2017, p. 146; Khuan and Hai Swee, 2018, p. 53; Nicoletti, 2020, p. 216). Furthermore, it is clear that digital tools no longer relate only to the operational part in the purchase-to-pay area, but are also increasingly being used in strategic processes such as plan-to-strategy or source-to-contract. Here, for example, semantic analyses or machine learning can support commodity group managers in the IT-supported implementation of their procurement strategies (Held and Koch, 2019, p. 501 f.). The

innovative use of procurement data and data analyses in particular is one of the most important factors for Procurement 4.0. With the help of intelligent technologies or algorithms, the aggregation, processing, and analysis of very large volumes of data from a variety of heterogeneous sources is made possible. The analytical conclusions can then be used to understand suppliers, markets, customers, trends or to investigate machine and product faults (Weissbarth, Geissbauer and Wetzstein, 2016, p. 4). This also changes the process of risk and logistics management. In Procurement 4.0 classic supply chain risks are complemented by other types of risk (Held and Koch, 2019, p. 503). These risks are above all strongly technology-driven. Accordingly, risks relating to IT security, compliance, and data protection are added to supply and failure risks (Welge, 2016, p. 60). In addition, procurement controlling and reporting will become an even more important basis for decision-making, as they provide the wealth of information in an aggregated manner. As mobile reporting in real time, this means a process-accompanying uniform and cascaded set of KPIs that is continuously fed with real-time data from production, logistics, and warehouses (Schlünsen and Schentler, 2016, p. 93). Finally, changes with regard to automation in Procurement 4.0 are also conceivable in the financing process, whereby blockchain technology is mainly expected to map secure payment transactions (Nicoletti, 2020, p. 107). A complete Procurement 4.0 process is described by Tripathi and Gupta and by Gottge et al. (Gottge, Menzel and Forslund, 2020, p. 737 ff.; Tripathi and Gupta, 2021, p. 449 ff.).

From a **supplier perspective**, stronger cooperation between the procurement organization and suppliers will become a key factor. To drive co-creation, strategic partnerships with highly innovative suppliers in particular will become an integral part of the procurement organization in the future (Batran, et al., 2017, p. 64 f.; Nicoletti, 2020, p. 200). New supplier formats such as supplier think tanks, communities, innovation days, excursions or creativity formats like supplier design thinking will contribute to the development of strategic partnerships (Batran, et al., 2017, p. 81 ff.). In addition, the exchange will increasingly take place on a digital base or sourcing platforms. This creates further opportunities, such as the emergence of new sources of supply, new types of partners, and new ways to obtain services. Conversely, such platforms may also enable companies to monetize underutilized assets and thus generate additional revenue

(Chopra, 2018, p. 220). Supplier innovation management will expand a company's own innovation capabilities by systematically integrating the knowledge and competencies of key suppliers, start-ups, and the external crowd (Schreiber, et al., 2016, p. 2). Accordingly, the innovative strength of a supplier is used as an important evaluation criterion in Procurement 4.0 (Batran, et al., 2017, p. 76; Kleeman and Glas, 2020, p. 32). In this context, for example, the term innovation scouting can be understood as a process for identifying new digital technologies and suppliers (Henke and Feldmann, 2016, p. 22).

In the **learning and development perspective**, a classification of the literature has taken place according to human, information and organizational capital. In the case of **human capital**, it can be assumed that the buyer profile will change significantly with the extensive autonomization of operational aspects (Kleeman and Glas, 2020, p. 36). Buyers will work more as consultants for other functions of the organization (Nicoletti, 2020, p. 216). The buyer of the future will become a multi-talented coordinator, controller, consultant, contract manager, product developer, data analyst, interface manager, and manager of the framework (Henke and Feldmann, 2016, p. 21). The term digital talent, which is particularly adept in dealing with emerging technologies, also falls in this context (Khuan and Hai Swee, 2018, p. 59). This will require deeper IT know-how and process or system understanding. In the future, this will be implemented by the employee himself and by recognizing the need for development with the help of innovative forms of learning (Kleeman and Glas, 2020, p. 36 f.). One possible trend is for buyers to take over the personalization of their activities themselves with the help of apps and thus largely define their own role in the procurement team (Batran, et al., 2017, p. 125 ff.). Accordingly, software solutions are also expected to be easier to operate, so that IT-expertise is necessary, but very complex tasks can still be performed as a service for the procurement function (Glas and Kleeman, 2016, p. 62; Welge, 2016, p. 62). It will be important that employees in Procurement 4.0 are open to the entire fourth industrial revolution and support the opportunities (Bienhaus and Haddud, 2018, p. 979). This includes not only technical competence, but also a certain methodological competence. In particular, agile methods, which are strongly oriented towards IT-related approaches such as Scrum, will become even more relevant in procurement (Kleeman and Glas, 2020, p. 27). With regard to **information capital**, a variety of digital technologies are presented

in the literature, all of which represent possible applications and only release synergies when combined (Chopra, 2018, p. 216). Such digital technologies include cyber-physical systems (CPPS), artificial intelligence (AI), neural networks, the Internet of Things (IoT), robotics, cloud computing, or 3D printing (Dubolazov, Simakova and Iusma, 2019, p. 241). Highlighted in literature is the term Cognitive Procurement, which stands for computer systems, that combine a range of capabilities such as Big Data analytics, natural language processing, and machine learning with Robotic Process Automation (RPA) (Khuan and Hai Swee, 2018, p. 57). In addition, some Authors name the blockchain approach to the exchange of procurement documents, payments, and guarantees (Rejeb, Sűle and Keogh, 2018, p. 82) and especially in the area of smart contracts (Nicoletti, 2020, p. 148 ff.). Also listed by some authors are the technologies at the logistics interface such as automated guided vehicles (Khuan and Hai Swee, 2018, p. 55; Rejeb, Sűle and Keogh, 2018, p. 80; Nicoletti, 2020, p. 157). Overall, however, it is noticeable that the core technologies in Procurement 4.0 relate to the intensive and integrated use of information and data. For example, a study with Italian companies showed that cloud systems, followed by IoT applications, Big Data Analytics, Horizontal/Vertical Integration and Cybersecurity are perceived as particularly critical for Procurement 4.0 (Bruzzi, Genco and Balbi, 2019, p. 106). How a combination of digital technologies in a common integrated information platform can look like is shown by Tripathi and Gupta (Tripathi and Gupta, 2021, p. 447 ff.). With reference to the **organizational capital**, Procurement 4.0 will become more agile (Nicoletti, 2020, p. 60). This includes moving away from classic organizational models toward a holistic view of processes, where processes are networked horizontally and vertically in line with the new technologies and systems (Henke and Feldmann, 2016, p. 22). The digital transformation calls on managers to create a culture of error in which the potential for creativity and innovation can be unleashed (Bienhaus and Haddud, 2018, p. 979). To address the digitalization issues of procurement, there may also be special digitalization officers who work alongside procurement. In particular, the importance of cross-functional teams to achieve standards in data, systems, or at the cross-company level in connecting suppliers becomes more relevant (Kleeman and Glas, 2020, p. 27 f.). Improved networking and linking with other departments such as R&D and production can be achieved, for example, by establishing cross-functional or common goals, digital dashboards, shared,

flexible workspaces, labs, and high-performing (virtual) teams (Schreiber, et al., 2016, p. 3). Closer collaboration between programmers and sourcing experts will also be required in the future, for example, to train AI systems to make decisions and provide feedback for its actions (Tripathi and Gupta, 2021, p. 452). Therefore, overall, it is clear that the central role of humans and personal contact will remain (Henke and Feldmann, 2016, p. 21; Batran, et al., 2017, p. 129; Bienhaus and Haddud, 2018, p. 978). Through new collaboration models, for example with start-ups, market experts, subcontractors, users, or programmers, an additional external perspective becomes more crucial for the company's success (Henke and Feldmann, 2016, p. 23). The topic of training, e.g., through own procurement academies and cross-functional webinars will also become an important factor (Weissbarth, Geissbauer and Wetzstein, 2016, p. 9 f.). Lastly, according to the results of a survey among CPOs of companies in North America and Western Europe, the centralization of the procurement function represents one of the most promising instruments for optimizing procurement activities (Dubolazov, Simakova and Iusma, 2019, p. 242 f.). The results of this chapter are assigned to the goals of the developed strategy map and mapped below (see Figure 8).

	Procurement goals		Goal specification in Procurement 4.0 through
Value Perspective	Support for the increase in sales	→	Unique value proposition through data sovereignty
	Increase in asset utilization	→	Transparency about resource use
	Substantial Savings	→	Optimized procurement
	Reduction of supply chain risk	→	Knowledge about suppliers and markets
Internal Customer Perspective	Customer satisfaction	→	Real-time information availability, Increased forecast quality, Lead time reduction, quality improvement, procurement of digital products
	Service	→	Proactivity, innovation driver, driver in digitization and networking
Process Perspective	Market opportunities	→	Digital logistics and risk management, Digital support of strategic processes through intelligent data processing
	Efficiency & Effectiveness	→	Digital Purchase to Pay, Operational Sourcing, Operational Automation
	Standardization	→	Digitales Procurement Controlling und Reporting, Digitales CLM, Procurement Finance
Supplier Perspective	Supplier selection	→	Supplier evaluation through innovation criteria
	Supplier performance	→	Supplier innovation, supplier quality and costs
	Supplier integration	→	Platforms, digital partnerships, data and SC integration, personal exchange, feedback culture, formats for co-collaboration
	Employer attractiveness	→	Digital Partner
	Beneficiary exchange	→	Trust, transparency and sharing of information, digital maturity level
	Lean & global supplier base	→	Transparency about supplier base
Learning & Growth Perspective	Employee competence	→	Strategy orientation, method and IT competence, multi-talent, digital consultant, Network coach, process and system manager, risk and interface manager
	Employee satisfaction	→	Personalization of work, personal responsibility
	Systems & Technologies	→	Information platforms, digital technologies (e.g., RPA, AI, blockchain, IoT, cloud, mobile)
	Knowledge Management	→	Training concepts, failure culture
	Efficient network	→	Purchasing integration, cross-functional teams, agility, centralization, process orientation, Horizontal/vertical integration, personal collaboration, digitization function

Figure 8: Goals and their characteristics in the P4.0-BSC

5 Evaluation with Expert Interviews – P4.0- BSC

In the final step of designing the P4.0 BSC, an expert survey was conducted. The experts were selected on the basis of their many years of experience in research and management consulting and were either requested directly or recommended. The survey of the experts was conducted online and with the aid of a previously tested semi-structured interview guide (see appendix). Interview A was conducted with a Consultant SCM, Procurement & Finance and had a length of 35 min, Interview B was conducted with a Department Manager SCM, Procurement & Finance and had a length of 55 min, Interview C was conducted with a Professor Business Administration, SCM & Industry 4.0 and had a length of 65 min and Interview D was also conducted with a Consultant SCM, Procurement & Finance and had a length of 50 min. The number of experts is limited to four and is therefore not representative. For the transcription of the transcripts, the content semantic transcription system according to Dresing and Pehl was used (Dresing and Pehl, 2018, p. 21 f.) For the content-analytical Evaluation following Mayring, deductive category application is used and supplemented in isolated cases by inductive category formation. The category system developed in this way relates to success factors of the P4.0 BSC, the strategy of a procurement 4.0 (see chapter 4.1) and on targets and key figures of the respective perspective (see Figure 9). The category system was adjusted through multiple material runs and the associated finding place analysis. In this way, redundant categories with the same content were removed. The quality criteria of intracoder reliability and construct validity can be regarded as fulfilled for the analysis.

Success factors that have been confirmed by the experts are:

- Employee motivation to implement the BSC and readiness for change
- Alignment of the BSC with the goals of the corporate strategy
- The use of a broad data basis and thus the incorporation of technological expertise and IT support
- The pursuit of a holistic view with regard to the organization and the type of metrics to be measured (potential and efficiency measurement)
- Developing a simple solution with few strategic key figures and low-effort, modular key figure generation

Regarding a P4.0 strategy, the experts' opinions can be summarized as follows:

Like the BSC, the procurement strategy must also be derived from the corporate strategy. In this context, it is advisable to define exactly what the contribution of procurement is. In addition, it becomes clear that the topic of digitization should be treated seriously, which in turn means a real strategic realignment with consequences for the organization, employees and business models. In this way, procurement digitization works in two directions. On the one hand, procurement will use digitization for its processes, but on the other hand, it will also use it to develop its products for the end customer. A systematic approach has become established in practice for defining the digitization strategy of procurement. This is characterized by the formulation of a vision, a derivation of goals, target/actual comparisons and an action roadmap as well as the corresponding organizational support. The objectives of the P4.0 BSC associated with the procurement strategy are summarized in the strategy map, taking into account the statements of the experts and the findings of the SLR (see Figure 9).

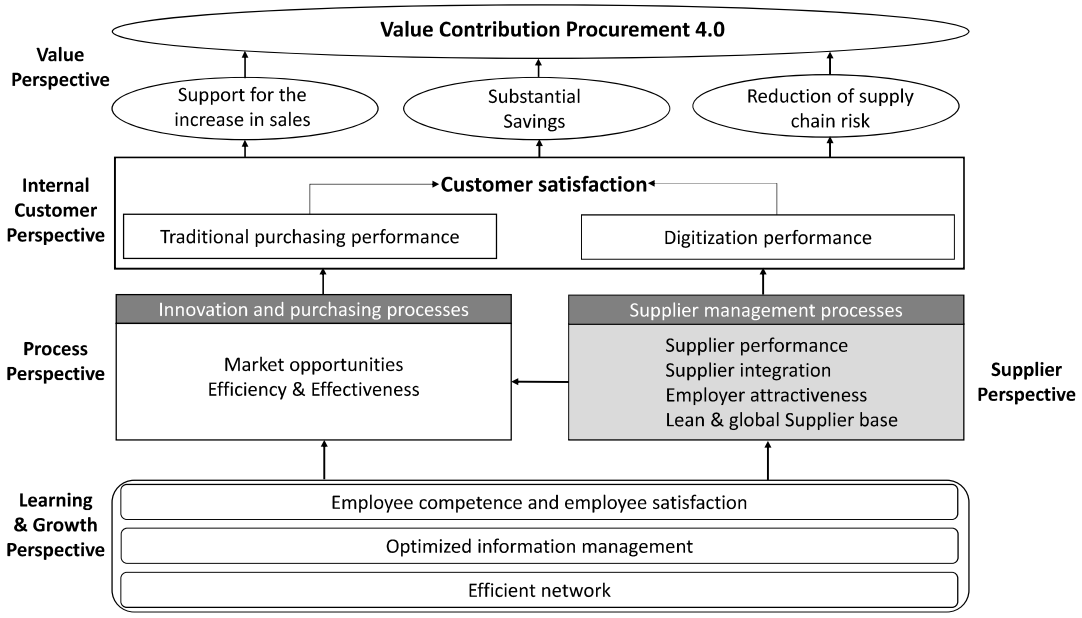


Figure 9: Strategy Map of the P4.0-BSC

The experts' statements make it clear that the development in the future will not be limited to procurement, but will relate to the entire inward and outward value chain

management. This development is supported by digital technologies and in turn affects the entire company. With regard to performance measurement with the help of the BSC, it is confirmed on the one hand that it remains the same in terms of system and logic, and on the other hand that it makes perfect sense to approach the subject with the help of the BSC. Furthermore, the experts agree that, in addition to the continued use of classic key performance indicators, there will also be new key performance indicators. In particular, it is assumed that the type of survey will take on a different quality. But overall, it is a question of additions at certain points, which will relate to technologies, processes, know-how and organizational matters. Such additions mainly concern strategic action, cross-functional thinking and the topic of value contribution. With regard to value contribution, Expert B emphasizes that this should be measured in terms of output-related variables: "So how much more business do I do through better procurement, how many new business models can I promote as a result, how many new innovations can I get into my products more quickly as a result? How lean will my own production become as a result of improving procurement? If procurement can be measured against these four or five additional things, then it can bring a lot of benefits in both directions."

The topics addressed culminate with the results of the SLR in the validated P4.0 BSC. Based on the validated P4.0 strategy map, this presents the strategic goals and the key performance indicators developed for them, including a brief description of the key performance indicators (see Figure 10).

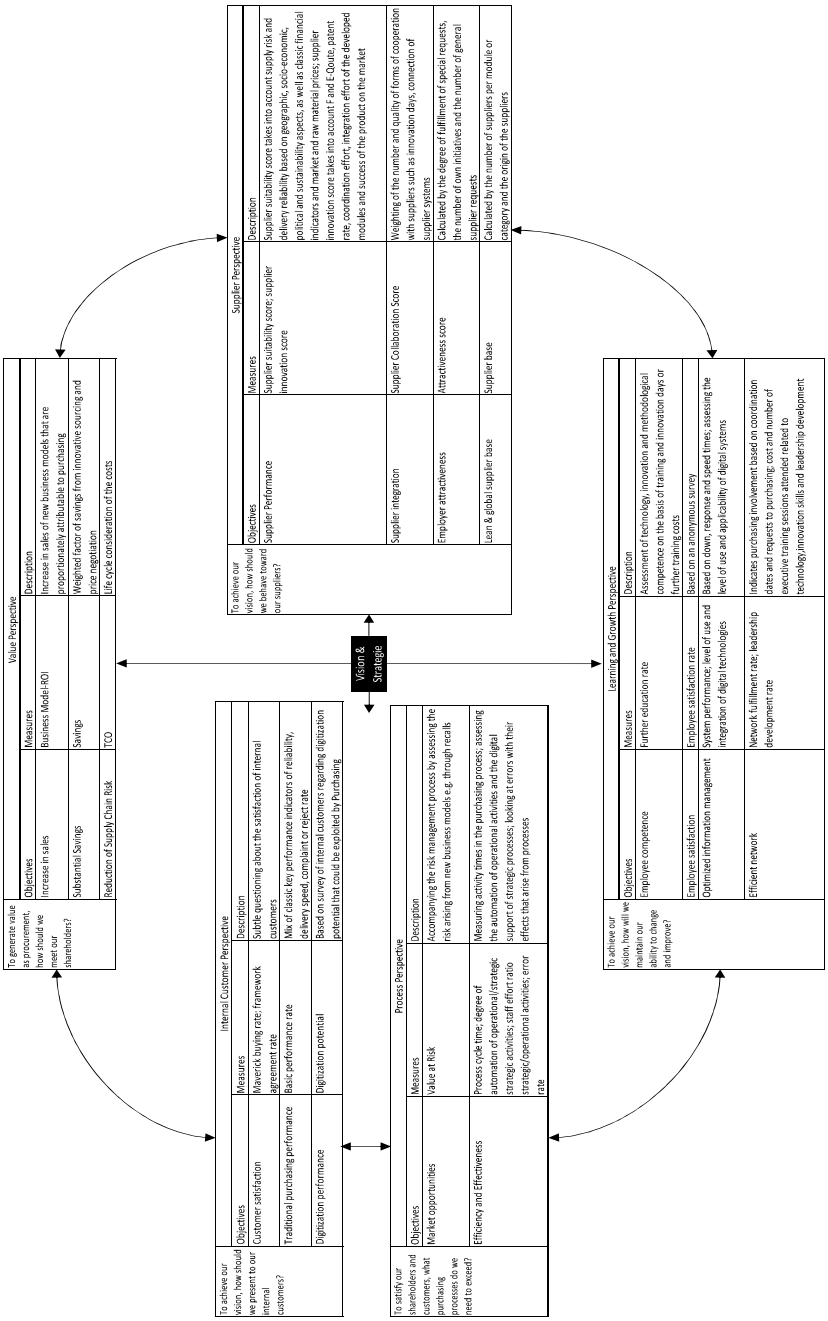


Figure 10: P4.0-BSC

6 Conclusion and Discussion

In this paper, a P4.0 BSC was developed using an SLR. Interviews were conducted to evaluate and further develop the P4.0 BSC. Through this approach, a conceptual reorientation of performance measurement in procurement could be presented. With reference to the research question posed at the outset, it becomes clear that, in addition to taking into account established key performance indicators and methods, the performance of procurement will in future be measured primarily in terms of strategy and value contribution. The technological developments of digitization in particular contribute to the fact that procurement must find good arguments for its justification in the company. Presenting and controlling this justification transparently is a task of modern PMS, such as the P4.0 BSC developed in this paper. In this way, performance measurement makes an important contribution to the implementation of digital transformation in procurement.

According to the authors, the P4.0 BSC represents the first of its kind. The practical use of the model would have to be carried out with adaptation and adjustment to the respective company-specific situation. Factors that can play a role here are the corporate strategy, degree of digitization, industry, products, previous type of performance measurement or company size. Nevertheless, the model represents a solid basis on which future research can be oriented.

7 Outlook

From a scientific point of view, it makes sense to conduct further interviews with experts in order to further validate and detail the previous results. With reference to practice, an exemplary use of the P4.0 BSC in companies should be aimed for. In particular, the exchange with practitioners will support the future development of the P4.0 BSC.

8 Appendix

Semi-structured interview guide

1. In your opinion, what are success factors for a beneficial PMS, especially in the form of a BSC, for procurement 4.0?
2. What aspects come to mind when defining a (digitization) strategy for Procurement 4.0? Which topics would need to be included in the formulation?
3. What would be the objectives of Procurement 4.0 from a value perspective?
4. What would be the most important key figures of a procurement 4.0 in the value perspective?
5. What goals would Procurement 4.0 pursue in the internal customer perspective?
6. What would be the most important key figures of a Procurement 4.0 in the internal customer perspective?
7. What goals would Procurement 4.0 pursue in the process perspective?
8. What would be the most important key figures of a procurement 4.0 in the process perspective?
9. What goals would Procurement 4.0 pursue in the supplier perspective?
10. What would be the most important key figures of a Procurement 4.0 in the supplier perspective?
11. What goals would Procurement 4.0 pursue in the learning and development perspective?
12. What would be the most important metrics of a Procurement 4.0 in the learning and development perspective?
13. What is your assessment of how key performance indicators in Procurement 4.0 change and differ from key performance indicators in Procurement?

14. Can you think of any other points for performance measurement in Procurement 4.0 that we have not yet addressed?

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Conceptual framework for a digital organization

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Purpose: *Innovative technologies are forcing companies to incorporate digitization more into their value creation processes in order to remain competitive long-term. A transformation to a digital organization is therefore required. Aim of the paper is to identify which key components should be covered during the transformation to a digital organization and should therefore be part of a conceptual framework. The conceptual framework will help companies achieving a holistic transformation into a digital organization.*

Methodology: *Based on an analysis of the literature, the key components necessary to successfully transition to digital organization are identified. The relevance of these core topics are then examined with the help of expert interviews. Based on the results, a conceptual framework for a holistic transformation into a digital organization is developed.*

Findings: *Six key components are identified for the framework, which represent the basic requirements for the transformation into the digital organization. Furthermore, drivers as well as challenges are shown that companies have to overcome in the digital transformation.*

Originality: *Scientifically sound concepts that include a holistic approach to transformation into a digital organization have, until now, lacked the scientific methods used to collect the content. The development of our framework has a scientifically grounding.*

First received: 02. Jun 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

In times of Blockchain, Big Data, the Internet of Things, and Artificial Intelligence, there is hardly a company that can avoid the topic of digitalization. The multifaceted flood of innovative technologies and novel forms of value creation forces companies to increasingly incorporate digitalization into their products and value creation processes in order to remain competitive in the long-term. A transformation to digital organization is therefore necessary (Bounfour, 2016; Salkin et al., 2018).

The unsuitable organizational structures and inflexible business processes of traditional systems present organizations with enormous challenges transitioning into the digital age (McKinsey & Company 2014, Beaudry and Pinsonneault, 2005). Results show that, after initial successes in implementing digital initiatives, companies increasingly find it difficult to sustain competitive advantages realized through digital transformation, including well-known organizations such as General Electric, Ford, Lego, and Procter & Gamble (Davenport and Westerman, 2018). This is partly due to the fact that often no holistic approach was taken during implementation.

The transformation to a digital organization, therefore, requires a holistic concept in which the individual components are coordinated to ensure long-term success. The aim of this paper is to identify which key components should be covered during the transformation to a digital organization and should therefore be part of this conceptual framework. First, core issues for the transformation into a digital organization are identified with the help of a literature analysis. The insights gained from the literature are then checked for their practical relevance with the help of expert interviews. Subsequently, the methods and procedures are explained. Based on the results of the literature analysis, a scientifically sound framework for digital transformation is developed. After a short discussion of the results, the paper ends with a summary and an outlook on further research.

2 Digital Transformation and Digital Organization

According to Mazzone (2014, p. 8) digital transformation is "the deliberate and ongoing digital evolution of a company, business model, idea process, or methodology, both strategically and tactically." The digital transformation, also known as digital change, pursues goals such as increasing flexibility, productivity, customer focus, securing and improving a competitive position, automation, increasing efficiency and company-wide innovation (Schroeder et al., 2014; Gilchrist, 2016; Bounfour, 2016). The cause and biggest driver of digital change is technological progress in conjunction with innovative technology concepts (Gilchrist, 2016). A large number of technologies can be cited here, such as cyber physical systems (CPS), additive manufacturing processes, augmented reality or artificial intelligence, cloud computing, 5G mobile phone standard, and Internet of Things platforms, among others (Salkin et al., 2018).

Digital change affects companies in all industries and brings with it both opportunities, such as efficiency gains or productivity increases, and challenges, such as a lack of knowledge, unclear target visions or complexity management (Gilchrist, 2016; Bounfour, 2016).

In order to change digital organization, all organizational structures and processes in the company must adapt to increasing digitalization. However, established approaches to organizational development have not yet been able to meet the requirements of digital transformation (Jones, 2013). Therefore, in the scientific literature there are numerous approaches to implementing a digital organization. These, however, focus primarily on individual core topics of digital organization, such as the implementation of new technologies and digital business models, intelligent products, and services/leadership through digital change (Casadesus-Masanell and Ricart, 2011; Gilchrist, 2016; Westerman et al., 2011; Esser, 2017; Cameron and Green, 2015). However, these core issues should be coordinated and embedded in a holistic framework to guarantee long-term success. Scientific concepts, which include a holistic approach to digital organization transformation, either rarely exist or lack a clear scientific method with which the content was collected (Snow et al., 2017; Kane et al., 2018; Gilchrist, 2016; Salkin et al., 2018; Westerman et al., 2014). However, it is apparent that in recent years a large number of

multi-faceted maturity models for Industry 4.0 and digitization have been developed to enable companies to speed along their digital maturity (Anderl et al., 2015; Back and Berghaus, 2015; Millack et al., 2015; Maier et al., 2012; Westerman et al., 2011; Catlin et al., 2015; Wendler, 2012). These should, therefore, be included in the following analysis so that the key components of transformation into a digital organization can be identified and then empirically tested. Finally, based on the results, a scientifically sound conceptual framework for transformation into a digital organization should be developed.

3 Research Methodology

While individual focal points for the transformation to digital organization have been the subject of scientific discussions over the previous years, developing a scientifically based conceptual framework remains relatively unexplored. Thus, an attempt is made with this paper, to answer the following research question: "What are key components of a conceptual framework for a transformation into a digital organization?"

To answer this research question, a systematic literature review was conducted. The scientific data bases, Science Direct, Web of Science, and Google Scholar were the primary post-2000 sources of published articles used to guarantee current results. Scientific papers were selected and evaluated using the keywords "maturity model", "maturity assessment", "digital maturity", and "digital organization". In addition, the literature research shows that, besides academia, consulting companies in particular issue their results on digital maturity models. Therefore, the generic approaches on organizational maturity published by the largest consultancy companies, like Accenture, Deloitte, PricewaterhouseCoopers, KPMG, and McKinsey & Company were also taken into account (Statista, 2017). In a second step, the dimensions of digital maturity used in the models and the various organizational areas examined were compared regarding their content.

Based on the literature results, expert interviews were conducted in July 2018 to confirm the relevance of the content. Table 1 shows the list of experts.

Table 1: List of experts

Number	Industry sector	Position
1	Education sector	Manager IT security
2	Automotive	Project manager additive manufacturing
3	Aviation	Material & logistics manager
4	Aviation	Head of innovation management
5	Medical and security technology	Digital systems management
6	Consultancy	Associate consultant
7	Aviation	Corporate innovation manager
8	Aviation	Digital business manager
9	Commerce & services	Senior online marketing manager
10	Human resource management	Digital human resource manager

The experts have significant experience and specific knowledge in the field of digitalization. All interviews were carried out in person in the native language of the interviewee. During the interviews, the different key components of a digital organization

were discussed in detail. All interviews were recorded and then transcribed using QDA software MAXQDA (Creswell, 2003).

4 Literature analysis about digital maturity models

The dimensions of digital maturity used in the models and the various organizational areas examined were compared regarding their content. These dimensions are crucial components of organizations and therefore best-suited as key components for the conceptual framework for a transformation to digital organization. Table 2 shows an extract of individual digital maturity models and the content considered. The models were developed by both scientists and consulting firms. In total, 34 digital maturity models and 216 dimensions of digital maturity were analyzed.

Table 2: Digital maturity models (extract)

Author	Year	Key components
Anderl et al.	2015	Business models, IT services, communication, connectivity, products, production, machine-to-machine communication
Back and Berghaus	2015	Customer experience, product innovation, strategy, organization, process digitalization, collaboration, ICT operation and development, culture, expertise, transformation management
Catlin et al.	2015	Strategy, capabilities, culture, organization, talent

Author	Year	Key components
Competence Center	2019	Strategy, Technology, Products and Services, Organization and Processes, Employees
Deloitte	2018	Customer, Strategy, Technology, Operations, Organization & Culture
KPMG	2916	Digital Strategy, Digital Governance, Digital Culture, Digital Customers and Channels, Digital Organisation and Process, Technology Management, Digital People and Capabilities
Maier et al.	2012	Structured process, organizational structure, people, learning
Millack et al.	2015	Strategy, organization, smart factory, smart operations, smart products, data-driven services, employees
Westerman et al.	2011	Customer experience, operational process, business model, digital capabilities

The evaluation of the maturity models showed that it is often impossible to understand how the content of particular dimensions is created. Furthermore, many of the models have a thematic focus; for example, Chaffey's maturity model (2010) focuses on the maturity of digital-marketing governance. In comparison, Som and Gamroth (2019) developed a model to determine the digital maturity for human resource management. Additionally, some models have an industry focus, like e.g. Mettler and Pinto (2018)

focusing digitalization in the health care sector. A generic, holistic approach for the transformation to a digital organization, which also considers interdependencies between individual dimensions does not yet, unfortunately, exist within these models (Westerman et al., 2014).

5 Results

With the help of the literature analysis, six content-related key components for the transformation to a digital organization were identified, and their respective content-related relevance was subsequently confirmed in the expert interviews. These key components include organizational structure, strategy, human resource management, new technologies and their infrastructure, value chain, and customer-considerations, and thus form the foundation of the framework (see Figure 1). Noteworthy: there is a large number of interdependencies between the individual key components; however, these key components have not been further subdivided for clarity.

Organizational structure

The key component “organizational structure” was rated as highly relevant by the experts. It reflects a company's efforts to adapt the strategic positioning of the organization to new challenges. In doing so, it aims to efficiently provide digital skills within the company. New approaches to the organization of a company to successfully and decisively transform to digital organization is made possible by emerging technologies and must be implemented with the help of an appropriate organizational structure (Geissbauer et al., 2016).

As an organizational structure changes during a digital transformation, new rules and structures are needed to organize collaboration both inside and outside the company to move away from traditional forms of organization towards an agile, adaptive one. The detachment of established structures refers to different areas of organizational structures. In addition to technical replacements (IT systems and communication channels), both leadership principles and interpersonal behavioral structures need to be reviewed.

In order to properly implement digitization and have it be successful, one must prepare a task force within the company, which is purely concerned with this topic, as well as designate a single expert contact person responsible for all corporate operational divisions.

"Many are trying to establish digital products and digital organizations in their old world, and it doesn't work." (Interviewee 8)

New, agile organizational structures that turn away from traditional corporate silo structures promote cross-departmental and cross-company cooperation in the management of digital projects. The replacement of a functional or matrix organization with a network organization is an example of this. These new structures also include flexible communities, centers of excellence, incubators, ideation labs, and acceleration centers.

"Digital organization is maintained above all through functioning processes." (Interviewee 10)

Under the key component "organizational structure", corporate processes are also enhanced. Suitable processes are then digitized in a data-focused manner, using a participatory approach in order to strategically align the organization and employees to new business areas and types of value creation. With the basic idea of agility, business processes can be made more flexible, faster, and more efficient. High levels of digitization of business processes and their interfaces are required to enable vertical process integration within the company and at the same time horizontal integration with partners along the value chain. In addition to agile structures, the agile management of business processes are also required. This can be achieved by establishing methods such as SCRUM, Design Thinking, and DevOps.

"But it is not only digitization which has become a major topic, but also the new working methods made possible by technology, which do not necessarily have anything to do with digitization. Key word: agile." (Interviewee 10)

Furthermore, a digital organizational structure should be coordinated with an overall digitization strategy and adapted for digital value creation.

Strategy

The experts also attributed an important role in the transformation to a digital organization to the "strategy" concept module. For the success and dynamics of the transformation to a digital organization, the development and targeted pursuit of a long-term sustainable digitization strategy is essential (Hess et al., 2016). This prioritizes a strategic focus on the implementation of digital projects and thus ensures both competitiveness and further business development (Berman, 2012). The relevant aspects of a digitization strategy include the definition of clear strategic objectives and digital visions, the company-wide communication and documentation of these visions and objectives, and the definition of concrete measures to achieve aforementioned objectives. It should be noted that a successful digitization strategy not only takes into account disruptive technological developments but also regularly adapts the defined strategy on the basis of new experiences (Puranam et al., 2014).

"IT and digitization should drive the company forward, new business models should improve the service, the internal collaboration, and so on. This is a new way of thinking, because IT used to be a pure support function." (Interviewee 6)

With the use of digital technologies, an organization experiences the possibility to develop new business models. Disruptive, digital business models often focus on additional digital revenue generation and the optimization of customer interaction via a software-based, active customer relationship. There is also a trend towards innovative product and service portfolios that create integrated customer solutions across supply chain boundaries, replacing traditional product-sales business models. Examples are pay-per-use models (e.g. car2go carsharing of Daimler AG), Product-as-a-Service (e.g. Power by the hour of Rolls-Royce Motor Cars Ltd.), and Platform-as-a-Service (e.g. Amazon Web Services).

In addition to business model development, strategic considerations for a digital organization should also take into account an increase in investment. This includes an increased capital investment or a higher project budget in order to enable both material (e.g. new technologies) and personnel resources (skilled workers).

Human Resource Management

Human Resource Management is considered by experts to be the third most relevant key component. The acquisition of digital expertise and the availability of necessary resources are essential for a sustainable transformation into a digital organization (Escher, 2005). Under changed working methods, digital technologies are used to support collaboration, communication, and mobile working by employees, enabling efficient networking while on the move.

Leadership in this sense includes the role of management in the implementation of a digitization strategy. Frequently, the organization's focus on digitization is achieved using a “top management commitment”, which delegates all of a company's executives as a driving force for digitization. To this end, there should be a Chief Digital Officer in top management, who focuses on the digitization strategy and is responsible for planning and managing the digital transformation within the organization.

"Be it an App Developer, the Head of IT, a Digitization Manager, or an Online or Digital Marketing officer, none of these roles existed before." (Interviewee 3)

Furthermore, the willingness of managers to involve employees in the change process has a strong influence on the success of the transformation to a digital organization.

The corporate culture illustrates its relevance in the openness and understanding of an organization towards digital technologies and associated changes (Tschirky, 2003). A kind of "digital culture" is thus created; this is characterized by the employees' trust in the new information systems and processes, which enable greater process stability and rapid role- and context-specific exchanges of knowledge. By raising awareness and involving employees in decision-making processes, an openness to innovation is fostered, leading to active participation in shaping future changes. Furthermore, open communication, using suitable communication technologies, is essential to achieve an exchange of knowledge and to establish an open collaborative culture. The disclosure and goal-oriented analysis of errors promotes a willingness towards change within the company, while fostering data-based learning and encouraging decision-making from employees.

"It's not enough to give a status update or explain why, but you have to keep the whole company fully informed: why you're taking this step, what this step involves, how long this step takes. Communication is the key." (Interviewee 3)

A democratic management style that offers a framework for decision-making from employees requires not only an appreciation of employee skills but also continuous investment into employee development. The decentralization of decisions generates a high degree of autonomy and independence for employees, which can lead to efficiency gains at the customer interface level, for example, by adapting data in real time. New manufacturing technologies and the increased use of ICT require an early recognition of employee training needs.

"Employees who are willing to do so are also willing to be retrained and to stay on top of the changes, but it's obviously a culture change." (Interviewee 9)

In addition, newly emerging positions and responsibilities, especially in the IT sector, require a precise definition of rights and duties. The specification of requirements for new types of activities and roles is necessary for personnel recruitment and a goal-oriented execution of tasks.

New technologies and infrastructure

New digital technologies and infrastructure are also identified as an important key component. Modern technologies enable the creation of an ever larger database, while flexible and agile ICT systems promote the dynamic implementation of strategic measures, thereby forming a basis for a successful digital transformation. ICT infrastructures and information systems enable new digital products, services, communication methods, and transactions. In addition to digital technologies, real-time data and standards should be considered as equally relevant topics (Badescu and Garcés-Ayerbe, 2009).

In order to use new technologies professionally, existing competencies and infrastructures in the company must be expanded. In this context, the skills for data analysis, process automation, and cross-channel management are considered to be crucial for the successful use of new technologies. Digital workplace concepts and the

agility of existing systems determine the type and possible applications of digital technologies in the company.

"Over the decades, many individual system solutions have been set up. Whenever new demands on IT arose, companies would either purchase new software or develop the technology themselves. This IT solution is then often not cohesive, [...], i.e. at some point one the IT infrastructure becomes completely fragmented – not linked at all, very stiff, and not agile." (Interviewee 6)

Digitalization and process automation are necessary for proper digital organization. The creation of a flexible technological environment is the starting point for process digitization and further process automation. In the course of vertical integration, IT is of great importance, since interdepartmental, fully networked IT solutions open up synergies to connect business divisions and create value. Traditional, legacy IT architectures cannot withstand the pressure of increasing customer requirements that digital product innovations demand.

For example, in data management, data analysis strategies under the umbrella of Big Data Analytics, often focus on predictive analytics (prediction of future events: e.g. load forecasts of smart grids, predictive maintenance, etc.), forecasting procedures, and prescriptive analytics (recommendations for action and automated decision making: e.g. planning of resources, ticket prices of airlines, etc.). The enormous amount of data, analysis methods, and algorithms exceed the capacity and functionality of existing Enterprise Resource Planning (ERP) systems. A data integration level is then built up to connect to the ERP system. In addition to optimized “Legacy IT” to support familiar business processes, digital organizations need to swiftly construct a second specialized IT architecture in parallel.

Value chain

The fifth key component focuses on value chains. Companies use digital technologies to develop innovative product and service offerings with significant customer and competitive advantages. The integration of data-based services into the business model leads to "smarter" products and networking with customers. Products are offered completely digitized or enriched with the help of additional digital functions.

"[...] the combination of both automation and the availability of new devices on the market, as well as the subsequent new possibilities of networking, have drastically grown in recent years." (Interviewee 4)

A digital organization should therefore drive the development of so-called smart products. Smart products are physical objects equipped with both extensive ICT add-on functions (e.g. product memory, self-disclosure, networking, and local development) and, thanks to mobile technologies, the ability to collect and communicate data during production and use. Some examples of this are novel digital services, blogs, customer boards, online shops, service platforms, mobile payment, and live chats.

Furthermore, with regard to the digitalization of the value chain, practice often follows the model of a smart factory. The "smart factory" is an intelligent and networked production environment in which production plants and logistics systems communicate with both superimposed IT systems (e.g. ERP, supply chain management systems) and "smart products" to organize itself in a manner where human intervention is replaced with CPS and an unified database.

"There are two main lines of action […] one is the digitalization of the products […] (the so-called top-line activities), and the bottom-line activities i.e., the digitization of the factory." (Interviewee 4)

The networking of people, objects, and systems also allows dynamic, real-time, self-organizing, value-added networks. Legally independent actors are connected to each other via complex mutual relationships in a system of individual value-adding processes. Furthermore, the cooperation of suppliers, business partners, and customers within a global, digitally-integrated network is a form of horizontal integration with the aim of achieving efficient and flexible customer solutions, extending far beyond the corporate boundaries of individual organizations.

Customer-considerations

Customer-considerations represents the sixth key component. Digital transformation is driven by the changing implementation of digital technologies associated with customer expectations, leading to companies gearing their value propositions and offerings to the

behavior of digital customers. So-called "digital natives" are shaping the way in which customers act, consume, and buy digital products and services.

"A digital organization must be strongly customer driven. Technological advances require that we respond incredibly quickly to customer needs, which means expanding product development and services. The process begins with the customer and ends with the customer." (Interviewee 10)

Starting with digital platforms, the horizontal integration of suppliers, customers, and other supply chain partners within the value chain aims to complete the customer ecosystem, consisting of third-party logistics partners, products of other competitors, and control systems. A central tenet of this ecosystem is customer-oriented, integrated solutions which allow for individualization, personalization, flexibility, and anticipation in order to foster a close, software-supported, active customer relationship. There are three areas in particular that are central to the customer relationship processes: information and communication, sales and consulting, and customer relationship management (CRM).

In the area of information and communication, search engine marketing (the use of social media networks and the personalization of advertisements on websites) in online advertising or email marketing is critical. In order to optimize the customer experience in sales and consulting, companies increasingly rely on individual product designs by customers using configuration tools, targeted data management for real-time information on product availability, order, service status, or delivery date or the operation of an online shop with chat functions and e-commerce. CRM can also constitute a web-based self-service/customer portal, customer database, and the integration of external information, such as geodata and data from social networks to enable individualization of customer advice and sales. The design of a successful customer journey is essential to achieve high customer satisfaction (Piller et al., 2011).

Figure 1 summarizes the key components which represent the basic requirements for the transformation into the digital organization.

Conceptual framework for a digital organization

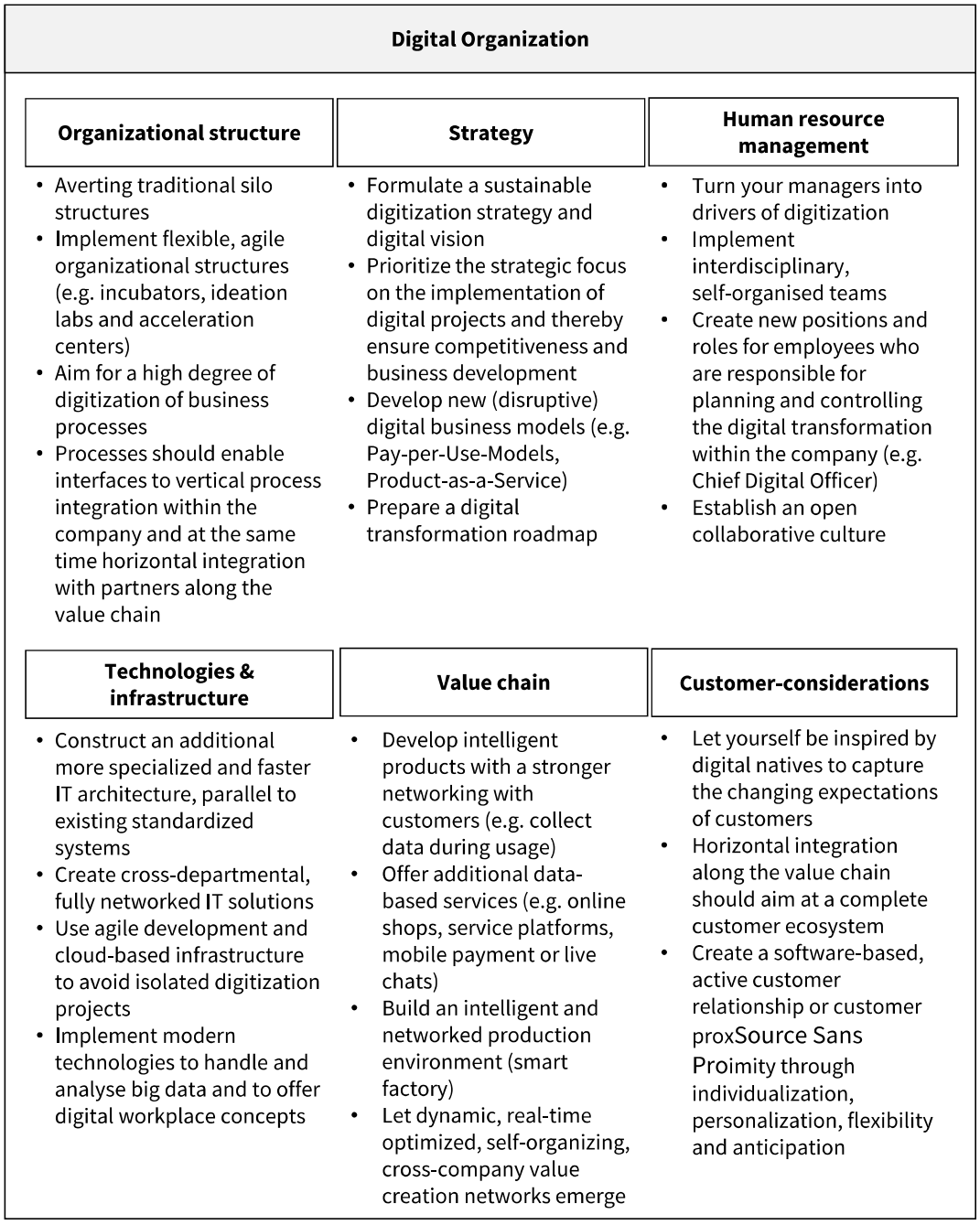


Figure 1: Key components for the transformation into a digital organization

6 Discussion

The results show that different core issues need to be addressed in order to introduce digital organization. The subject areas show a high degree of interdependence with each other, which must be taken into account during implementation.

During the transformation process to a digitally organized company, the firm must also face numerous challenges (Kotter, 1995; Prahalad and Krishnan, 2002). Four challenges are described below, which the interviewed experts regard as the greatest challenges during the transformation process. These are organizational effort, poor change management, lack of knowledge, and innovative technologies.

Organizational effort seems to be one of the most critical challenges in the transformation process, as it results from a reorganization process of the existing organizational relationships. Many organizational functionalities depend on complex, slow, bureaucratic corporate processes as well as old-fashioned IT architectures. In addition, existing legal conditions and low adaptability of employees and infrastructure impede companywide digitization.

The second fundamental challenge organizations must face is change management, which is a term for the systematic approach of change processes within companies, usually resulting in refusal and resistance. This may result from employee's fears, frustrations, and low motivation or from present hierarchical structures. So, a lack of communication, knowledge, and information transparency may hinder employee's awareness of change. Dealing with resistance constructively is crucial for a holistic digital transformation (Groysberg et al., 2018).

Expertise within an organization is an important driving force for the development of innovation and the execution of change processes. In addition, missing experiences in data, innovation, and digitization hinder decision processes and corporate agility. Therefore, the company must counter a lack of workforce and expertise, particularly in the field of information technology, with various sustainable success strategies such as hiring qualified developers and data analysts.

Furthermore, organizations' digital development depends on innovative technologies; however, innovative technologies also often imply vulnerability in organizations, resulting from technical risks such as cybersecurity and loss of control over data. Therefore, the issues of data and risk management should be given high priority within digitizing organizations.

Figure 2 shows a conceptual framework that enables companies to take a holistic approach to digital transformation in order to make digital change successful and sustainable.

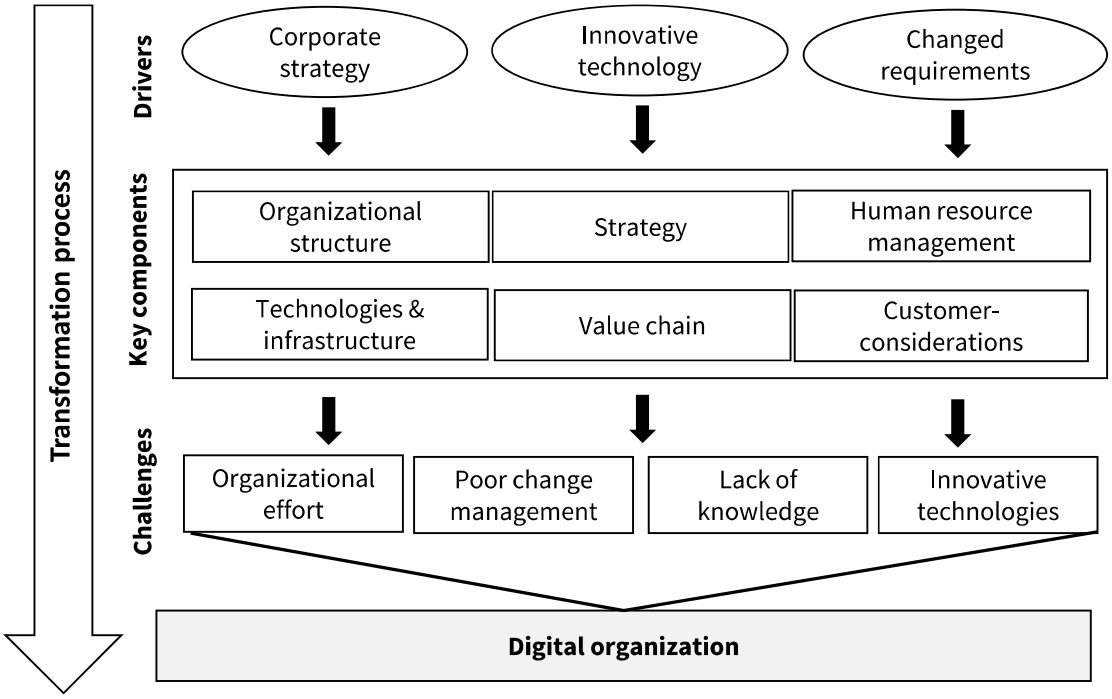


Figure 2: Conceptual framework for a digital organization

Triggered by various drivers, the transformation process is initiated. Examples of triggers can e.g. be the corporate strategy, innovative technology, or changed requirements. The key components previously identified and described in chapter 5 should all be considered in the transformation into a digital organization, but they must be designed individually for each company.

The key components form the foundation of the change process and are triggered by the drivers of the transformation. During the transformation process, the company must overcome various challenges, such as poor change management or lack of knowledge.

7 Conclusions

Numerous innovative technologies and associated increases in digitized value chains are forcing companies to incorporate digitization into their products and value creation processes in order to compete long-term. A transformation to a digital organization is therefore required. This means that all aspects of the organizational structure and processes must be adapted to the digital transformation. In this paper, based on an analysis of the literature, core issues were identified which will need to be addressed during the digital organization transformation. These core topics were examined for their practical relevance in expert interviews. Based on the results, a conceptual framework was developed to help companies take a holistic approach to digital transformation.

Within the framework of further research, the scientifically based framework developed in this paper will be validated within companies.

Lastly, it should be noted that the work is characterized by limitations. The research method used is limited by the small number of expert interviews, which limits the significance and comparability of the results. In addition, the concept development in the context of this paper is based on digital maturity models whose suitability has not yet been comprehensively empirically substantiated. Furthermore, it is evident that organizational change processes are influenced not only by situational factors but also by political and legal framework conditions as well as other companies in the environment. However, these dependencies and influences are not fully captured in the concept developed.

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Integration of stakeholders in the innovation process of transportation networks

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Purpose: Transportation networks play an important role in providing reliable and resilient transport solution for their customers. To stay competitive, members of freight forwarding networks use their joint knowledge to innovate. This paper provides information about the influence of commitment on the success factor of integration of stakeholders.

Methodology: To evaluate the influence an online survey was conducted with participants of several transportation networks. The findings of the quantitative study were analysed with the help of the partial least square (PLS) approach.

Findings: The study demonstrates that the attitude-oriented commitment has a positive effect on the integration of stakeholders. Hence the proposed hypothesis of a positive effect was confirmed.

Originality: The presented study provides a guideline for members of transportation networks to precisely ensure that the success factor integration of stakeholders is considered in the innovations process. Furthermore with regard to the success factor the influence of attitude-oriented commitment needs to be involved to enhance the output within the inovation process.

First received: 21. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Faced with dynamic markets, medium-sized freight forwarders are challenged to create innovative products and processes that will ensure the company's continued survival in a globally operating customer supply chain. At the same time, it is becoming increasingly apparent that freight forwarders are attempting to join together in company networks in order to meet these requirements. This can be attributed to the fact that, given the many influencing factors, this form of cooperation is regarded as the superior organisational structure for overcoming the various challenges presented. (Möller, 2006)

One of the features considered to be a significant advantage for participating haulage companies is that they are given a platform in the network that enables a targeted exchange of knowledge in innovation projects between the stakeholders. It is worth emphasising that it is essential to take the integration of stakeholders into account as a success factor in order to take full advantage of the network and to incorporate all the expertise of the participants.

For a freight forwarding network to achieve this goal, it is crucial that the stakeholders are committed to working together in the business network. Research into success factors considers commitment to be an important factor for targeted success, and the question of what influence commitment has on the integration of stakeholders during the innovation process needs to be investigated.

2 Theoretical background

This chapter provides the necessary theoretical background. As well as a brief description of freight forwarding networks and innovation processes, the factors of stakeholder integration and commitment are presented, followed by the research method and the results.

2.1 Transportation networks

When examining freight forwarding networks, it should first be noted that, according to Sorat's definition, freight forwarders are defined as agents that possess logistics expertise. Transport services, which are responsible for transporting goods from one destination to another, represent one area of logistics expertise. (Sorat, 2005) As such, they hold an important position within the value chain. Figure 1 below illustrates the respective interface to the transport service based on the value creation process of a supply chain. The transport services are depicted by a graphic notation and further emphasise their importance within a globally operating value chain.

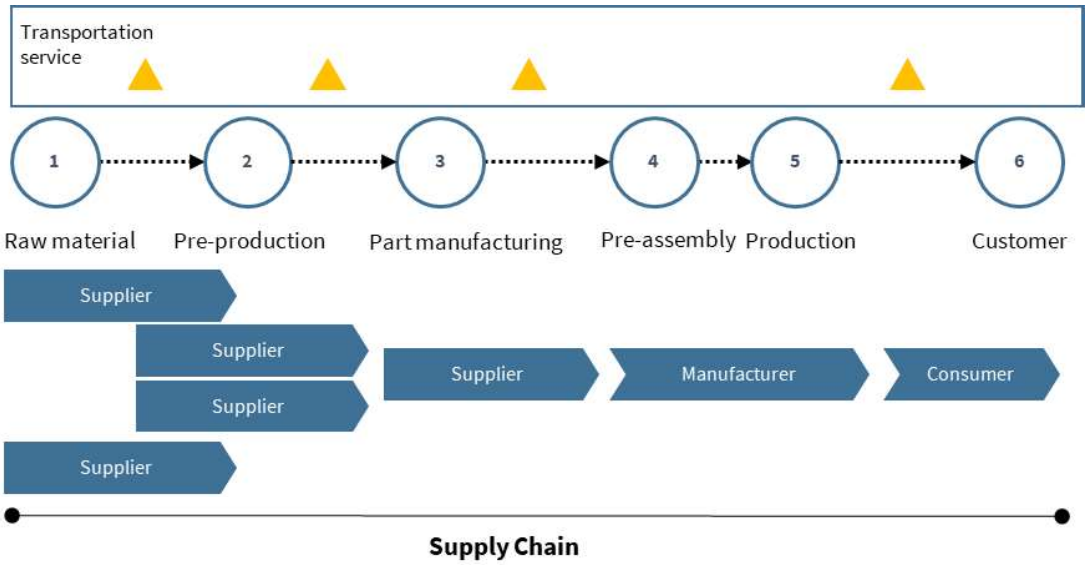


Figure 1: Transport services within the supply chain

With consideration given to the supply chain described above, a wide variety of network structures and process flows are possible. Freight forwarding networks are unique in that they are a cooperation of horizontally oriented companies. These networks are based on the premise of providing logistical services. This situation is explored and illustrated in Figure 2.

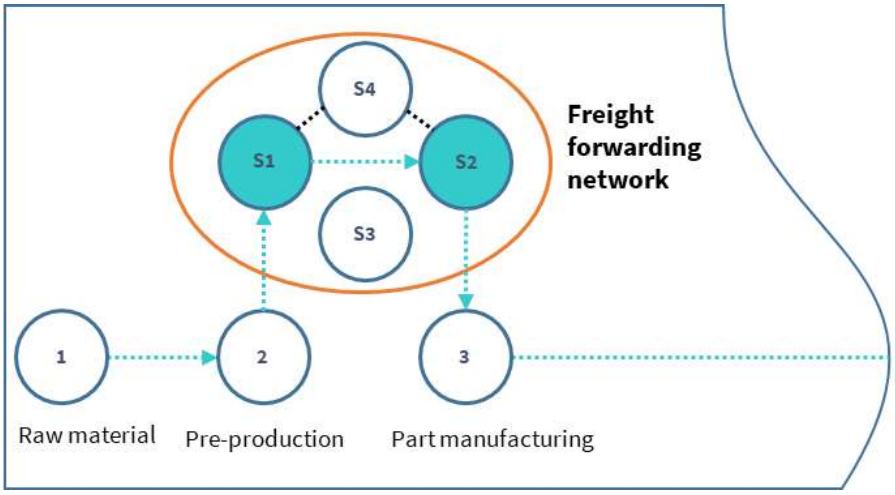


Figure 2: Use of freight forwarding company networks within the value chain

The figure 2 also illustrates that freight forwarding networks systematise the use of resources for the handling of the transport services and that not all network partners necessarily have to be involved in the creation of the service.

2.2 Innovation process

The literature presents a variety of phase models for the innovation process which are characterised by different stages and break down the process of innovation. (Verworn/Herstatt, 2000; Cooper/Kleinschmidt, 1990; Wagner/Busse, 2008, Thom, 1992; Herstatt, 1999) Here it can be inferred that the level of abstraction of the respective phase model is regulated by the number of process steps.

Table 1 illustrates the range of different phase models within innovation process research and clarifies the different approaches.

For this research, the Wagner/Busse innovation process model was used because it relates to logistics innovations. (Wagner/Busse, 2008) The innovation development phase has also been chosen as the frame of reference in order to narrow down the topic.

Table 1: Innovation processes from the literature

Authors	Process steps					
Cooper/ Kleinschmidt (1990), S. 46	Idea	Preliminary Assessent	Definition	Development	Validation	Commercialization
Thom (1992), S. 9	Ideengenerierung			Ideenakzeptierung		Ideenrealisierung
Cooper (2008), S. 215	Discovery	Scoping	Build Business Case	Development	Testing and Validation	Launch
Herstatt (1999), S. 73	Ideengenerierung und Bewertung	Konzepterarbeitung Produktplanung		Entwicklung	Prototypenbau Testing	Produktion Markteinführung
Wagener/ Busse (2008), S. 115	Ideengenerierung und Selektion	Innovationsentwicklung			Realisation	Innovationsprozessentwicklung

2.3 Influence of commitment on the integration of stakeholders

The commitment of the stakeholders to the respective activity is a central aspect of cooperation in business networks. (Morgan/Hunt, 1994) What is crucial in this context is the commitment during the innovation development process.

The term commitment is nevertheless discussed in many different ways and is distinguished in a one-dimensional concept between behaviour-oriented and attitude-oriented approaches. The attitude-oriented commitment approach primarily focuses on the inner attitude of the stakeholders. This approach therefore lends greater weight to the congruence of values and goals of the partners and places the purely economic-rational aspects downstream. (Wallenburg, 2004)

Alongside the importance of commitment, it is necessary to define the integration of stakeholders in order to subsequently determine, on the basis of a hypothesis, what influence each factor has.

Stakeholder integration is primarily concerned with the participation of all relevant stakeholders in the innovation development phase with the aim of creating a harmonious and cooperative attitude among the stakeholders. As a result, communication between partners and the use of resources are crucial for intensifying integration.

From this, the following hypothesis can be assumed regarding the influence of attitude-oriented commitment on the integration of stakeholders.

The greater the attitude-oriented commitment of the stakeholders in freight forwarding company networks, the more comprehensive the integration of stakeholders in a freight forwarding company network will be in the innovation development phase. (Leven, 2022)



Figure 3: The effect of the attitude-oriented commitment on the integration of the stakeholders

3 Methodology and sample description

In order to investigate the impact of commitment on stakeholder integration, an online survey was conducted with the help of a quantitative study over a one-month period, which was sent to various members of freight forwarding networks. The software LimeSurvey was employed as a supporting tool for conducting the online survey.

The sample consists predominantly of medium-sized logistics service providers and the response rate as well as the group of participants illustrate the significance of the topic.

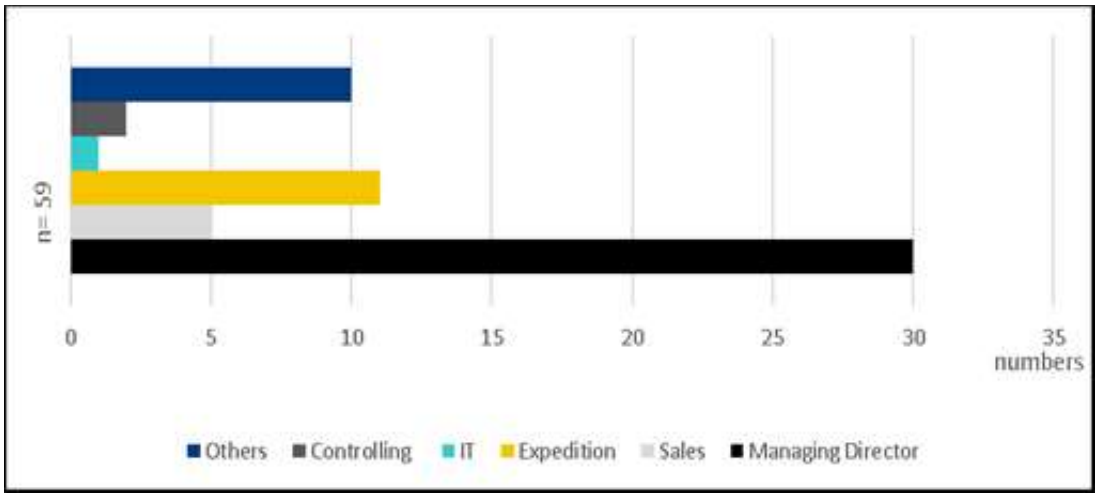


Figure 4: Sample of the survey I

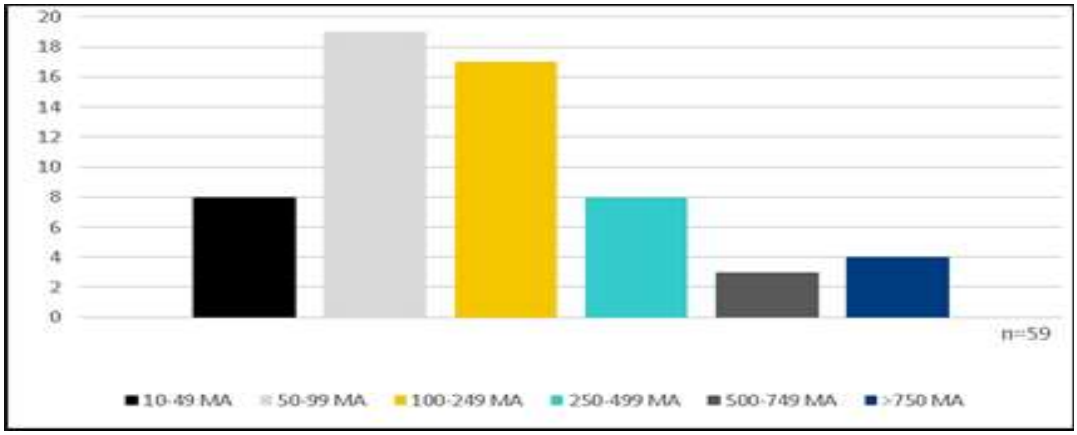


Figure 5: Sample of the survey II

The group of participants is composed of representatives from the various corporate divisions, whereby the importance of the topic is underlined by the number of participating managing directors.

The questions in the questionnaire were coded with a seven-point Likert scale. The scale ranges from Not at all applicable (level 1) to Fully applicable (level 7). This type of coding was subsequently converted into a statistical analysis form. 59 fully assessable questionnaires were evaluated as a result.

A variety of multivariate analysis methods may be used to analyse cause-effect relationships. (Fischer, 2006; Ohlwein, 1999; Rink, 2008; Wallenburg, 2004) Structural equation modelling offers a suitable method for this, as the aim of the procedure is to analyse cause-effect relationships between latent and manifest variables. The number of questionnaires that can be analysed makes the partial least square (PLS) approach particularly suitable as an evaluation method, as it allows for an analysis to be carried out even with a small sample size. Furthermore, this approach can be evaluated with the user-friendly software smartPLS 3 and a model assessment can be performed.

The aim of this research is to make non-measurable variables measurable in order to be able to assess the factors. In order to do this, it is first necessary to operationalise the constructs. In this process, it is possible to develop an adequate measurement model by drawing on already proven measurement models. (Bagozzi, 1992; Weiber/Mühlhaus, 2014; Backhaus/Weiber, 2007) The operationalisation of Siguaw, et al. is used for the

attitude-oriented commitment. (Siguaw, et al., 1998) Nevertheless, attention is paid to the specifics of the application environment and adaptation of the wording is considered.

Table 2: Indication of the construct “attitude-oriented commitment”

Indicator number	Indicator (complete formulation)	Source
C01	We defend the supplier when outsiders criticize the company.	Siguaw et al. (1998)
C02	We are patient with this supplier when they make mistakes which cause us trouble.	
C03	If another supplier offered us better coverage, we would most certainly take them on, even if it meant dropping this supplier.	
C04	We are continually on the lookout for another supplier to replace or add to our current supplier. (R)	
C05	We are willing to dedicate whatever people and resources it takes to grow sales for this supplier.	

The construct of stakeholder integration is also operationalised and made accessible through five indicators. As with the construct of attitude-oriented commitment, various aspects are examined in order to gain a comprehensive picture. These are based on the already proven operationalisation method according to Neubauer. (Neubauer, 2008)

Table 3: Indicators of the construct "Integration of stakeholders"

Indicator number	Indicator (complete formulation)	Source
IN01	The stakeholders of the freight forwarding company network communicated *formally* with each other very frequently during the development phase (i.e. scheduled meetings, regular exchange of forms or reports, existence of written documented rules, etc.).	Neubauer (2008)
IN02	The stakeholders of the freight forwarding company network communicated *informally* with each other very frequently during the development phase (i.e. irregular/unscheduled conversations, etc.).	
IN03	The stakeholders of the freight forwarding company network exchanged information with each other to a large extent during the development phase (e.g. market analyses, technical support).	
IN04	The stakeholders of the freight forwarding company network exchanged resources with each other very often during the development phase (e.g. Financial resources, staff and/or physical work output).	
IN05	During the development phase, the stakeholders of the freight forwarding company network had a high degree of agreement on their goals.	

4 Results

The results of the research are presented below. This is followed by an examination of the measurement models and subsequently an assessment based on the structural equation model. It is important to distinguish between reflective and formative measurement models. This is especially important when considering the different quality criteria that are used for the assessment.

The assessment of content validity is based on the comprehensive literature research and the use of proven operationalisation.

The relevant criteria for assessing the quality of reflective models are also presented. The criteria for the assessments are the Average Variance Extracted (AVE) value and the Composite Reliability (CR) value. Values above 0.5 for the AVE and above 0.7 for the CR value are considered relevant. These have been achieved and can be seen in the table below.

Table 4: Assessment result of the measurement model

Construct	Item	Loading	AVE	CR
Attitude-oriented commitment	C01	0.879	0.625	0.832
	C02	0.767		
	C03	0.713		

The following tables illustrate the different quality criteria for assessing formative measurement models.

Table 5: Assessment result of the measurement model

Construct	Item	VIF value
Integration of stakeholders	IN01	1.362
	IN02	1.038
	IN03	1.578
	IN04	1.570
	IN05	1.417

The Variance Inflation Factor (VIF) is used to test the multicollinearity of formative measurement models. Scores below five are conducive to this, as it must otherwise be assumed that there is a high degree of multicollinearity. (Hair, et al., 2011; Hair, et al., 2014) All indicators fulfil these requirements.

The significance of the individual indicators is examined below. A bootstrapping procedure is carried out to obtain the t-values of the outer weight. Values greater than 1.96 are necessary in order to assume significance. (Hair, et al., 2014) Indicator IN05 meets this criteria. The outer loadings are then also subjected to a bootstrapping procedure for the purpose of inferring the remaining t-values. This reveals that, in addition to IN05, the values IN01 and IN03 also produce the required values.

Table 6: Assement result of the outer weight and loading

Construct	Item	Loading	t-values	Loading	t-values
		Outer Weight		Outer Loading	
Integration of stakeholders	IN01	0.253	0.578	0.565	1.664
	IN02	-0.138	0.405	-0.057	0.153
	IN03	0.216	0.532	0.516	2.084
	IN04	-0.268	0.719	0.354	1.363
	IN05	0.896	2.260	0.930	2.980

In summary, after assessing the quality, it can be assumed that the measurement model is valid and reliable.

Following the presentation of the measurement models, it is useful to assess the structural model. The coefficient of determination R^2 is used to assess the construct. The results show that the Integration of Stakeholders success factor accounts for over 22% of the variance in the construct.

Table 7: Assessment of R^2

Construct	R^2
Integration of stakeholders	0.226

The hypothesis is then tested. The table below summarises the various results. The path co-efficiency and the significance level are indicated. Furthermore, the t-value illustrates the level of significance that can be assumed. (Backhaus, et al., 2011) The effect size f^2 is also shown. The value indicates a moderate effect size. (Chin, 1998) Finally, the notation is used to depict the confirmation of the hypothesis graphically.

Table 8: Path coefficients and significance level of the relationship

Effect relationship of the hypotheses	Path co-efficients	t-value	Significance	f^2	Hypo-thesis result
Attitude-oriented commitment -> Integration of stakeholders	0.465	2.557	<0.05	0.243	✓

5 Discussion

The positive effect of attitude-oriented commitment on the integration of stakeholders can be fundamentally confirmed.

The participants of the study indicate that they display loyalty towards the stakeholders. (C01) At the same time, this does not support the assumption that stakeholders will withdraw their commitment and go elsewhere if a better offer is made. Rather, it was found that the stakeholders would defend members in the face of external criticism and thus contribute to strengthening the cohesion of the network. This behavior can also be seen when stakeholders make mistakes, which suggests that there is a strong bond in this context. (C02)

The provision of resources is also essential for a high level of commitment and the resulting greater integration of stakeholders. It is clear that the stakeholders are using this resource to promote joint growth. (C05)

In addition, it could be confirmed that the integration of stakeholders is strengthened by scheduled meetings and the exchange of targeted information. (IN01) It should also be noted that exchanging information ensures that all stakeholders have the same level of knowledge and thus contributes to progress within the development phase of the innovation process. (IN03) The exchange also ensures that the stakeholders have a high degree of agreement on their goals. (IN05)

This above mentioned factors provide valuable insights on the behavior of the participants from freight forwarding networks during the innovation process. Additionally it demonstrates the linkage as well as the willingness to succeed within an innovations process. Taking into consideration that potential competitors contribute their expertise into the innovation project it demonstrates the potential of the success factor.

6 Limitations and Outlook

The survey is subjected with some limitations with respect to the several connecting factor. Further the sample of the study is concentrated to freight forwarding networks in the area of Germany. Furthermore, the survey was mainly conducted by small and medium-sized enterprises which represent a limitation for the study. Additionally, the participants represent an industry group with a focus onforwarding companies.

These limitation represent the need to conduct further research on quantitative and qualitative level. For instance, further research may also include success factors besides the integration of stakeholders, while transferring the research into another stage of the innovation process. Furthermore the limitation of the sample provides the opportunity to expand the size of the sample as well as the geographic location of the freight forwarding networks. Additionally, future research work should also consider involvement of further operations.

7 Conclusion

The aim of this study was to show the impact of attitude-oriented commitment on the integration of stakeholders. The focus was on the freight forwarding network environment and the development phase of the innovation process.

To do this, theoretical foundations were first developed. This involved taking a closer look at innovation processes and freight forwarding networks. In connection with the innovation process, various flow processes were outlined that divide the innovation process into different stages. A number of different perspectives on freight forwarding networks were presented to illustrate their role within the supply chain.

The influence of commitment on the integration of stakeholders was also theorised, resulting in the development of a hypothesis.

In order to move towards the goal of concretely demonstrating its influence, a structural equation model was created for the hypothesis. A quantitative study was used to interview various stakeholders in freight forwarding networks. The results of the study were then analysed using the smartPLS3 software. The findings of the research confirm the hypothesis that attitude-oriented commitment has a positive effect on the integration of stakeholders. The results were verified by the relevant quality criteria and the efficiency of the individual indicators of the measurement models could be shown. This yields a range of recommendations for action, which are presented in the discussion chapter and reveal, among other things, added value for practical application.

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V.
Supply Chain Risk and Security Management

Cold Chain Logistics: The Case of Turkish Airlines Vaccine Distribution

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Purpose: *The world is going through unprecedented times since the beginning of the COVID-19 pandemic. Billions of people will be vaccinated in the next few years. This mass vaccination effort requires setting up complex cold chain organizations and meticulous coordination of distribution networks. Keeping coronavirus vaccines at appropriate temperatures during the distribution process is not easy; however, it is one of the key factors battling against COVID-19. The purpose of this paper is to discuss and identify the essential logistics capabilities of cold storage and logistics service providers during the COVID-19 vaccine distribution.*

Methodology: *First, we identify the prominent risks that cold chain distributors encounter during vaccine transportation by conducting an in-depth literature review and an interview with the vice president of one of the largest air cargo companies in the world. Then we discuss logistics capabilities for the mitigation of these risks. Finally, we explore the Turkish Cargo's cold chain footprint enlargement strategy during the pandemic.*

Findings: *Cold chain logistics requires special attention to specific capabilities due to the nature of the cargoes being transported. On-time delivery time, special storage and transport equipment, and process monitoring ability are among the core capabilities for cold chain logistics service providers. Ensuring the reliable and effective distribution of temperature-sensitive vaccines is crucial since millions of lives depend on them.*

Originality: *This study is one of the first papers investigating the cold chain capabilities of air cargo distributors during the COVID-19 pandemic.*

First received: 27. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Humanity is experiencing an unusual human death toll, unprecedented economic costs, disruption of lives and livelihoods, and sociological and psychological damage worldwide due to the COVID-19 pandemic since late 2019 (Teijaro & Farber, 2021; WHO, 2021). The coronavirus SARS-CoV-2 has infected more than 158 million people, caused over 3.2 million deaths, and changed many aspects of our lives since its discovery (COVID-19 Map - Johns Hopkins Coronavirus Resource Center, 2021). Despite all the lockdowns and restrictions in many countries, the COVID-19 disease continues to spread and becomes a global problem due to the rapidly increasing infected patients. Many healthcare systems are unable to meet the patients' demand against the high morbidity rate (Landi et al., 2020). The first effective COVID-19 vaccines were approved for human use within a year after the disclosure and global expansion of the new type of coronavirus (Heinz & Stiasny, 2021). Now, an unusual number of individuals need to be vaccinated to reach herd immunity and protect the entire global community. Hence, the manufacturing and distribution of huge quantities of effective vaccines have become a critical global issue (Corey et al., 2020). According to WHO (2021), more than 200 COVID-19 vaccine candidates are in the research process as of February 2021. However, not all candidate vaccines are expected to be successful against the COVID-19 virus, and none of the suppliers has the capacity to meet the global demand alone. Hence, countries may not have a wide variety of vaccine types to choose from at first; however, their options will grow as supply increases in time. Some of these vaccine types, especially the messenger ribonucleic acid (mRNA) vaccines, must be kept at low storage temperature to maintain their freshness and efficacy. In this respect, cold chain storage and transportation become a critical issue for the safe movement of these vaccines, especially to the remote areas from the origin of production or refrigeration facilities. Cold chain logistics companies play a crucial role in the COVID-19 vaccine distribution process, and they must have certain capabilities to maintain effective, safe, and on-time delivery.

The main purpose of this paper is to provide an extensive literature review on the challenges that logistics service providers encounter during vaccine transportation and

address the prominent logistics capabilities that logistics service providers (LSPs) must focus on to maintain flawless pharmaceutical logistics operations. Each of these research questions below addresses the motivation behind this study.

- RQ 1: What are the COVID-19 vaccine distribution challenges that LSPs encounter during their logistics operations?
- RQ 2: How do LSPs eliminate these challenges and maintain effective logistics performance?
- RQ 3: How did Turkish Cargo manage to adapt its logistics operations rapidly and establish robust logistics operations?

Our main motivation is to investigate key strategic capabilities that improve operational efficiencies, such as the speed of vaccine distribution and reliable delivery. Maximizing operational efficiencies during the COVID-19 pandemic is crucial for saving millions of lives; hence air cargo companies must evaluate the current situation of their strategic capabilities to improve operational efficiencies.

The proposed research design is based on the qualitative approach, and two sources of empirical data are used: interviews and a case study. Reliable and valid research designs are obtained through extensive literature reviews. Following the extended research framework proposed by Mohr & Khan (2015), we illustrated our extended research framework in Figure 1.

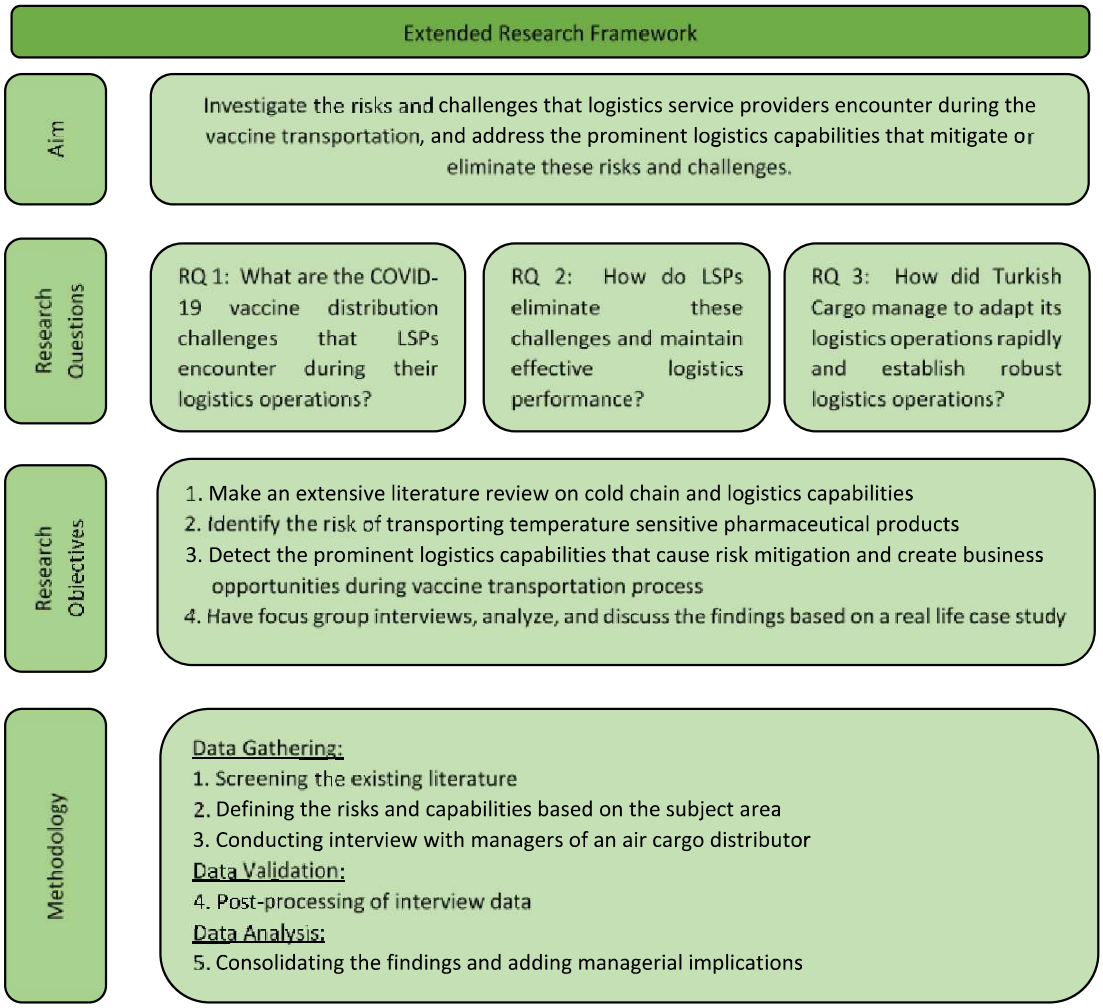


Figure 1: Extended Research Framework (adopted from Mohr & Khan, 2015)

This paper discusses cold logistics service providers, their essential cold storage and distribution capabilities, and the possible risks they encounter during COVID-19 vaccine distribution. This study is organized as follows: Section 2 reviews the cold supply chain. Section 3 presents the capabilities of cold logistics service providers and their importance during the COVID-19 vaccine distribution. Section 4 discusses the Turkish Cargo case. Section 5 discusses the implications on research and practice, while the conclusion is summarized in Section 6.

2 Cold Supply Chain

Cold chain management becomes an important aspect of supply chain management in recent years. The goods in cold chains include but are not limited to pharmaceutical products, chilled food, and frozen food. Unlike traditional supply chains, the goods that are moved by cold chains have a short shelf life, and they are more vulnerable to surrounding factors such as temperature, humidity, and lighting intensity. For this reason, the use of refrigeration and dehumidification systems throughout the entire cold chain is essential to preserve the useful life of products (Tsang et al., 2018). Cold chain logistics activities set the stage for the safe transportation of temperature-sensitive goods and products along the supply chain. The cold chain evaluates the link between temperature and perishability (ShipCalm, 2019). The frozen food industry has been growing rapidly in Ireland, and these foods require either frozen or chilled cold chains to their optimum quality (Gormley, Brennan, and Butler, 2000).

The shelf life of perishable food products is highly dependent on the temperature conditions during storage and transportation processes of supply chain operations. Lead time, optimal temperature conditions during the logistics operations, and effective monitoring of the cold chain environment are the most critical factors to ensure efficient cold chain operations (Montanari, 2008). The cold supply chain management focuses on the cost-efficient storage and transportation of temperature-sensitive products such as food, vegetables, confectionaries, flowers, and medicines (Hariga, As' ad and Shamayleh, 2017).

A cold supply chain is a branch of logistics and supply chain operations that requires a set of facilities and equipment for maintaining ideal movement conditions for goods within an optimal temperature range from the point of origin to the destination point. A cold supply chain is also named a temperature-controlled supply chain and is mostly used to transport food products. This kind of supply chain is exposed to many risks and uncertainties such as product perishability, product diversity, relatively short shelf lives, the need for multiple raw material suppliers, compulsory monitoring requirement of the supply chain operations, and large distribution network. Hence, the characteristics of the cold chain bring about the high risk of food waste, increased cost, and human health

risks due to the possible food spoilage (Tsai & Pawar, 2018). According to Montanari (2008), a cold chain is “the equipment, processes and information management used to protect chilled and frozen foods.” Saravanan & Anubama (2017. pp. 1) define a cold chain as “the transport and storage chain between the initial production and the final consumer of temperature-controlled perishable goods” or “a supply chain of perishable items.” The possibility of product spoilage and the extra operating conditions and cold chain requirements are the two main differences between traditional supply chains and cold chains. The infrastructure of a typical cold chain is given in Figure 2.

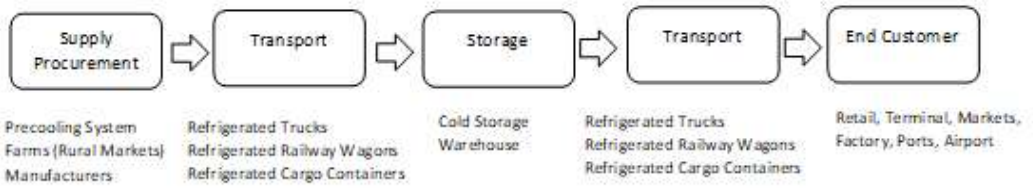


Figure 2: Infrastructure of a cold chain (adopted from Brzozowska et al., 2016)

The frozen foods or items are always maintained in the required temperature range in the production, transportation, storage, sales, and consumption periods in a cold chain logistics system to protect the food quality ad prevent food loss. Hence, a cold chain logistics system requires complex processes, higher investment, and superior management skills than conventional logistics operations (Zhou, 2021).

The spoilage or deterioration of fresh food results in essential economic losses and health problems. Hence, fresh food supply chains must set up cold chains to slow down the food decay and deal with these problems. The cold chain system requires to invest in refrigeration facilities, temperature-controlled trucks, warehouses, and retail shelves (Wang & Zhao, 2021).

The introduction of Industry 4.0 and emerging digital technologies transform conventional logistics operations into smart logistics systems. The Internet of Things and the Internet of Services (IoT & IoS), sophisticated sensor systems, and cloud-based technologies have altered the way companies perform their logistics operations and turn them into more efficient, productive, and customer-focused activities (Demir, Paksoy

and Kochan, 2020). Figure 3 depicts the operational and sensor network views of a cold supply chain for pharmaceutical products.

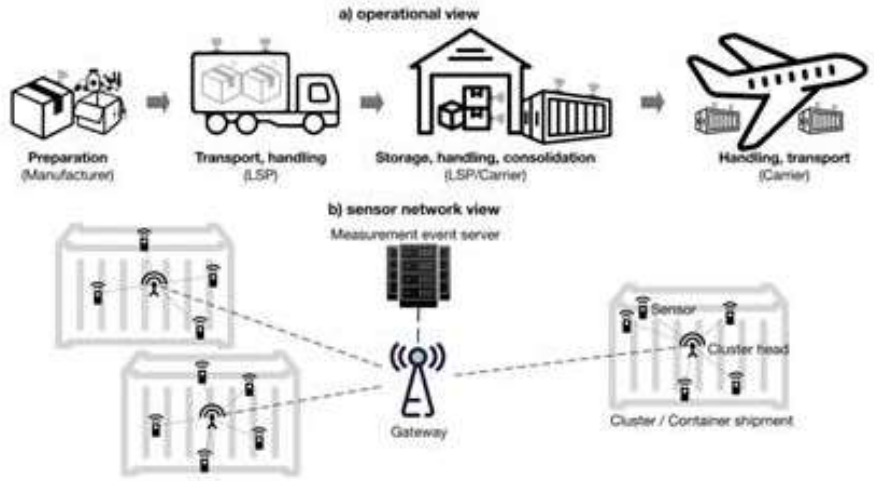


Figure 3: Operational and sensor network views of a cold pharmaceutical air SC (Konovalenko, Ludwig and Leopold, 2021)

Cold Chain Management (CCM) is the logistics management activities of perishable products such as food, medicine, blood, and flowers, which are time-sensitive and required to be kept in special storage conditions. Monitoring the logistics process is essential due to the spoilage risk of these products (Shabani, Saen and Torabipour, 2012). The real-time monitoring systems introduces several advantages to cold chain operations (Chaudhuri et al., 2018):

11. Logistics operations cost is reduced,
12. Loss of product value is minimized, and the total value of an item is maximized,
13. Optimal decision-making process is supported,
14. Quality failures/problems are identified.

Temperature change in a cold chain during storage and transportation can cause food spoilage and create risks to the consumers' health. Food shelf life and optimum quality of pharmaceuticals are affected by the immediate fluctuations in temperatures (Konovalenko, Ludwig and Leopold, 2021). Perishable products should be transported with extra attention since these products impose challenges to the cold supply chain

operations due to their nature. For instance, continuous monitoring of the transportation conditions is a critical factor that ensures the quality of products such as produce, dairy, or meat. A small deviation from the required transportation conditions can cause the lack of quality standards resulting in waste and profit loss. Furthermore, the deterioration of pharmaceuticals and other bioproducts can create harmful situations for human health (Mejjaouli & Babiceanu, 2018).

The undesired temperature conditions such as incorrect refrigeration in the cold chain cause food-borne illnesses. Temperature monitoring and control during transportation operations can help minimize the risk of food-borne illnesses since most harmful microorganisms cannot grow in cold temperatures (Rediers et al., 2009).

Products are stored and transported at very low temperatures in cold chains; hence, refrigerated warehouses and trucks are required. Large quantities of energy are used to power these refrigeration systems, and this results in high carbon dioxide (CO2) emissions and high global warming potential due to the Hydrofluorocarbon (HFC) gases used by refrigeration systems (Saif & Elhedhli, 2016). Due to rising social and environmental awareness, companies develop strategic plans to be part of the low-carbon economy, respond to global warming and maintain sustainable operations. Cold chain logistics companies should focus on balancing customer satisfaction and carbon emissions for their vehicle routing strategy to reduce the contribution to the greenhouse effect (Wang & Wen, 2020).

2.1 Cold Chain Literature Review

Babagolzadeh et al. (2020) study the impact of increasing carbon emission due to the storage and transportation processes in the cold supply chain by incorporating demand uncertainty. Bishara (2006) investigate the current practices and trends in pharmaceutical cold chain management. Dai, Wu and Si (2021) focus on the cold transportation systems and dynamic characteristics of the vaccine supply chain. Hariga, As' ad and Shamayleh (2017) study the lot sizing optimization problem of a cold chain with a single facility, distribution center, and retailer. Saif & Elhedhli (2016) formulate a mathematical model to assist the design of a cold supply chain by focusing on its economic and environmental effects. Wang & Zhao (2021) introduce an optimization

model for a cold supply chain to maximize the profit of its members. The authors focus on determining the optimal investment levels of cold chain build-up and advertisement and optimal pricing. Zhang et al. (2020) study the cold chain transportation mode selection problem in a multi-period setting with independent perishable product demands. James & James (2010) focus on the relationship between the cold chain and climatic change by reviewing the literature. The authors investigate the impact of the cold chain on global climate change and the effect of climate change on the cold chain. Shabani, Saen, and Torabipour (2012) propose a mathematical model to evaluate the performance of sales agents and select the best agent under non-discretionary factors. Chaudhuri et al. (2018) present a comprehensive literature review to analyze the data collection and decision-making processes in cold chain management. Ji & Guo (2009) study the cold chain and its security features and discuss essential food chain problems in China. The authors analyze cold chain transport security under four elements: the carriage of goods factors, transport factors, human factors, and environmental factors. Wen et al. (2019) propose a multi-criteria decision-making model for the selection problem of drug cold chain logistics suppliers from the perspective of risk aversion.

Montanari (2008) proposes structured frameworks that help decide the less costly configuration to manage a cold chain. Ferretti et al. (2018) develop a mathematical model and present a novel portable refrigerated unit to keep the goods throughout the cold chain. The performance of this refrigerated unit at the different stages of the cold chain is evaluated to understand its environmental impacts. Saravanan & Anubama (2017) study MCDM methods for selecting and ranking an alternative logistics service provider for a manufacturer that operates in the pharmaceutical industry. Singh, Gunasekaran and Kumar (2018) present a hybrid MCDM approach for selecting cold chain logistics service providers under a fuzzy setting. Li & Chen (2011) explore potential applications of RFID technology in pharmaceutical cold-chain logistics. The following section discusses the essential supply chain capabilities of LSPs for their vaccine distribution operations during the COVID-19 pandemic.

Many papers in the literature mainly focus on the operational capabilities of pharmaceutical transportation and miss the strategic and environmental capabilities such as flexibility and environmental sustainability. We include operational, strategic,

and environmental logistics capabilities to fill the gap. Furthermore, we explore the Turkish Cargo's cold chain footprint enlargement strategy and essential capabilities to introduce a real-life case study. We conduct literature reviews from Emerald, Taylor & Francis, EBSCO, ScienceDirect, and Web of Science.

3 Logistics Service Capabilities during COVID-19

The development of COVID-19 vaccination is the most critical effort to fight against the epidemic. In addition, efficient, safe, and timely delivery of the vaccines from their point of origin to the point of consumption requires a challenging effort, and it is a matter of life and death for the patients infected with the virus. The transportation processes and methods of COVID-19 vaccines are much more complex and difficult to control than regular supply chains. The transportation process in a vaccine supply chain includes storage factories, cargo stations, airplanes, and warehouses. A coordinated global strategy is vital for the delivery of vaccines. In this sense, the air cargo industries play a crucial role in realizing the fast and safe transportation of the COVID-19 vaccines (Dai, Wu, and Si, 2021).

The transportation and storage phases of the logistics operations arise the quality risk for some medicines due to the failure of providing special storage conditions. The drug cold chain logistics system is responsible for ensuring the quality of the medicines by storing and transporting them from production to the consumption point at the recommended temperature. Drug cold chain logistics is differentiated from the traditional supply chain by its characteristics such as small lot size, multi-batch process, time sensitivity, high operation costs, coordination difficulties, operation unpredictability, and process monitoring challenges. Drug cold chain logistics hold many risks and uncertainties due to its operational characteristics and equipment requirements. Hence, selecting a drug cold-chain logistics supplier with the lowest potential risk is an essential move to ensure the quality and safety of medicines and avoid business risk (Wen et al., 2019).

Pharmaceutical supply chains carry valuable and sensitive cargoes. The quality of pharmaceutical products is compromised when they are exposed to inappropriate

temperatures. Too long exposure to incorrect temperatures causes the loss of effectiveness for most medicines and vaccines. Time is an essential constraint for pharmaceutical shipments due to the possibility of spoilage and quality loss; hence air transport is the best solution compared to other modes of transportation. Pharmaceuticals are carried in cold chains to minimize quality loss. Each operator in the cold chain must install cold storage facilities and equipment and guarantee that temperature remains within the required range (Haan et al., 2013). The typical flow of goods and payment in a pharmaceutical cold supply chain is illustrated in Figure 4.

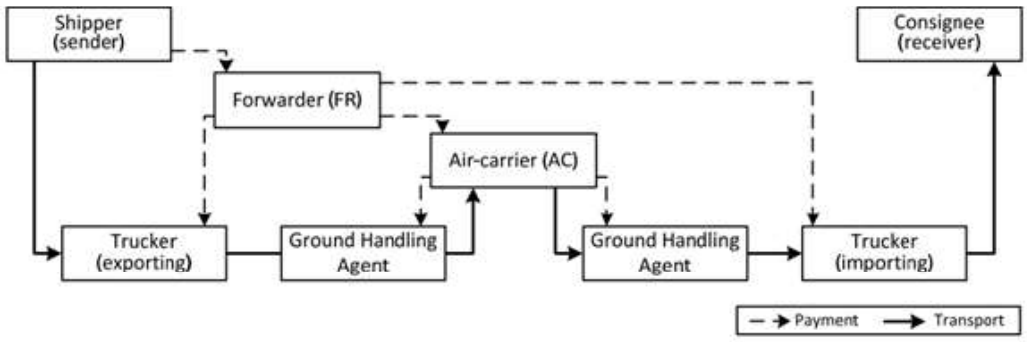


Figure 4: Flow of goods and payment in a pharmaceutical cold supply chain (Haan et al., 2013)

A typical pharmaceutical cold supply chain includes a shipper, forwarders, an air-career, truckers, ground-handling agents, and a consignee. There might be some problems among these players during the cold chain processes, such as incorrect or unnecessary storage conditions, unavailable facility or equipment, or battery problems of the temperature-controlled containers (Haan et al., 2013).

The risk of transporting temperature-sensitive pharmaceutical products can be categorized under operational, product, people, information, and execution risk.

Table 1: Risk of transporting temperature-sensitive pharmaceutical products (adapted from wto.org. 2021)

Type of Risk	Example
Operational	- Scarcity of air cargo capacity - Delayed/cancelled flights - Breakdowns in operational processes - Unsecured environment
Product	- Absence of stability data and experience of new Product development - Integrity of the product and security of doses - Lack of specialized packaging to protect product
People	- Limitations of available manpower - Lack of appropriate training and relevant knowledge
Information	- Lack of coordinated approach and information sharing - Lack of reliable document and data exchange between stakeholders and lack of full supply chain data visibility
Execution	- Lack of all-party collaboration

Type of Risk	Example
	- Broken or unstructured communication channels
	- Lack of preparedness for receiving shipments

The transportation of medical products is one of the main concerns for the pharmaceutical industry. Pharmaceutical logistics management is responsible for organizing complex operations and ensure the low-cost flow and storage of medical supplies. Medical suppliers work with 3PL providers to focus on their core business, improve logistics capability, add product value to the enterprise, and increase customer service levels. Hence, selecting a 3PL partner is of great importance for medical enterprises (Liao et al., 2020). Organizations want to focus on their core businesses in recent years.

For this reason, they establish cooperation with 3PL service providers. A 3PL service provider is an external company hired to perform some or all of the logistics activities on behalf of the employer. Some important selection criteria should be taken into consideration for the 3 PL service providers selection process. These criteria are; transportation and warehousing cost, logistic infrastructure and warehousing facilities, customer service and reliability, network management, material handling capabilities, quality control and inspection, automation of processes, innovation and effectiveness of cold chain processes, IT applications for tracking, and tracing and flexibility of processes (Singh, Gunasekaran and Kumar, 2018).

Logistics service providers must continuously improve their service operations due to the ever-changing customer requirements and harsh market environment (Chen, Fung and Yuen, 2019). Teece et al. (1997. pp. 516) define dynamic capabilities (DCs) as “the firm’s ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments.” These dynamic capabilities help companies to create, implement and protect their assets and enhance business performance in the long run (Teece, 2007). Due to the potential risks and uncertainties in cold chain transport, logistics service providers must have specific capabilities to ensure smooth and reliable

operations, especially during unexpected situations such as pandemics. Saravanan & Anubama (2017) categorize factors for the effective cold chain operations of insulin distribution into seven groups: on-time delivery, responsiveness, flexibility, price, quality, and technology. Ship ABCO (2018) correlates the quality standards in the cold chain industry with high-quality shipping requirements: shipping speed, guidelines for temperature, and compliance regulations. The selection of a cold chain logistics service provider for a pharmaceutical enterprise depends on various factors. When comparing the candidate logistics companies, some factors in their service level must be taken into consideration. These factors are consistent and reliable transportation, trusted experience, proactive best practices, security, and continuous improvement (Expak Logistics, 2018). Some of the most important capabilities for the vaccine distribution operations of cold chain service providers are given in Table 2.

Table 2: Capabilities for the vaccine distribution operations of cold chain logistics service providers

Capability	Definition	Source
Delivery Reliability	the probability of satisfying the announced delivery time	Xiao and Qi (2012)
Delivery Speed	the ability to reduce the time between order receipt and customer delivery to as close to zero as possible	Morash (2001)
Expedited Delivery	the ability to expedite shipments or partial shipments	Morash (2001)
Resilience	the ability of a supply chain to return to normal operating performance, within an acceptable period of time, after being disturbed	Brandon-Jones et al. (2014)

Capability	Definition	Source
Robustness	the ability of the supply chain to maintain its function despite internal or external disruptions	Brandon-Jones et al. (2014)
Strategic Flexibility	the ability of the organization to adapt to substantial, uncertain, and fast-occurring environmental changes that have a meaningful impact on the organization's performance	Aaker and Mascarenhas (1984)
Visibility	the ability to track the identity, location, and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events	Francis (2008)
Information Capability	the ability of a focal company to identify, utilize, and assimilate both internal and external information to facilitate the information sharing activities among supply chain partners and develop inter-organizational relational competency	Youn et al. (2014)
Widespread Distribution Coverage	the ability to achieve and serve customers effectively at a broad geographic area	Multaharju and Hallikas (2015)
Environmental Sustainability	The ability to meet the resource and services needs of current and future generations without compromising the health of the ecosystem	Morelli (2011)

Delivery reliability and delivery speed are crucial capabilities since millions of lives depend on the safe and on-time delivery of the vaccines. The transportation sector has

been disrupted because LSPs were directly affected by the COVID-19 virus. Resilient and robust supply chains have the ability to recover rapidly after the first impact of the pandemic and continue their operations amidst the pandemic. Strategic flexibility is directly associated with the efficient use of organizational resources. In case of an unexpected event, a flexible company can allocate its resources to the departments that need them most. Monitoring the processes of a cold supply chain is a vital factor due to the nature of the cargoes being transported. Hence, the visibility of a cold chain is one of the most critical capabilities, and it is an indispensable feature for successful cold chain operations. Vaccines are time and temperature-sensitive products, and they need to be delivered on time and under specified temperature ranges. Information capabilities of a cold chain service provider facilitate the dissemination of information to the stakeholders during the distribution of the vaccines. The economic and social impacts of COVID-19 are on a global scale. Since immunization efforts are required worldwide, the vaccines need to be distributed in geographically dispersed areas.

For this reason, widespread distribution coverage becomes a critical capability for a cold chain. Finally, cold chains must adopt environmentally friendly processes. For instance, integrating low global warming potential refrigerants and minimizing carbon dioxide (CO2) emissions are essential steps that cold chain service providers must take.

4 Turkish Cargo Case

The aviation industry has a key role in delivering COVID-19 vaccines worldwide. The global distribution of vaccines and the organization of the logistics operations are complicated processes. This process becomes even harder for the vaccines that are required to be stored in freezing temperatures. Fifteen thousand flights and 15 million cooler boxes are needed to complete the transportation of 10 billion doses of vaccines. Turkish Cargo, a subsidiary of Turkish Airlines, has become one of the prominent and rapidly growing companies in the vaccine distribution business. The company strives to maintain global food, medicine, and medical product transportation without any disruption during the pandemic. The company uses wide-body passenger planes by removing seats to increase carriage capacity against high demand (Turkey News, 2020).

In November 2020, Turkish cargo carried seven containers of COVID-19 vaccines from the manufacturer country, China, to Brazil. The containers were equipped with cooling systems that keep the vaccines within the required temperature range. Turkish Cargo's cold chain is ensured by "TK Pharma" solutions designed to transport pharmaceuticals at world-class standards (Sahin, 2020). Pharmaceutical products need to be cared for with particular attention during the flight and loading/unloading and preserved carefully while being held at a cargo terminal. TK Pharma offers active and passive solutions for the transportation process of pharmaceuticals (TK Pharma, 2020).

Table 3: TK Pharma Active and Passive Solutions (TK Pharma, 2020)

Active Solutions	Active Temperature-Controlled Container	Pharmaceutical products such as vaccines, insulin, and anti-cancer drugs are carried within a specified temperature range in active temperature-controlled containers. Therefore, temperature fluctuations that might be experienced during the transportation process can be rapidly reported to the customers via a data recording system.
	Thermal Dolly	Thermal Dolly is active temperature-controlled equipment used to transfer the time and temperature-sensitive cargo from the temperature-controlled rooms at the cargo terminals to the aircraft cargo ramp or vice versa.
Passive Solutions	Single-Use Thermal Cover	The single-use thermal cover protects temperature-sensitive pharmaceutical products from the external environment by isolating the heat.

Turkish cargo has conducted 2,900 cargo transportation flights in 2020. As of February 2021, the company has carried 50,000 tons of health products and medical equipment worldwide since the beginning of the pandemic. As the vaccination ramps up in many countries, air carriers become key players in global logistics activities. As a result, Turkish Cargo has increased its global market share in medical transportation to 7.5% throughout the pandemic (Daily Sabah, 2021a).



Figure 5: Temperature-controlled containers carrying China's Sinovac COVID-19 vaccines are loaded onto a Turkish Cargo plane at Ataturk airport before departing to Brazil, in Istanbul on November 18, 2020 (Daily Sabah, 2021b)

Turkish Cargo carries UNICEF's (United Nations International Children's Emergency Fund) Covid-19 vaccines and health equipment worldwide. The company offers a unique service quality and the widest range of flight networks in the air cargo industry (Turkish Cargo, 2021). In March 2021, Turkish cargo carried 1.7 million doses of UNICEF-supplied vaccines from India to the Democratic Republic of Congo (Ergocun, 2021). Furthermore, the company carried hundreds of thousands of syringes from Barcelona, Spain, to the capital city of Tunisia, Tunis, and COVID-19 vaccines from Amsterdam to Kyiv, Tbilisi, and Amman on behalf of UNICEF. The company claims that it has the daily capacity to carrying up to 40 million doses of COVID-19 vaccines (Daily Sabah, 2021b).

From the interviews we have conducted with two officials from the upper management of Turkish Cargo, we concluded that the company's most powerful capabilities are resilience, robustness, and flexibility. At the beginning of the pandemic, the company did not lay off any employees; instead, they lower salaries in every position to reduce overall expenses. Hence, the company economizes and keeps the trained human resources needed in the future. Turkish Cargo's robust operational structure allows the company to maintain cargo operations from the beginning of the pandemic. For instance, a cargo operation was conducted with an empty passenger plane on March 20, 2020, at the beginning of the pandemic. As the number of cargo operations increases throughout the

pandemic, the company shifts workers from passenger operations to cargo operations to meet human resource needs. It was stated that some of these personnel shifts are temporary, while some others are permanent.

5 Implications for Research and Practice

This paper investigates the risks and challenges that logistics service providers encounter during vaccine transportation and addresses the prominent logistics capabilities that mitigate or eliminate these risks and challenges. These risks and challenges emerge due to the nature of the cargoes being transported; hence pharmaceutical products should be carried with additional care. The potential contribution of this paper is to identify the most prominent logistics capabilities that mitigate the risks that emerge during vaccine transportation, especially for air cargo operations.

We explore ten logistics capabilities that are essential for air cargo operations. Among these, resilience, robustness, and flexibility constitute the durability and maintenance of Turkish Cargo's air transportation operations since the beginning of the pandemic. The company managed to return to its normal operations shortly after the beginning of the pandemic with the aid of company-wide resiliency.

The suspension of national and international commercial flights harmed many airliners worldwide. Shortly after the commercial flights stopped, Turkish Cargo has started to deliver cargoes, including vaccines, with empty passenger planes. The robust operational structure of the company allows this transition in a relatively short period. The flexible working practice and job rotation help the company balance cargo operations' workload due to the high demand. Some employees are shifted from passenger service to air cargo operations, which need a higher volume of staff.

6 Conclusion

This paper discusses the essential cold chain logistics capabilities for vaccine distribution as the world is going through difficult times due to the COVID-19 pandemic. Drug cold chain logistics is a supply chain system that transports medicines from the point of origin to the consumption point by complying with the required temperature ranges necessary for keeping the quality of medicines. Since medicines and vaccines are temperature sensitive, the transportation process of these medical products must be designed meticulously. In that respect, a drug cold chain logistics service provider must possess various capabilities that create a competitive advantage and put a company forward among its competitors. Delivery reliability, delivery speed, expedited delivery, resilience, robustness, visibility, information capability, widespread distribution coverage, and environmental sustainability are among the most crucial capabilities of cold chain logistics service providers.

Delivering billions of COVID-19 vaccine doses at the right time by meeting storage conditions is the main concern of drug cold chain logistics service providers. Due to the vulnerable characteristics of medical products, the delivery speed and temperature conditions become crucial for the patient safety and quality standards of the vaccines. Turkish Cargo is one of the pioneer companies that undertakes an important responsibility in transporting Covid-19 vaccines worldwide. In addition, the company cooperates with national and international authorities for the struggle against the global pandemic. The company offers air cargo service to 127 countries and maintains operations in the biggest cities of continents (Turkish Cargo, 2020).

There are some limitations to our study. Firstly, we include only one air cargo operator in this paper. Second, the interviews are conducted with the upper management of the focus company. In future research, the researchers should include multiple companies and interviewees from upper, middle, and lower-level management. Including several international cargo companies will help us understand the role of different capabilities based on various operating conditions in different regions. Furthermore, a multi-criteria decision-making model can be proposed to select a subset of prominent logistics capabilities for adverse events such as pandemic-related supply chain disruptions.

Acknowledgement

The authors would like to thank all reviewers and the interviewees who made valuable contributions to the study with their comments, feedback, suggestions, and criticisms.

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Organizational Flexibility of Airlines During COVID-19: A Study on The Airline Companies in Turkey

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Purpose: *COVID-19 caused a highly uncertain environment and introduced a radical change in the airline industry. In that time, idle capacity due to drastic decline in passenger traffic, change in travel rules, and increases in air cargo demand have emerged as the main challenges. Effective responses to these issues became a fundamental requirement for airlines' survival and sustainability of supply chains. Organizational flexibility plays a vital role in dealing with those situations. Flexibility allows airline companies to adapt to changing environmental conditions and take advantage of opportunities. This study aims to explain the strategies of airline companies in Turkey to the COVID-19 crisis based on organizational flexibility.*

Methodology: *This study is structured on the qualitative research method. We interviewed five experts and compiled information by reviewing various publications on COVID-19. We analyzed obtained information within the framework of organizational flexibility.*

Findings: *The results indicated that airlines mitigate the effects of COVID-19, mostly through protective and exploitative maneuvers of organizational flexibility. Airlines focus more on cost reduction and saving strategies as protective maneuvers, while exploitative maneuvers focus more on the cargo market.*

Originality: *This study is novel in that it examined airlines' responses to COVID-19 within the framework of organizational flexibility.*

First received: 27. Mar 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The world has been struggling with COVID-19 since December 2019. COVID-19 was first reported in Wuhan, China (WHO, 2020a), then spread worldwide and was announced as a pandemic by the World Health Organization (WHO, 2020b). As of May 2021, the COVID-19 pandemic has caused more than 152 million cases and over 3 million deaths worldwide (WHO, 2021).

Countries have had to respond to this crisis with quarantine, lockdown, and travel bans to reduce its impact. This reaction negatively affected the economic activities of the world. In 2020, the gross domestic product of G20 countries shrank by 3.3%, except China and Turkey, which recorded growth of 2.3% and 1.8%, respectively (OECD, 2021). In 2020, global working hours decreased by 8.8% compared to the fourth quarter of 2019, equivalent to 255 million full-time jobs (ILO, 2021). COVID-19 has severely impacted poverty around the world. Poverty has increased for the first time in 20 years. It was estimated that between 119 and 124 million people suffer from severe poverty in 2020 (Lanker et al., 2021; CCSA, 2021). The tourism industry experienced its worst year in 2020, with a 74% decline in international arrivals compared to the previous year. Globally, tourism destinations hosted less than 1 billion international arrivals due to an unexpected drop in arrivals and strict travel restrictions (UNWTO, 2021).

The aviation industry is among the most affected sectors by the COVID-19 pandemic. Strict measures such as lockdown and travel bans to combat COVID-19 have resulted in an unprecedented drop in air transport demand. Compared to 2019, global passenger traffic declined by 60 %, equivalent to 2,699 million passengers in 2020 (ICAO, 2021).

Turkey has been one of the countries that have taken steps to respond to the pandemic proactively. In aviation, all international flights were suspended between May 27 and June 11, 2020. Also, domestic flights were restricted. As a result, in 2020, the number of domestic passengers decreased by 50.4%, and the number of international passengers fell by 70.5% compared to the previous year. Similarly, domestic, international, and transit traffic decreased by 31.5%, 60.8%, and 57.9%, respectively. Also, domestic and international cargo traffic decreased by 39.8% and 41.6%, respectively (SHGM, 2021).

The COVID-19 is continuing to pose a risk for the aviation industry. This risk is mainly due to uncertainty in the business environment. Uncertainty in the business environment causes a serious survival problem for companies. An uncertain business environment makes it difficult for companies to set future business standards and predict demand. Uncertainty, a significantly fatal feature of the business environment, affects firms' withdrawal from the market. So, it requires firms to go beyond their routines and develop new capabilities to maintain their activities. On the other hand, turbulent times allow companies to turn the change in the market to their advantage with appropriate strategies (Anderson and Tusheman, 2001).

Airlines offer safe, efficient, and fast transportation services. They provide time and efficiency advantages in the delivery or transportation of perishable, subject to rapid obsolescence, and urgently required products (Wensveen, 2007). In 2015, 52.2 million tons of cargo worth $5.6 trillion was transported by air. Although this amount corresponds to 1% of world trade in volume, it constitutes 35% of the value (Shepherd, Shingal and Raj, 2016). Despite the decrease in belly cargo capacity due to the suspension of passenger flights, the amount of cargo transported by air reached 57.5 million tons in 2020 (IATA, 2021). Airlines carried more than 1.5 million tons of medical supplies and protective equipment with 46,500 special cargo flights during the peak period of the pandemic. They also reorganized flight routes and compensated for disruptions in other modes of transport. These show the importance of airlines in the sustainability of the supply chain and world trade, especially during the COVID-19 period. (ATAG, 2020). Examining the strategies of airlines in the period of COVID-19 will contribute to the effective maintenance of the supply chain and make them more resilient against crises in the future. Although some studies have been conducted on airlines' responses to the COVID-19 pandemic, to the best of our knowledge, there has been no study examining the topic within the framework of organizational flexibility components. The purpose of this study is to examine the responses of airline companies operating in Turkey to the COVID-19 crisis in terms of dimensions of organizational flexibility. It is also aimed to reveal the practices of airline companies to cope with the uncertainties brought by the pandemic.

2 Theoretical Background

2.1 Organizational Flexibility

Flexibility is a key factor enabling organizations to operate in a dynamic, particularly changing and uncertain business environment. Flexibility refers to the capabilities of an organization to respond to its business environment in a variety of ways (Phillips and Tuladhar, 2000). It is related to the abilities of an organization to adapt its policies, practices, and procedures in response to the varying demands of the environment (Rowe and Wright, 1997). "*Flexibility is the degree to which an organization has a variety of managerial capabilities and the speed at which they can be activated, to increase the control capacity of management and improve the controllability of the organization"* (Volberda, 1996, p. 361).

Organizational flexibility occurs due to the relationship between two main components: management task and organizational design task. Managerial tasks refer to the timely and proper response of management to the environment. It consists of a variety of dynamic capabilities. Dynamic capabilities enable management to respond to changing environmental conditions and influence the environment to prevent organizations from external changes. Variety and speed are two main elements of managerial capabilities. Speed allows management to respond to change at an appropriate pace. Variability enables management to react to different conditions of the environment. Variability is related to the quality and quantity of capabilities required. Both elements increase the maneuvering capacity of management in changing environments. Organizational design task deals with organizational conditions that make managerial capabilities effective. Organizations have to have adequate organizational conditions to utilize managerial capabilities and respond to change effectively. In this respect, proper organizational structure and culture should be created, and efficient technology should be obtained (Volberda, 1996).

Many researchers regard the concept of flexibility as the dynamic capabilities of an organization (Teece, Pisano and Shuen, 1997; Hattum and Pettigrew, 2006). Dynamic capabilities are defined "as the firm's ability to integrate, build, and reconfigure internal

and external competencies to address rapidly changing environments" (Teece, Pisano and Shuen, 1997, p. 516). In this definition, the term dynamic refers to the capacity of an organization to recreate its competencies in accordance with the changing business environment. Thus, capabilities indicate the primary function of strategic management in effectively adapting, combining, reshaping organizational skills, assets, and competencies to respond to the changing conditions of the environment (Teece, Pisano and Shuen, 1997).

The dynamic capability approach focuses on a way of gaining a competitive advantage for companies. This competitive advantage highly relies on the managerial capabilities and organizational processes of a company. In this approach, organizations should develop capabilities and assets that are unique and difficult to imitate. Those capabilities should be embedded into organizational processes in a novel way to be responsive to the environment. These capabilities, in particular, culture, values, and distinctive competencies are internal to the company, and they can not be bought or obtained from outside (Teece, Pisano and Shuen, 1997).

Flexibility requires the development of dynamic capabilities for the uncertain environment (Volderba, 1996). Organizations can achieve flexibility through the implementation of various methods. The simplicity of business processes and disciplines in procedures in the production industry enables companies to achieve flexibility (Collins, Cordon and Julien, 1998). In addition, the flexible structure can be created through the proper integration and management of components of their value chains by taking them into consideration (Sawhney, 2006).

Organizational flexibility in a broad sense consists of tactical, operational, and strategic flexibility (Carlsson, 1989). Operational flexibility refers to an organization's built-in procedures that allow variation in the production process and can accommodate disruptions that occur in a short period. Tactical flexibility indicates the flexibility in technological elements that allow an organization to cope with variations in production rate or production mix. Strategic flexibility is related to the company's long-term positioning in terms of production, marketing, and competition (Carlsson, 1998).

Strategic flexibility relies on capabilities to create variety to do something different when required. Strategic flexibility means doing something different from the initially intended

to respond to unexpected changes. In a sense, it refers to an organization's capability to change itself to take advantage of its environment. Strategic flexibility consists of two different dimensions. These are temporal and deliberate dimensions. Temporal dimensions include ex-ante and ex-post modes. Ex-ante means being ready for future changes in advance, while ex-post means adjusting after the triggering event occurs. The intentional dimension is related to defensive and offensive modes of flexibility. Both modes of flexibility can be achieved through four types of maneuvers: preemptive, protective, exploitative, and corrective maneuvers, as indicated in figure 1. Preventative maneuvers are implemented to speed up transformation. The preventative maneuver can introduce new things like radical innovation and develop many options before required. Protective maneuvers refer to methods implemented by an organization to protect itself against the negative consequences of risky activities during the positioning process. Corrective maneuvers indicate the reformative capacity of the organization to return to a normal state from the consequences of damaging occurrences. Exploitive maneuvers refer to the capability of an organization to respond to opportunities that emerge in the environment. Exploitive maneuvers enable an organization to take advantage of opportunities in the environment (Evans, 1991).

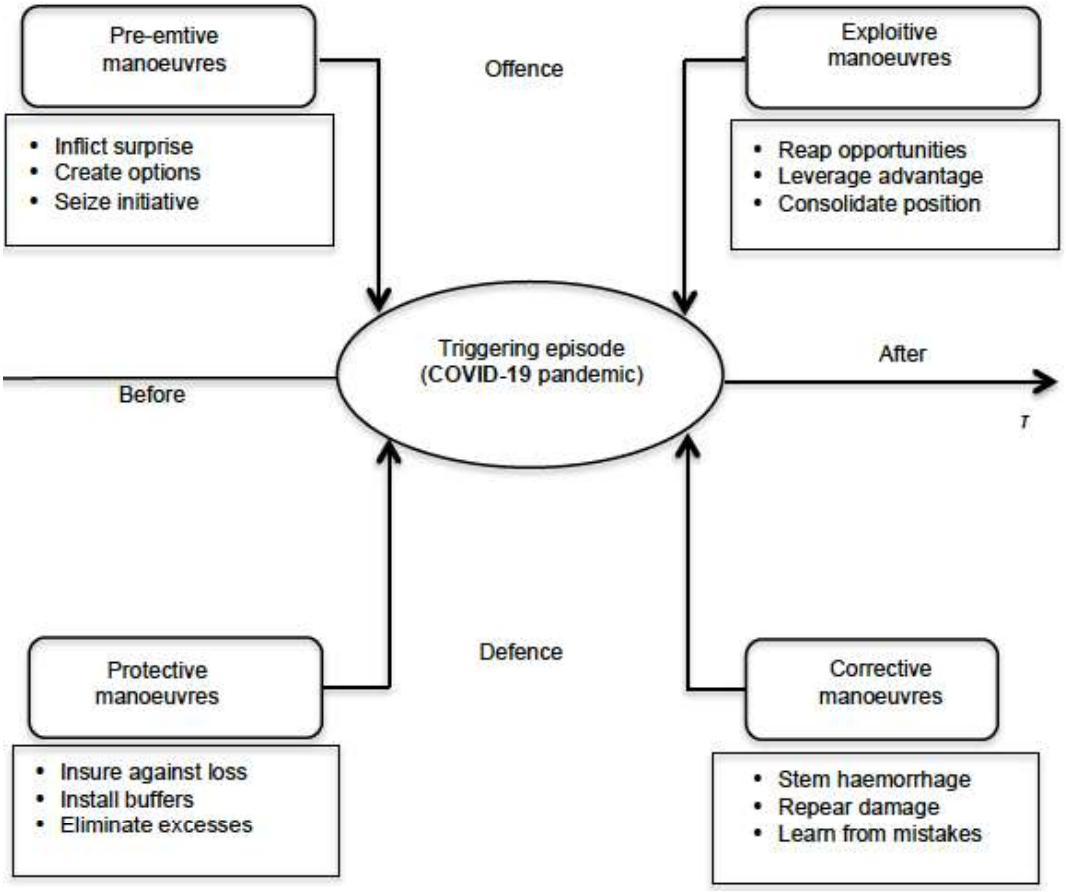


Figure 1: Strategic flexibility archetypal maneuvers (adapted from Evans, 1991)

Offensive and defensive modes of flexibilities could be regarded as anticipatory and adaptive flexibility. In anticipatory flexibility, companies try to predict the possible consequences of uncertainties and are prepared to be least affected by the negativities. The companies implementing this type of flexibility create more than one business scenario for the future and formulate many strategies to deal with the most likely ones (Engau, Hoffmann and Busch, 2011). In this preemptive move, organizations take action ahead of their rivalries and occupy an advantageous position in the market. Preventive actions should target essential positions and be easy for organizations to return when needed. Also, it should be challenging for competitors to implement them by using similar methods (MacMillan, 1983). In adaptive flexibility, organizations prepare to react

quickly and adapt to the actual situation after uncertainty is eliminated (Engau, Hoffmann and Busch, 2011).

Engau, Hoffmann and Busch (2011) identified five capabilities required to create both types of flexibility. These are diagnostic, coordinative, integrative, transformative, and cultural capabilities. As shown in Figure 2, diagnostic, coordinative, and integrative capabilities are associated with anticipatory flexibility, while transformative and cultural capabilities are mostly related to adaptive flexibility.

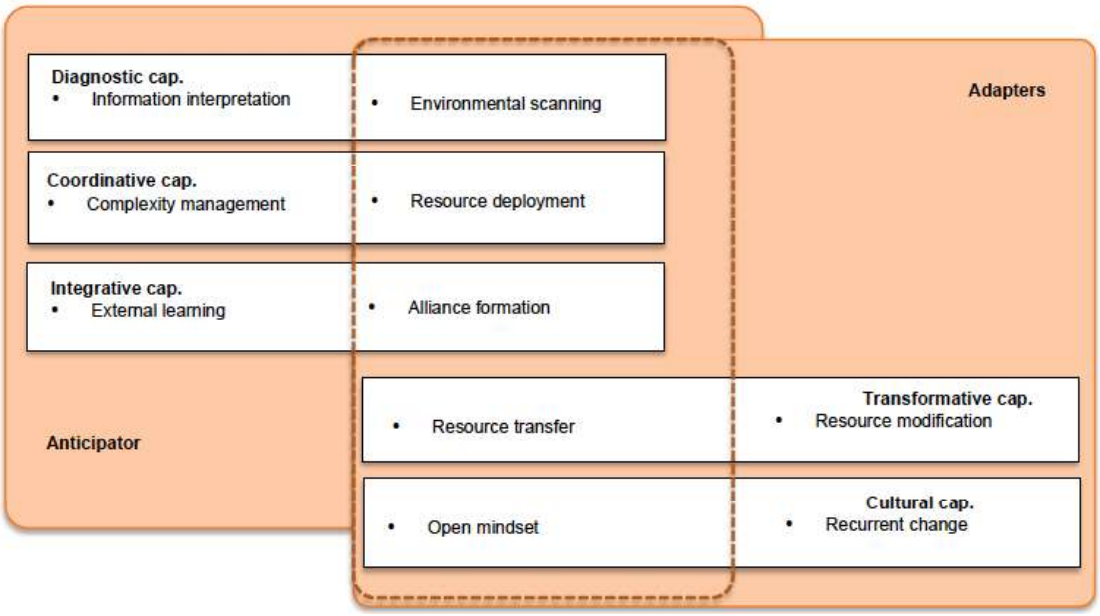


Figure 2: Capabilities for building up strategic flexibility (Engau, Hoffmann and Busch, 2011)

Diagnostic capabilities allow companies to scan the environment and analyze information to identify resources that enable them to survive in an uncertain business environment (Engau, Hoffmann and Busch, 2011). In addition, environmental scanning and information interpretation contribute positively to an organization's strategic action, which takes place in the form of changes in its products and services (Thomas, Clark and Gioia, 1993).

Coordinative capabilities refer to a company's distinctive capabilities that enable it to direct its resources in a specific way (Teece et al., 1997). Companies use such capabilities to deploy resources and manage complexities (Engau, Hoffmann and Busch, 2011).

Integrated capabilities function to accumulate critical information from external sources and processes in which information with technical capabilities is specific to the organization's various departments. External integrative capabilities allow an organization to capture functional and tacit information using managerial process, external communication, networking, empowerment of workers, and external technical experts. Internal integrative capabilities determine methods or ways the organization use obtained information. Managerial processes, internal communication, integrative structures, and culture and values affect internal integrative capabilities (Verona, 1999). Forming alliances and collaboration for learning plays an essential role in having integrative flexibility that provides access to new resources (Engau, Hoffmann and Busch, 2011).

Cultural capabilities consist of habits, attitudes, beliefs, and values that affect human resources. An organizational culture oriented to high standards can be recognized as a capability that contributes to competitive advantage (Hall, 1993). An open mindset and promoting change are two critical elements of such a culture that are important in building flexibility (Engau, Hoffmann and Busch, 2011).

Transformative capability refers to a company's ability to maintain and develop its already owns technology (Garud and Nayyar, 1994). Transformative capabilities that enable a company to transfer and modify resources play an essential role in flexibility (Engau, Hoffmann and Busch, 2011).

2.2 Literature review on airlines' strategic responses to COVID-19

Albers and Rundshagen (2021) investigated strategic responses of European airlines to COVID-19 based on news items and related articles. Results indicated that airline companies followed retrenchment, preserving, innovative, and exit strategies sequentially or simultaneously in response to the crisis. As a retrenchment strategy, most

airlines discontinued their flight operations, grounded their fleet, and were involved in cost reduction activities. Some airlines aimed to preserve their existing structures with government support and external resources such as bailouts and subsidies. In addition, some airline companies sought to take advantage of the opportunities arising from urgent needs with innovative approaches. Especially, airline companies converted their passenger aircraft into cargo aircraft and responded to increased cargo demand. Also, airlines entered new markets, were involved in joint ventures and other partnerships, and expanded their cargo operations. Lastly, some airline companies have resorted to withdrawal methods from specific markets and partially or completely stopped their operations (Albers and Rundshagen, 2020).

Amankwah-Amoah (2020) examined internally generated and externally exposed strategic responses of airline companies to the COVID-19 pandemic in the short and long periods. Results revealed different approaches of airlines to the uncertainty. First, as internally generated short-term responses, airlines were involved in environmental scanning and tried to understand the nature of viruses and government regulations. Secondly, as externally required short-term responses, airline companies took steps to comply with health organizations' initial directives and measures against COVID-19. Thirdly, as internally generated long-term response, airline companies focused on post-crisis activities. Finally, airline companies focus on new normal, new industrial, and government directives rules as externally imposed long-term responses.

Suk and Kim (2021) investigated airlines' response to the COVID-19 pandemic based on a matrix containing the time dimension and devastating magnitude of COVID-19. The results indicated that airline companies changed their decision-making and strategic priorities due to the increase in the negative effects of COVID-19 on the industry. Airlines struggled to maintain their current position in the early stages of the crisis and resorted to capacity adjustment. As time elapsed and the crisis deepened, they asked for government supports and focused on the cargo market.

Akbar and Kisilowski (2020) examined airlines' non-marketing responses to governments' COVID-19 measures. They emphasized that the perceived legitimacy of travelers ultimately shapes non-marketing strategies. In addition, airlines do not prefer to bargain measures with the government when the economic and health impact of the

decisions is small. Instead, they resort to selective avoidance and adherence to measures. Airline companies collaborate with the government to effectively achieve common goals with high health and economic impact. Airline managers prefer to bargain hard with investors when the economic impact is high and the health impact on society is low.

Scheiwiller and Zizka (2021) investigated the communication strategies of airlines during COVID-19. The results showed that airlines mostly posted informative messages about safety measures, adjustment of flight activities, praising stakeholders, and reminders of the company's past. Low-cost carriers sent more informative and adjusting messages, while full-service carriers implemented the bolster communication strategy, which included mostly messages to praise stakeholders and remind them of the company's good past.

Ou and Wong (2020) examined airlines' responses to crises through the modified message framework. The results showed that airline companies emphasized corporate resilience, social responsibility, and empathy in their messages to strengthen their image and reputation.

Budd, Ison and Adrienne (2020) investigated European airlines' strategies to the COVID-19 crisis. The results revealed that although COVID-19 poses similar challenges for airlines, they have implemented different saving and cost reduction strategies. In addition, staff reduction and rearrangement of flight operations, fleet, network structure, and capacity were shown as airlines' main responses to mitigate the negative effects of the COVID-19.

3 Research Method

In this study, the qualitative research method is used. The research method applied in this study is twofold. First of all, we examined the news, press releases, annual reports, and interviews with the managers of airline companies in terms of the content regarding the airline companies operating in the Turkish civil aviation industry during the COVID-19. Secondly, we conducted a detailed interview with five experts, consisting of middle

and senior managers working in the various airline companies in Turkey, focusing especially on organizational flexibility components. Having experience in the operative processes of the airline and taking an active role in the management of the COVID-19 crisis were set as the criteria for the selection of interviewees. The interviews were conducted via online tools and phone lasted between 30 minutes and one and a half hours. During the interviews, the note-taking method was used instead of recording for confidentiality reasons. The interviewees were first asked to describe the strategy of the company and company-specific practices to deal with the COVID-19 crisis. Then, the framework of the study, consisting of the concept of flexibility and preemptive, protective, corrective, and exploitive maneuvers (Evans, 1991), was explained to the interviewees. In line with this framework, the interviewees were asked which practices of the airline companies during the COVID-19 could be considered flexibility maneuvers.

The information obtained by both methods was evaluated in terms of the response of airlines in Turkey to COVID-19 and organized according to the four components of organizational flexibility offered by Evans (1991).

4 Results and Discussions

The first approach of the airline companies to the COVID-19 was to follow the latest developments regarding the outbreak at the national and international level and assess the situation. Airline companies made an effort to understand the nature of the outbreak with information obtained from subject matter experts and relevant institutions (Ayci, 2021).

As a first reaction to the outbreak, Turkish Airlines temporarily suspended its flights to China and some destinations in Iran and announced that it is closely monitoring the situation (Turkish Airlines, 2020a). Similarly, some interviewees expressed that their first reaction to the crisis was to find an answer to the question of “what we can do.” In line with this inquiry, the main priority was the protection of flight crews which is the most critical element of the airline operation. Interviewers stated that working from home, reducing the number of employees in the operations control center and briefing pilots online are common practices to minimize the contact of flight crews with other people.

In addition, regular testing for COVID-19, the absence of anyone other than flight crew members (no transfer crew) on cargo planes for flights, and the selection of alternative crew stay, transfer and change bases were indicated as other health measures crew members during the crisis.

Airline companies regularly disinfected the planes, distributed public health information brochures to passengers, closely followed passengers showing COVID-19 symptoms, and kept masks on board for travelers. In addition, airline companies held regular informative meetings, organized seminars, and shared these activities with all their employees on the Internet to raise employees' awareness about the COVID-19 (Pegasus Airlines Flypgs, 2020a). At the senior management level, the airlines held strategy discussions focusing on alternative scenarios to protect the company, public health, and resources (Ayci, 2021).

After the World Health Organization recognized the COVID-19 outbreak as a pandemic, the seriousness of the situation began to be understood more clearly. Airlines companies had to ground most of their fleets in line with stringent measures of governments to combat COVID-19. This has prompted airlines to find effective cost reduction strategies. Turkish airlines followed a “zero-lay-offs” policy (Chui, 2021; Turkish Airlines Annual Report, 2021). The interviewees stated that the company aims to protect its qualified human resources and reinforce its sense of belonging by a zero layoff policy. In addition, this method has been evaluated as not experiencing the difficulties that the company may encounter in creating a new team in the post-crisis period.

As a cost-saving strategy, the flag carrier company has made a deal with the union to cut pilots’ salaries in half by 2021. Also, it was decided to reduce cabin crew salaries by 35 percent and ground workers by 30 percent (Ozbel and Bilgiç, 2020). Also, the national flag carrier reviewed its fleet planning and canceled some of the orders (Turkish Airlines Annual Report, 2021).

During the COVID-19, keeping grounded aircraft safe and operative became a challenging issue for airline companies. In order to reintroduce airplanes to flight operation after a long period of ground position, plenty of works, including maintenance, safety, and security checks, must be completed (Kotoky, Stringer and Saxena, 2020). These cause airline companies to incur additional maintenance costs and face the challenging issues

of safety. Some airline companies had flown airplanes alternately to reduce aircraft maintenance costs and avoid such safety problems (Nane, 2020). On the other hand, Turkish Airlines has one of the largest aircraft maintenance and repair organizations (MRO), which provides aircraft maintenance services internationally (Turkish Airlines Annual Report, 2021). Interviewees stated that having an MRO provides a cost advantage for aircraft on the ground compared to its competitors.

During the COVID-19 crisis, the shipping industry experienced a shortage of containers. This negatively affected the shipping industry in carrying freight or cargo via sea transportation and increasing demand for air transportation (Brett, 2021). On the other hand, the suspension of passenger flights caused a decrease in the total air cargo capacity supplied (Philip, 2021). Besides the continuity of the supply chain, the urgent need to transport medical supplies has increased the importance of air cargo. Airline companies, which had to suspend their flights within COVID-19 restrictions, responded to this situation by arranging their passenger planes for cargo transportation (Horton, 2020). Pegasus Airlines, a leading low-cost carrier of Turkey, carried cargo in the cabin and belly-hold of a passenger airplane (Pegasus Airlines Flypgs, 2020b; Harry, 2020).

Turkish Airlines is one of the first companies to start carrying cargo with passenger planes and cargo planes. When passenger flights were completely cut off, Turkish Airlines assigned 50 wide-body passenger planes to cargo operation. At that time, Turkish Cargo managed to differentiate itself positively from its competitors in cargo transported and revenue generated. The company has become the 6th largest air cargo carrier globally, with 1.5 million tons of cargo volume and a 4.7% market share in the global cargo market in 2020. This enabled the company to compensate for a significant part of the loss caused by the passenger flight suspension. In addition, the company managed the crisis without financial support from the government and with no layoffs (Turkish Airlines Annual Report, 2021). The interviewees attributed the effectiveness of the company in crisis management, especially its success in the air cargo market, to be an agile organization that has a network of teams capable of quick learning and making decisions in a short period (Brosseau et al., 2019). In addition, effective coordination and working with other stakeholders and business partners, especially with government agencies, have been shown among the factors contributing to crisis management. In particular, the positive

approach of government agencies to the company's requests, effective decision-making mechanism, and quick response to the company's demand have been emphasized in terms of this coordination. Besides, the managerial skills and practices were highlighted as the core elements of effective crisis management. As a managerial practice, the company met increased workforce need on the cargo side from other departments of the company.

On the other hand, with the increasing demand on the cargo side, the flag carrier airline gave particular importance to the management and organization of the cargo business. Firstly, revenue management is reorganized to be represented at the upper managerial level. Thus, it became possible to manage the revenue effectively under a single roof. Many regional sales offices were established for effective cargo marketing. Furthermore, the company hired foreign managers to create diversity in decision teams. For the cargo capacity of the airplanes to be used effectively, practices such as deferred transportation and fines were applied to the agencies that did not use the reserved capacity or were unable to present shipment on time.

Moreover, the company's strengths on the cargo side were used effectively. The low rate of pre-contracted cargo (less block space agreement with freight forwarders), wide flight network, geographical location of the company's cargo base, and experienced cargo management teams were highlighted as the company's internal capabilities by interviewees.

The practices mentioned above of airline companies can be broadly classified as follows within the framework of pre-emptive, protective, exploitive, and corrective maneuvers that Evans (1991) put forward as components of organizational flexibility:

First of all, practices of airline companies such as holding COVID-19 information meetings, converting and reorganizing passenger planes for cargo transportation, and following the latest developments regarding the disease can be considered preventive maneuvers because they indicate proactive approaches of airline companies to be prepared for the undesirable situation.

Second, compliance with regulatory agencies' health and safety requirements, various cost reduction, saving strategies, alternately utilization of airplanes, and practices to

reduce COVID-19 transmission can be classified as protective maneuvers, as airlines' practices stay in a safe zone. Thirdly, the practices of airlines such as organizing the cargo unit as a separate company, establishing regional cargo sales offices, establishing facilities that meet the storage requirements of special cargo can be categorized as exploitative maneuvers as they point to get more shares from the growing cargo market. Lastly, the practices of airline companies, such as reviewing fleet plans and canceling some orders, reorganizing revenue management, changing the amount of hedged oil according to the market situation, quarantining personnel infected with COVID-19, can be considered as corrective maneuvers as they are practices to eliminate the negativities they encounter.

Based on the research findings, it can be reasonable to conclude that the basic capabilities that play an important role in organizational flexibility are organizational culture and managerial practices. Turkey has a collectivist culture. Collectivist culture is characterized by members' greater commitment to their organizations (Hofstede, 1984). As members of such culture, employees of airline companies in Turkey prioritized organizational purposes by accepting wage cuts and flexible working in different units during the crisis period. In addition, such sacrifices for organizational goals contributed to effective coordination and quick implementation of decisions.

5 Conclusion

COVID-19 pandemic has posed an unprecedented risk for airlines. Airline companies designed various strategies to deal with these uncertain times. By focusing on organizational flexibility dimensions, in this study, we investigated responses of airline companies operating in the Turkish Civil Aviation Industry to COVID-19. We have shown that airlines in Turkey manage the COVID-19 crisis with pre-emptive, protective, exploitative, and corrective maneuvers as organizational flexibility components. These maneuvers, in particular, enabled the flag carrier airline to manage the crisis without layoffs, downsizing, and without government financial support, as well as significantly increasing its share in the cargo market.

Although the COVID-19 pandemic has caused similar challenges for airline companies, airlines responded to the crisis with different strategies. In this study, we have shown that organizational culture and managerial practices are the two most important capabilities that influence the strategy of Turkey's airline companies, particularly the flag carrier airline, in managing the COVID-19 pandemic. As a source of motivation for cooperation and common goals, the collectivist culture has enabled the employees of airline companies in Turkey to work effectively for the company's future. This result demonstrated the importance of developing a collaborative culture for companies to respond effectively to crises.

Analysis of secondary data sources and in-depth interview methods enable us to obtain meaningful results in the study. However, this study has some limitations. In this study, we interviewed five experts from different airline companies. Interviewing more experts may allow different perspectives to be reflected in the study. Thus, it may be possible to learn more specific practices related to the management of COVID-19. In addition, as the impact of COVID-19 continues, airline companies may have to take new measures and implement different strategies. This study includes the practices of airline companies for a certain period of COVID-19.

This study suggests research topics for future studies. Examining the effects of the elements of culture on the components of organizational flexibility will make important contributions to the airline flexibility during the crisis. In addition, the effectiveness of flexibility dimensions and their sub-elements in the management of the crisis caused by COVID-19 can be investigated using quantitative methods. Lastly, this study was focused on airline companies in Turkey. Similarly, the actions taken by various airline companies against COVID-19 in different countries can be compared within the framework of organizational flexibility components.

Acknowledgment

The authors would like to thank all reviewers and the interviewees who made valuable contributions to the study with their comments, feedback, suggestions, and criticisms.

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Feasibility Study on Augmented Supplier Audit

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Purpose: *Conventional supplier audits are outdated as traditional instruments in supplier management. At least since travel and contact restrictions were imposed due to Covid-19, digital instruments must be used for remote supplier audits. Augmented Reality (AR) technology supports international supply management to work more efficiently and sustainably.*

Methodology: *For this purpose, the feasibility of Augmented Supplier Audit in Industry applications will be analyzed based on a literature review and use case research. The focus is on hardware/software, legal/normative specifications as well as procedural feasibility. First research findings are pictured in a use case and described in this paper.*

Findings: *The study shows the high potential of Augmented Supplier Audit as a standardized instrument in industry. Nevertheless, there are barriers to consider. Beside the lack of appropriate software applications to execute a fully integrated Augmented Supplier Audit, data security and the provision of hardware at supplier side has to be defined.*

Originality: *Current research activities on technology-supported supplier audit are primarily limited on video conferences, the prevalence of remote audits in practice is marginal. However, since the beginning of the corona pandemic, (re)-certification audits are either postponed or allowed to be held remotely, whereby first practical experience could be generated.*

First received: 06. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Due to the reduction in depth of value creation in many companies, the pressure on quality management in the supply chain is constantly increasing. The growing connection between suppliers and customers, as well as the push for new technological innovations, lead to increasing competitive pressure. As a result, companies are forced to abandon traditional supplier strategies and pursue new strategies to maintain competition. In this context, a target-oriented supplier management plays a key role, creating a link between the company and its suppliers. Companies must select those suppliers that meet their needs best and establish and maintain an optimal relationship with those suppliers. The benefits from working with an optimized supplier base are widely recognized in both practice and academia. (Obmann, 2014)

The term supplier management is only very generally defined in the literature and there is a high degree of disparity in terms of content. Thus, although the topic is discussed intensively, the extension of the understanding of the term is interpreted in different ways. In general, supplier management can be seen as a management process that encompasses the entire supplier-customer relationship from the beginning to the end of the cooperation, whereby the entire process can be divided into different phases, depending on the literature as shown in Figure 1.

A key factor of the model presented is the ability to integrate supplier management as a holistic process and to enable a systematic approach. This is achieved through segmentation into the individual phases of supplier management. The procedure for implementation is divided into these individual elements, whereby each individual phase includes risk assessment under the aspect of the respective design field as well as a possible phase-out process. This integrated risk assessment for each individual phase of supplier management distinguishes the planned model significantly from other models. Supplier development and -auditing represents an important step in the presented model and builds systematically on the results of the two preceding phases. This phase basically ensures suppliers potential in the future. Important task of this phase is to eliminate defined deficits through targeted measures to improve supplier performance. In addition, however, emerging risks must also be identified in an early

stage. For this reason, a supplier audit is an essential element in this context. This paper presented here deals with the important phase of the supplier auditing.

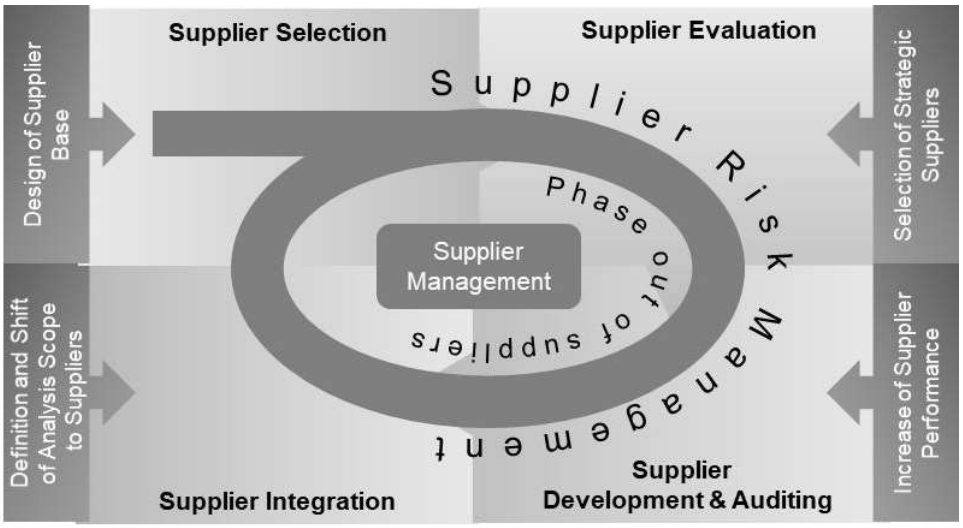


Figure 1: Holistic Supplier Management (Obmann, 2014)

An essential task of supplier management is, as already mentioned, to ensure that the company's needs are met at the right price and in the specified quantity at a given time, taking quality into account. To identify those suppliers who can also fulfill these criteria in the long term, careful supplier selection is an essential criterion, as the company's success depends on it. The goal of supplier selection is therefore to find the ideal supplier who can provide the desired service even in a long-term cooperation (Helmold and Terry, 2016).

Selecting the ideal suppliers is difficult because global networking means that suppliers can be located anywhere in the world, resulting in supply chains that span the globe with the result of a global supplier base which causes cost-intensive audits. The aim of the audits is to gain an insight into supplier’s production sites to generate more information. This should include information about the suitability for a long-term cooperation and furthermore to what extent the supplier is able to provide the desired service. (Hofbauer, Mashhour and Fischer, 2009)

As already mentioned, supplier audits that are carried out in widely dispersed locations often lead to high costs. Furthermore, valuable human resources are not available for the

organization due to long travel distances. To maintain competitiveness in the future, it is necessary to reduce the aforementioned disadvantages in order to save costs, among other things. Nevertheless, it should be possible to determine and continuously monitor the ideal supplier by means of more efficient supplier audits. (Peddie, 2017)

2 Supplier Audit as Part of Supplier Management

As already mentioned at the outset, supplier audits primarily pursue the goal of increasing the performance level of suppliers, for example by imparting know-how or training employees.

Audits are generally divided into internal and external audits. In addition, external audits are further divided into second-party and third-party audits. The two types of audits – supplier and certification audits – are part of these external audits (Kallmeyer and Kretschmar 2019).

Figure 2 illustrates the relationships between these different types of audits.

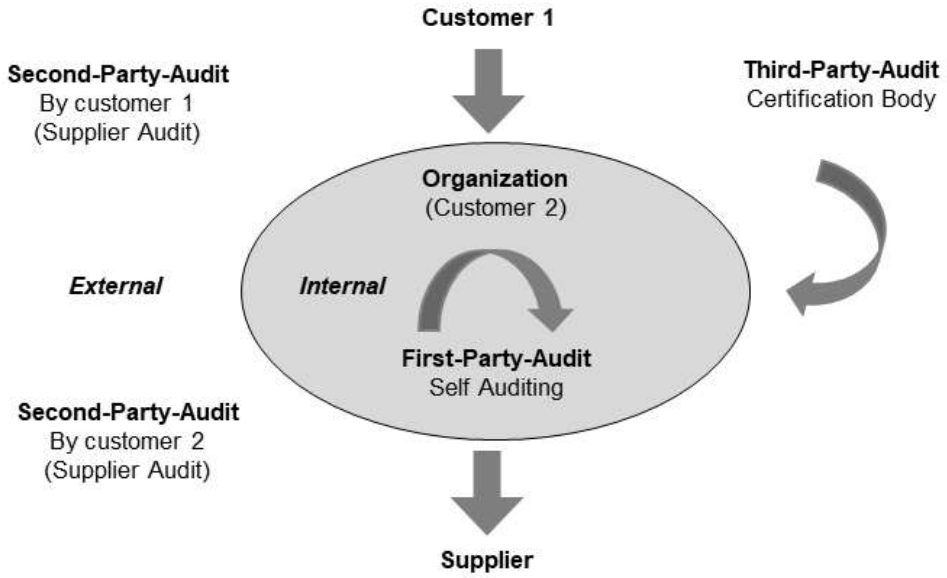


Figure 2: Internal and External Audits (Gietl and Lobinger, 2012)

Internal audits are usually performed by or on behalf of an organization and are basically for internal purposes. Therefore, this type of audit is often attributed to first-party audits. Employees of the organization usually perform the auditing of these internal audits. However, it is also possible to use consultants as deputies for an internal audit if, for example, the company does not wish to train its own employees for this activity. Internal audits are carried out to check the management system for conformity to standards.

The focus is primarily on identifying potential for improvement and thus also represents a component of the continuous improvement process (CIP) (Kallmeyer and Kretschmar 2019) (Gietl and Lobinger, 2012).

External audits, on the other hand, are carried out on behalf of the company's own organization or that of a customer. The auditing by an external party and thus by a person outside the organization is usually carried out by an auditor of a certification body. For the execution of these audits, rules exist according to which generally applicable checklists and questionnaires have been drafted, which are based on these sets of rules. External audits can be divided into second- and third-party audits. The supplier audit belongs to the second-party audits, as the customer and the supplier are thus two parties involved. The performance of this type of audit is generally not mandatorily defined by sets of rules for all industries.

ISO 19011 provides the basis for conducting internal and supplier audits and regulates the systematic auditing of management systems. Nevertheless, as a guideline, the standard is only a recommendation. In addition to this, there is also the ISO 9001 quality standard, which represents an essential set of rules for supplier audits. There are also industry-specific standards, such as VDA 6.1 in the automotive industry. Among other things, these quality standards specify audit criteria for supplier audits. Third-party audits can also be certification audits. In this case, neither the customer (second-party) nor the supplier company (first-party) is responsible for conducting the audit. The auditing is carried out on behalf of the customer by an independent and external third party, for example a certification company. An independent audit is carried out by the auditing organization to check the management system for conformity to the standard. Its main task in the certification audit is to achieve the maintenance of the certificate or the granting of the certificate.

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A supplier audit is therefore a systematic monitoring of a supplier that the customer initiates to determine whether the quality management is suitable and to what extent it is implemented to meet the customer's requirements. It represents a supporting element to guarantee the assurance of the upstream supply chain in terms of the supplier's ability to provide the products or service and the correct quantity to the customer at the right time and with the specified quality. Audits are also conducted to support supplier selection and evaluation with results and findings. Among other things, an audit can also be used for the initial assessment of a supplier as part of the preselection process, but it is also used to audit existing suppliers for supplier controlling purposes. (Janker, 2008)

Furthermore, in addition to monitoring compliance with the existing condition, an audit should also aim to continuously improve the processes and procedures (Helmold and Terry, 2016). For this reason, supplier audits are increasingly being carried out to identify potential for improving performance and quality.

Supplier audits require mutual trust in any case, as company-specific know-how and internal company information are disclosed. Hence, supplier audits are often viewed from a critical perspective. Therefore, a contractual basis between the customer and the audited company is recommended. The supplier is generally not obligated to permit an on-site audit, which is why the customer should be granted the right to do so. To ensure confidentiality, a non-disclosure or confidentiality agreement between the parties is recommended.

Not only the customer, but also the supplier can gain valuable insights from these supplier audits. They can prepare for possible audits by a certification company, improvement potentials are uncovered and can be implemented promptly to increase the quality level or even reduce costs. (Wagner, 2002). In addition, the supplier learns to understand the needs of his customers much better and can respond to them in a targeted manner, which in turn can contribute to a competitive advantage (Obmann, 2014).

As the auditing process involves a great deal of work for all the institutions involved, care should be taken to conduct an audit only for those suppliers for whom the supplier's performance is of great importance to the procuring company. This applies above all to critical or very complex products. The supplier audit can be carried out either by the

customer personally or by a qualified person or company. The latter opens the possibility of reducing or even avoiding long journeys and additional effort, thus saving costs. This reflects one of the reasons why the way audits are conducted is changing. Thanks to modern technology, remote audits are possible nowadays, with auditing being carried out via interactive means of communication.

In this context, however, it should be noted that special attention should be paid regarding the information security and confidentiality requirements that must be met. This primarily concerns data integrity. Mention should be made here, for example, of faked data from suppliers that can hardly be verified at present with the tools available, or data leaks that can have consequences that threaten the existence of the company. For example, not all information and communication tools are suitable for use in remote audits. General regulations, such as the EU Data Protection Regulation (EU-DSGVO) on the processing of personal data, also play a significant role regarding data security.

Unfortunately, it must be stated in this context that complete security is currently not technologically feasible. In this context, standardization bodies will have to implement mandatory standards for remote audits to ensure high data quality and security, stable IT infrastructure and knowledge of people involved in the audit process. In 2018 the International Accreditation Forum (IAF) already provided a mandatory document for the use of information and communication technology for auditing purposes, called IAF MD 4:2018. The scope is to provide a standard for the consistent application in auditing and for the usage of information and communication technology within the audit methodology. Additionally, IAF offers further standards like IAF ID 12 (Principles on remote audits). Both are compatible with ISO standards for conformity assessments (Third-party). Therefore, the target should be to derive aligned standards for second-party audits as supplier audits in industry by standardization bodies.

3 Existing Research on Augmented Supplier Audit

Remote audits presuppose industry-ready hardware devices and technology. Due to the Garnter Hype Cycle AR technology is finally ready to go from pilot to productivity in enterprise space (Herdino, 2021). AR is described as extended or enriched reality since

the fading in of digital information leads to a fusion of reality with non-real content. The enrichment by virtual objects takes place continuously and makes it possible to adapt the representation to the current viewpoint of the respective viewer (Broll, 2013).

AR can be realized on various hardware devices such as smartphones, tablets, notebooks, or smart glasses and offer a wide range of applications from playful to highly technical applications such as the head-up display (HUD) in vehicles. (Peddie, 2017) (Mehler-Bicher, Reiß and Steiger, 2011)

The scope of AR applications in industry is varied. Employee training, support issues or simple visualization of data are just a few applications which are already implemented in industrial area. (Peddie, 2017) Especially sales specialists see high potential in the visualization of products as part of the customer service which leads to a highly innovative view on products and services (Ludwig and Reimann, 2005).

Research also shows high potential for AR in supplier audits. In past, remote audits of suppliers were already part of the business for third party-audits, whereby due to low efficiency and technical limitations such remote audits are not seen as feasible method. Nevertheless, with the augmentation of supplier audits, modern technology and industrial-ready hardware devices like data glasses enables companies to audit suppliers in a new way.

The following section presents research on the feasibility of augmented supplier audits. In a comprehensive literature review, AR technology was analyzed to understand the technology itself and check the possibility for application of AR-ready hardware devices like smartphones, notebooks, or data glasses in selected supplier audit process steps. Subsequently, based on the literature research two relevant types of augmented supplier audits were identified. Both deal with the development of an augmented supplier audit supported by AR technology and are based on the selected standard process of supplier auditing showed in Figure 3.

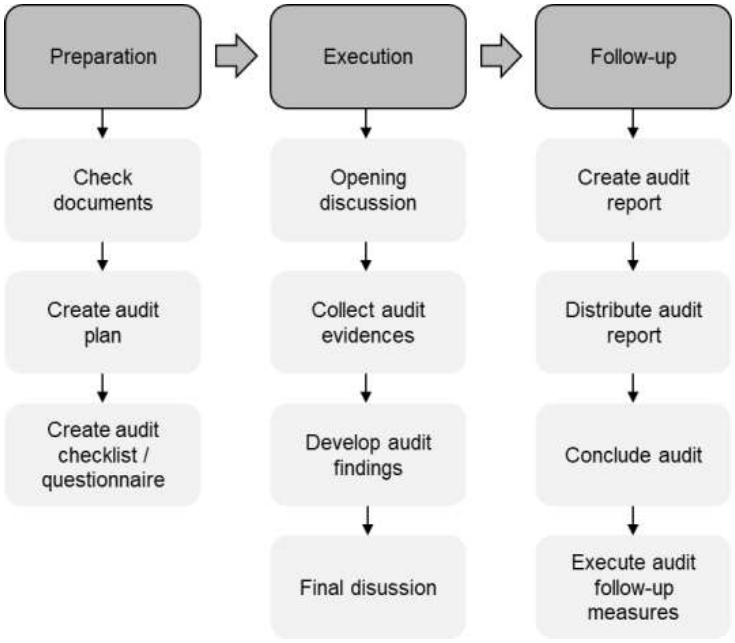


Figure 3: Process of Supplier Audit (Kallmeyer, 2019)

Firstly, before preparing the audit, it is crucial to define, resources for the execution of the audit, objectives, criteria, and the extent. During this preparation phase, the auditor must decide with the concerned supplier, which type of augmented supplier audit should be executed. Both types will be explained by using phase 1 (preparation) and 2 (execution) of the supplier audit process, which were identified as phases with high potential for AR technology support.

3.1 Augmentation of On-Site Supplier Audits

In this type of augmented supplier audit the auditor from the buying company is physically present at the supplier's production site. Especially in the supplier selection phase, approval as well as detection and monitoring of weaknesses in the process of existing suppliers, this type of audit should be preferred. (Kallmeyer, 2019) (Janker, 2008) The main objective of AR in this type is to achieve greater efficiency in the auditing processes.

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Based on the literature research on augmentation of on-site supplier audits, following functions supported by AR devices could be identified. The functions are allocated to elements out of the audit process mentioned before.

Table 1: Identification of AR Potential in On-Site Supplier Audits

Element	Function	Device
Display company information	Overview of augmented processes, organizational charts, handbooks, certifications, and other related information for the audit process. Essential information can be marked as relevant to retrieve in the final discussion. (Kallmeyer, 2019)	Smartphone, tablet, notebook, data glasses
Augmented plant inspection via remote	Navigation of the auditor by using defined paths displayed directly on the floor to be guided to marked checkpoints of the audit process. (Shen, 2013) (Tönnis, Plecher and Klinker, 2013)	Smartphone, tablet, notebook, data glasses, helmet
	Emergency routes and hazardous areas can be marked to ensure safety measures during the audit process. (Khakurel, Melkas and Porras, 2018) (Peddie, 2017)	Smartphone, tablet, notebook, data glasses, helmet
Collect audit evidence	A list of available interview partner can be called up quickly. (Kallmeyer, 2019)	Smartphone, tablet, notebook, data glasses, helmet

Final discussion	The marked information in the company documents can be called up for final discussion of the supplier audit.	Smartphone, tablet, notebook

Main advantage of this type of supplier audit is the direct contact with the supplier. Though the auditor is on-site, costs can be saved by reducing the personnel expenditures. Experts from different areas do not have to join physically. Displaying relevant information as well as guiding the auditor through the production site are seen as main advantages and potentials to reduce audit times.

3.2 Augmentation of Remote Supplier Audits

The remote supplier audit is defined as fully remote audit without delegating an auditor to the production site of the supplier. The objective of this type is to reduce travel and time expenses for short audits in far off countries. This type of audit can be combined with the on-site supplier audit to ensure the interpersonal relation and communication. Therefore, headquarters can be audited on-site, while relevant secondary plants can be easily audited by remote. (Kallmeyer and Kretschmar 2019) (Kallmeyer 2019)

Table 2 shows the identified AR supported functions for remote supplier audits allocated to the supplier audit elements.

Table 2: Identification of AR Potential in Remote Supplier Audits

Element	Function	Device
Display company information	Overview of augmented processes, organizational charts, handbooks, certifications, and other related information for the audit process. Essential information can be marked as relevant to retrieve in the final discussion. (Kallmeyer, 2019)	Smartphone, tablet, notebook, data glasses
Augmented plant inspection via remote	The selection of certain areas/processes which should be specified by related persons to get further information. (Caricato et al., 2014) (Ludwig and Reimann, 2005)	Smartphone, tablet, data glasses
	Navigation of the auditee by using defined paths and easy changing of the defined path. (Chung, Pagnini and Langer, 2016)	Smartphone, tablet, data glasses
	Additional information or notes can be displayed directly in the viewing area of the auditee to easily check them.	Smartphone, tablet, notebook, data glasses
Collect audit evidence	The interviews with available employees can take place by using the remote connection. The device is used for image and audio transmission. (Kallmeyer, 2017)	Smartphone, tablet, data glasses
Final discussion	The marked information in the company documents can be called up for final discussion of the supplier audit.	Smartphone, tablet, notebook

The execution of remote supplier audits is linked to operational requirements. A stable internet connection as well as secure and reliable data transmission are mandatory to ensure an uninterruptable supplier audit. Therefore, infrastructure plays an important role. Hardware devices must be available on supplier-side, the supplier is entrusted with it and is able to use software and hardware efficiently. The substantial advantage is that the auditor has not to be physically at the supplier. Therefore, audit times can be reduced, several suppliers can be audited spontaneous and randomly. (Kallmeyer, 2019)

This leads to a higher comparability between the audit results for supplier benchmarking. It also requires suppliers to be trained sufficiently for executing augmented remote supplier audits. AR is seen as final enabler of remote audits. Until now, remote were understood as bilateral communication by using collaboration platforms like *Microsoft Teams* or other data sharing platforms. On the one hand by using AR technology, auditors can additionally be guided through productions sites by using portable and ergonomic devices. But on the other hand, remote supplier audits are not an equivalent substitute for supplier audits. Personal contact and advanced insights as part of a holistic supplier audit cannot be achieved in remote supplier audits.

4 Definition of an Augmented Supplier Audit Use Case

Based on the investigation of AR potential in supplier audits, the target was to define an industrial-suited augmented supplier audit use case. Therefore, both types of augmented supplier audits were analyzed in a subjective benefit analysis on different categories. Within this analysis essential hardware/technology and software was evaluated. These categories were selected based on the information gathered in the literature research and are seen as basic elements of augmented supplier audit. The target of the use case was to check the feasibility of augmented supplier audits in the industrial area and derive further research fields in this area. The focus of the use case is on data glasses, which enable an ergonomic and efficient supplier audit process. The evaluation and definition of the use case is a four-stage approach visualized in Figure 4,

whereby the last stage is including exemplary audit plans based on the production processes in the Smart Production Lab and is not mentioned in this paper.

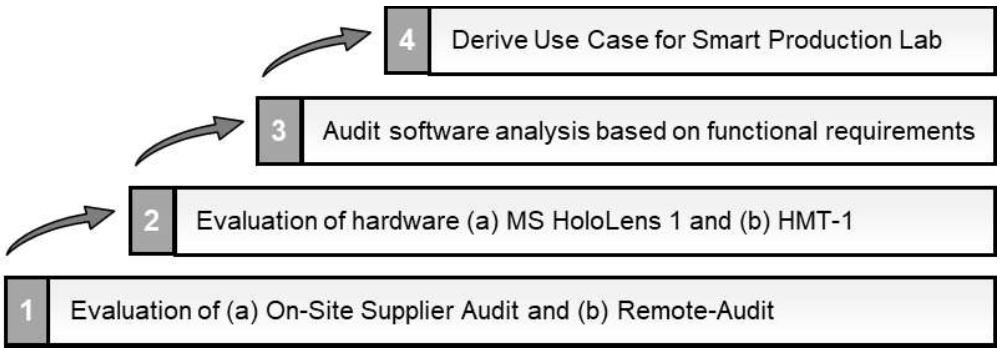


Figure 4: Structure of Subjective Benefit Analysis for Use Case Creation

The lab is part of the infrastructure of the University of Applied Sciences JOANNEUM and is used as research lab for Industry 4.0 and digitalization use cases. Within the lab different machinery is vertically integrated from the ERP (Enterprise Resource Planning) system to automation level, creating data by producing a customizable clock. The use case should enable the project team to simulate a supplier audit, whereby the Smart Production Lab is seen as the supplier.

The structure and the results of stage 1 to 3 are described in the following sub chapters.

4.1 Evaluation of Augmented Supplier Audit Type

In the first stage both types of augmented supplier audit, explained in the previous chapter are compared and evaluated by following criteria, which are based on literature research and experience of research project members in practical test runs.

Table 3: Evaluation Criteria for Use Case Selection

Criteria	Explanation
Audit Output	The objective of the audit is to collect as much relevant information as possible. Therefore, the audit output describes the audit evidence density generated during the audit process.
Soft Facts	Soft facts are as important as processes and KPIs to get general impressions. Corporate culture, HSE (Health, Safety and Environment) or 5S concepts are often recognizable as soft facts.
Audit Availability	This criterion evaluates the possibility for uncomplicated and rapid execution of supplier audits. In extraordinary situations business trips are not possible immediately due to resources and planning of audits.
Audit Costs	To execute supplier audits costs in sense of personnel and travel costs incur for the auditor. The costs are evaluated subjectively by researching the impact of the audit type on the overall costs of auditing.

Based on this evaluation criteria and the information gathered from the literature review, the following selection criteria were created. The pugh matrix method is the basis for weighting the criteria and was also selected for evaluations presented in the following chapters. In the next step the project team did a subjective evaluation based on the experience of first field tests and the knowledge out of the literature analysis. The higher the score, the better the result. This means, that “Audit Costs” are ranked higher in the category of low costs. In general, the evaluation is based on a scale from 0 to 10, whereby the value 10 represents an excellent score. The method of pugh matrix is also

recommended to management within the evaluation phase to ensure a profitable use case.

Table 4: Subjective Evaluation of Augmented Supplier Audit Types

On-Site-Audit / Remote Audit	Weighting [%]	Evaluation On Site / Remote	Score On Site / Remote
Audit Output	25	8 / 5	200 / 125
Soft Facts	15	9 / 3	135 / 45
Audit Availability	30	4 / 9	120 / 270
Audit Costs	30	4 / 7	120 / 210
Result	100		575 / 650

For an augmented supplier audit use case, the remote audit is selected as best fitting type due to its potential in terms of audit availability and costs. Doubtless the decrease of soft facts impressions and audit output must be considered anyhow in the audit report. The evaluation of hardware and software in the following stages is based on the requirements of the remote supplier audit.

4.2 Evaluation of Augmented Supplier Audit Hardware

The augmentation of supplier audits posits high-performance hardware for industrial usage. Therefore, two different hardware devices were tested in the Smart Production Lab, which enables industrial conditions for practical tests. With the *Microsoft HoloLens 1* and the *Realwear HMT-1* the Smart Production Lab provides state-of-the-art hardware devices which are suitable for industrial use. The main difference of both devices is the

technology. While *Microsoft HoloLens 1* supports Virtual Reality (VR) applications, *Realwear HMT-1* is based on Augmented Reality (AR) technology. Based on initial experiences with both devices, the following criteria were defined for a comparison of the AR hardware.

Table 5: Evaluation Criteria for Hardware Selection

Criteria	Explanation
Durability	Considers the industrial readiness. Especially IPC (International Protection Code) certifications or ATEX (Atmosphères Explosibles) explosion protection as well as durability in risk of falling are important characteristics for industrial usage.
Intuitiveness	Describes how the devices are controlled. Data glasses are based on different technology like gesture or voice control. Different disturbance factors may have an impact on the device control. Industrial background noises or unfavorable incidence of light could complicate handling.
Applications	The operating system (OS) determines the availability of applications in specific app stores of the OS providers. Comparable to the usage of applications on smart watches, not each app is ready for data glasses usage and may require specific adaptions and developments.
Hardware	The technical specification of the device. Conditions for the technical realization of augmented supplier audits include high data storage capacity, long battery life and enough sound and visual quality for video communication.

The evaluation and practical tests of *Microsoft Hololens 1* showed that VR technology is not relevant for supplier audits. Firstly, the creation of a fitting supplier audits use case supported by VR presupposes a strong relationship between both partners as well long preparation and development time. Due to comprehensiveness of the research, VR is evaluated and tested anyway. The subjective evaluation based on technical specifications practical experience is listed in Table 6.

Table 6: Subjective Evaluation of Hardware

HoloLens 1 / HMT-1	Weighting [%]	Evaluation HoloLens / HMT	Score HoloLens / HMT
Durability	20	4 / 9	80 / 180
Intuitiveness	25	7 / 7	175 / 175
Applications	30	2 / 8	60 / 240
Hardware	25	8 / 7	200 / 175
Result	100		515 / 770

Particularly the durability as well as the variety of applications are the main differences of both hardware devices. While *Microsoft HoloLens 1* is neither featured with ATEX certification nor IPC, *Realwear HMT-1* is designed for industrial usage by IP66 (dust protection and resistant to hose water). Furthermore, the *HMT-1Z1* is certified for ATEX zone 1 for oil, chemical, gas, or other industries. As this device works on an Android operating system, the *Google Play Store* offers many different applications for *Realwear HMT-1*, while *Microsoft HoloLens 1* operates on *Windows 10 platform*. The operating system is an important factor in this context because the app stores for each operating

system and consequently the availability of applications differ. With the release of the next *HoloLens generation (HoloLens 2)* the development and support of many applications has ceased for *HoloLens 1*. For the mentioned reasons, *HMT-1* is selected as the preferred hardware for further research.

4.3 Evaluation of Augmented Supplier Audit Software

As mentioned before, depending on the OS the user can download applications from different app stores. Since many applications are not optimized for the usage on data glasses devices, the number of appropriate solutions for augmented supplier audits is strongly restricted. Most of them are typical video conference of business communication platforms which were already used before AR for remote audits. To create an efficient augmented supplier audit process, applications with focus on core processes of supplier audit are needed. For example, for augmented maintenance, software developers provide a lot of solutions for AR devices.

Nevertheless, existing, and available applications were analyzed in a 2-stage approach to identify three software applications for further research. Table 7 shows an overview of functional requirements of the audit processes as well as compatible software applications usable on *Realwear HMT-1*. Marked cells indicate if the software application meets the requirements. The requirements are not ranked and are simply illustrated to show the most important functionalities of such compatible software applications.

Table 7: Market Screening of Applications for Augmented Supplier Audit (Extract)

Functional Requirements	Evocall	Teamviewer Pilot (TVP)	RISE	Skylight	blitzz
Live Communication	x	x	x	x	x
Send documents	x	x	x	x	

Functional Requirements	Evocall	Teamviewer Pilot (TVP)	RISE	Skylight	blitzz
Live instructions			x		x
Frozen instructions	x	x	x	x	x
Dynamic 3D instructions		x			
Share screen			x		x
Chat function	x		x	x	x
Communication History	x		x	x	

Based on the market screening, *Evocall*, *Teamviewer Pilot* and *RISE* were selected for further practical tests. These applications are available for *Realwear HMT-1* and support the functional requirements “Live Communication”, “Document Sending” and “Frozen Instruction”, which allow to guide through the audit process, offering and sending audit documents or recording video sequences or photos for further audit evidence and final discussions. These functionalities were practically tested by the research group and evaluated based on following criteria. Furthermore, these applications are already available in the Smart Production Lab infrastructure. For further research in industrial environment, it is recommended to enlarge the list of software applications. It is expected, that software developer will offer new features for audits soon based on the current need of industry.

Table 8: Evaluation Criteria for Software Selection

Criteria	Explanation
User friendliness	Describes the technical and functional user experience. This criterion shows the efficiency in usage as well as the prevention of operating errors. It concerns the hardware user view as well as the auditor view, who is steering the audit by using respective software.
Functionality	Describes how the technical requirements are solved by the application and which assorted specifications are provided. Screen sharing, creation of protocols or create other audit evidence are possible functionalities.
Costs	The evaluation of costs may be different in each company depending on the need and usage in other areas. In this case, the evaluation is based on a single case principle, which means that this use case is the only one which is executed. This fact reduces the need of licenses to a minimum.

After evaluating the practical experience made in the software tests, *RISE* was selected as most suitable software for augmented supplier audits. *RISE* offers remote zoom functionality, laser pointer, screen sharing, history of data transfers and report export functionalities. The final evaluation is listed in Table 9, showing advantages of *RISE* in all criteria.

Table 9: Subjective Evaluation of Software

Evocall / TVP / RISE	Weighting [%]	Evaluation Evocall / TVP / RISE	Score Evocall / TVP / RISE
User-friendliness	30	5 / 6 / 8	150 / 180 / 240
Functionality	50	8 / 5 / 9	400 / 250 / 450
Costs	20	3 / 6 / 7	60 / 120 / 140
Result	100		610 / 580 / 830

The functionality of *Evocall* and *RISE* is quite similar, the costs for software licenses are based on different pricing models. While *Evocall* offers single-client licenses, *RISE* offers multi-user license with tiered pricing. Nevertheless, the overall costs of *RISE* are evaluated better in the research.

The project team and authors were able to identify further potentials in each stage of the research. In the final use case, the Smart Production Lab represents the supplier's production site, which should be audited within the augmented supplier audit. The idea behind the use case is to show especially small and medium-sized enterprises (SME) new possibilities triggered by modern technology in daily business. New findings in this topic are presented to managers as well as to students within the courses of the University of Applied Sciences JOANNEUM. The feedback on prior and actual insights is thoroughly positive, whereby further research fields arise from this use case.

5 Further Research and Outlook

It is undisputed that the rate of digitization has increased manifold in recent years and is having an enormous impact on generating a competitive advantage at many different corporate levels. This development also affects auditing, and it is fair to assume that the proportion of AR audits will continue to rise in the future. Companies are continuously evolving and digitizing their process flows. It is clear to see that auditing will not be exempt from this. The authors of this article therefore recommend dealing with this topic at an early stage to gain greater experience in this area. The current COVID-19 pandemic has highlighted how relevant and useful remote AR auditing can be. As the Gartner Hype Cycle illustrates, AR technology should reach the next phase and emerge from the valley of disillusionment and be further developed accordingly so that it can then actually be used in companies in a way that adds value. Although remote audits are an excellent alternative to on-site audits, the authors do not believe that they will be able to completely replace them in near future.

However, AR has sufficient potential to make supplier audits more efficient and thus reduce the use of resources.

At this point, however, it should be noted that not all information and communication tools are suitable for use in remote audits. Special emphasis should be placed on legal concerns relating to information security requirements and confidentiality, which must be met. These are, for example, security aspects regarding data protection, image rights or the prohibition of recordings. Unfortunately, it must be stated in this context that complete security is not technologically feasible at present. This also applies to faked data, which could be generated by suppliers.

In conclusion, it can be said that the use of remote audits has both opportunities and limitations, and, depending on the situation and requirements, it is necessary to weigh up whether a remote audit is a suitable method for conducting audits. However, due to the current digital transformation and the crisis-induced switch to virtual tools, it can be assumed, as mentioned at the beginning, that remote audits will become increasingly popular in the future. (Fridl, 2020)

6 Concluding Remarks

The research shows the increasing necessity for modern supplier audit processes. Based on this fact, AR technology is arriving in supplier management now. Especially current disruptions in supply chains as well as sustainability aspects require substantial amounts of time and extra processes to induce cost saving measures.

As already mentioned in the use case, the integration of AR technology enables many advantages in the process of supplier audit. Whereby the need for standards concerning data privacy in supplier audits as well as for recommendations to ensure plant safety during the supplier audit is significant. Moreover, soft facts are a key omission in the fully remote supplier audit and are hardly replaceable in the process.

The created use case shows that many factors must be considered in the selection of software and hardware. Especially in the step of software selection, functional requirements should be known out of the defined audit process. The operating system of the hardware device could restrict the number of potential applications. Furthermore, software developers have not yet recognized the potential market of augmented supplier audits. Applications with interfaces in ERP or Supplier Relationship Management (SRM) systems are desired.

Concerning the hardware devices, auditors and auditees must ensure the availability of performing data glasses. The provision of hardware on the supplier's side may relate to export control regulations and could require temporary export authorization. Training employees should be part of a joint effort within supplier development measures. Business practice shows that companies are not yet ready for this transformation. Minimal standards and requirements for digitalization are not being fulfilled in the industry at the time of publication. A target-oriented usage of AR devices in supplier audits require these standards of digitalization to ensure an increase in efficiency of supplier audit processes.

Efficient augmentation of supplier audits not only ensure efficient processes, further advantages in supplier management can be realized. New auditing methods also

influence supplier selection as a further coverage of potential supplier market, which leads to more flexibility and risk reduction in sourcing.

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Approach for Application-Specific Selection of Risk Assessment Methods

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Purpose: *The field of risk assessment contains many methods for evaluating risks. For companies who face the need of dealing with risks, the large number of methods might be confusing and overwhelming. This paper helps to introduce companies to the existing methods and its different requirements as well to support the application-specific selection of a risk assessment method.*

Methodology: *A systematic literature review regarding existing risk assessment methods is executed using the following identification terms: 1. "risk assessment" AND (method OR technique OR instrument OR tool OR process) AND "supply chain" 2. "risk analysis" AND (method OR technique OR instrument OR tool OR process) AND "supply chain". Used databases are EBSCOhost, Scopus, and Web of Science.*

Findings: *194 sources containing relevant content on the methods of risk assessment are identified. 138 sources are published as journal articles and 56 sources as conference contributions. The main result is a classification and an application-specific selection procedure for risk assessment methods.*

Originality: *This publication enables a comprehensive comparison and evaluation of existing risk assessment methods. It further supports the decision-making by presenting an overview and a selection procedure for choosing an application-specific method.*

First received: 07. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Motivation

During the last years, companies of all industries were exposed to supply chain risks (SCR) like price volatility, risk working capital, and inventories caused e.g. by changing demand or supply disruptions due to natural disasters, financial instability, or political interference (Galanton 2019).

Previously unknown risks arose from increasing technical progress, especially in the context of digitization, and from the complexity increase in the creation of value (Zsidisin and Henke 2019). Based on the mentioned factors and due to significant events around the world and the increased vulnerability of the supply chains (SC), supply chain risk management (SCRM) moved into the focus of many organizations (Elzarka 2013).

SCRM is already widespread in the literature. However, despite the wealth of research, several research gaps are revealed. (Bak 2018; Col-occhia and Strozzi 2012; Falkner and Hiebl 2015; Ho et al. 2015; Sodhi, Son and Tang 2012; Tran, Dubrovnik and Krummer 2018) One major gap is the lack of focus on small and medium-sized enterprises (SME).

Only with the right risk assessment SME can find the right solution to handle risks. Regarding limited time, investment capital and know how in many SME a pragmatic procedure is needed for choosing the right risk assessment method and to accompany the implementation process of SCRM by presenting an application-specific selection procedure for risk assessment methods. These needs are not addressed in literature, yet.

Since the basis of this paper is a collection of existing risk assessment methods and the categorization of them, chapter 2 presents background information regarding the literature review as a basis for a valid result. Chapter 3 deals with the identification of distinctive criteria of the identified methods. Finally, chapter 4 presents the application-specific selection procedure for risk assessment methods. Chapter 5 completes the paper with a conclusion.

2 Literature Review Regarding Risk Assessment Methods

According to Tranfield, Denyer and Smart (2003) a systematic literature review (SLR) is a fundamental scientific activity to create a transparent, systematic, and reproducible way of research (Tranfield, Denyer & Smart 2003). These characteristics of a SLR are important to generate valid input and are therefore considered for this research. The SLR includes sources available on the databases EBSCOhost, Scopus and Web of Science. The selection of databases is grounded on the extensive literature in the relevant field. The databases provide thematically appropriate, scientifically proven and peer-reviewed specialized literature. The literature is independent, i.e. there are no legal obligations or ties to specific publicists or publications. The international databases contain a large number of English literature, what reflects the globally distributed state of research. This justifies the selection of the databases. Used identification terms are:

1. "risk assessment" AND (method OR technique OR instrument OR tool OR process) AND "supply chain"
2. "risk analysis" AND (method OR technique OR instrument OR tool OR process) AND "supply chain"

3.517 publications were found which are further divided by several rejection rules. The first rejection deals with source batches of 20 publications which are in scope as long as >10% of a batch has a relevant title or keywords. In this case the first 71 batches with 1.420 sources are included for the review. Following rejections are based on detailed review of the relevance of the title, keywords, abstracts, content, and duplicate rejection. The outcome of the SLR are 194 relevant sources including nine reviews, which were published regarding risk management including risk assessment. These reviews are important for further elaboration, since there many sources are already analysed. According to the publishing years it is conspicuous that the earliest publication found in this SLR is from 2003 and till 2009 the number of publications is just on average 2,5 per year. After 2009 the interest grew significantly to an average of 17,5 publications per year till 2019. In 2016 the highest number of publications is identified with 26. Since 2003 it took ten years until the first review was published. This paper not only includes journal paper like most of the other reviews but also considers 56 conference paper as valuable input. Further the time range of reviewed papers is extended compared to the other

reviews by at least 1,5 years what leads to the analysis of additional 42 sources. The reviews (Table 1) generate valuable input regarding the existing methods, their characteristics, elements and further existing criteria. This is also the required input to classify the methods, and finally create the aspired approach. Since this paper do not aim to develop new differentiation criteria, the criteria are based on these reviews.

Table 1: List of identified literature reviews regarding risk assessment methods

Review Title	Reference
Mechanisms for assessing food safety risk	Manning and Soon, 2013
A Critical Review on Supply Chain Risk – Definition Measure	Heckmann, Comes and Nickel, 2014
Quantitative models for managing supply chain risks	Fahimnia et al., 2015
Supply Chain Risk Management : A Literature Review	Ho et al., 2015
Survey of supply chains risk assessment approaches	Rangel and Leite, 2015
How Mangaers perceive and assess Supply Chain Risks? Empirical Results from a Sample of European Organizations	Gaudenzi, Confente and Manuj, 2015
Method and approach mapping for agri-food supply chain risk management. A literature review	Septiani et al., 2016
The ISO 31000 standard in supply chain risk management	Olivera et al., 2017
Supply Chain Risk Assessment: A Content Analysis-Based Literature Review	Tran, Dobrovnik and Kummer, 2018

The main part of the identified reviews not only deal with risk assessment methods but also focus e.g. on risk classification (Fahimnia et al 2015; Ho et al. 2015), general methods in SCRM (Ho et al. 2015; Septiani et al. 2016), or the implementation process for risk assessment methods from a theoretical- and practical view (Gaudenzi, Cofente & Manuj 2015; Manning & Soon 2013; Rangel & Leite 2015). In comparison to these reviews the focus in this paper as well as the focus of the review by Tran, Dobrovnik and Kummer (2018) is set on risk assessment methods for practical use (Tran, Dobrovnik and Kummer 2018). This paper presents an application-specific selection procedure for risk assessment methods, which does not exist in literature, yet. One of the biggest advantages of this paper is, that the classification criteria for further assessment are based on several individual literature reviews, combined with a huge number of additional literature.

3 Classification Criteria for Risk Assessment Methods

The outcome of the research regarding classification criteria for risk assessment methods is structured and presented in chapter 3 to define the development elements for the selection procedure. Chapter 3 presents the basic components of the approach. Essential is the clear definition of characteristics of existing risk assessment methods to provide advice for a suitable method. The different methods must be viewed from various perspectives. The structure of chapter 3 (figure 1) supports this intention.

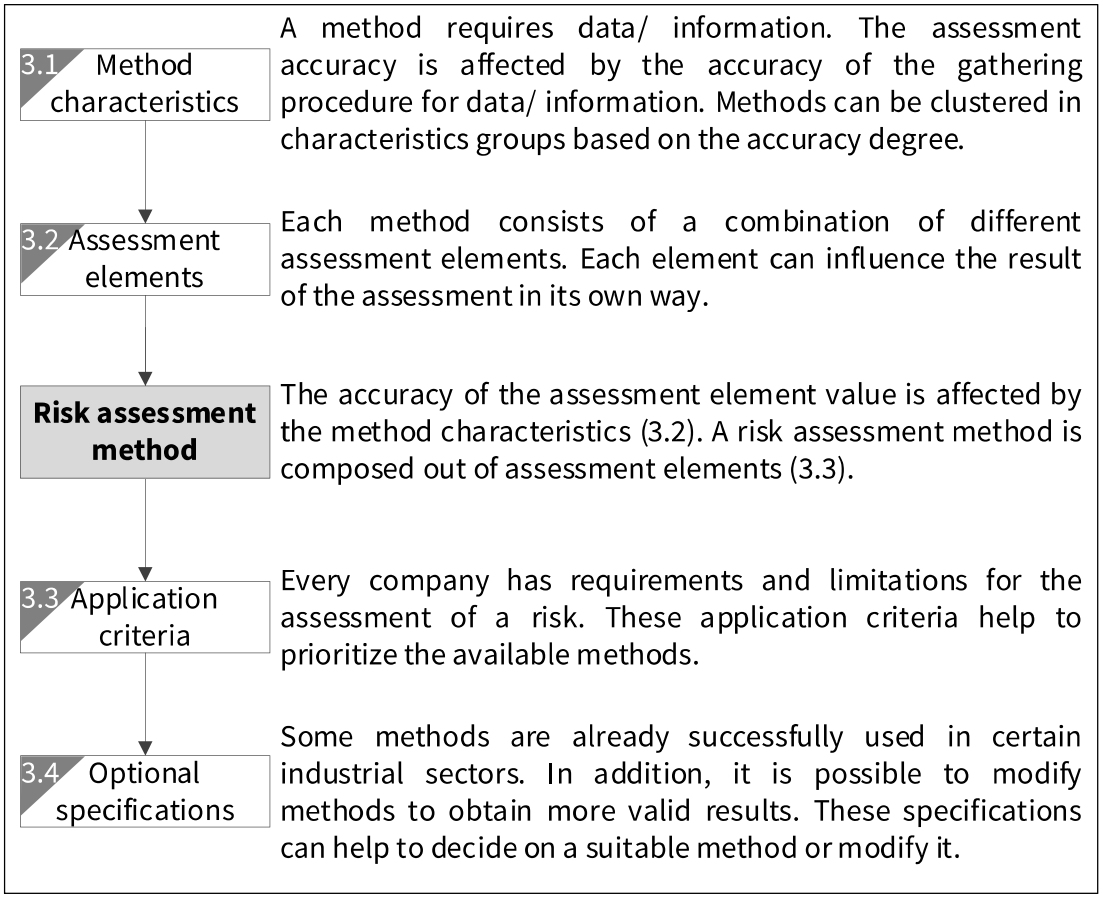


Figure 1: Structure of chapter 3

3.1 Method Characteristics

This chapter gives an insight into the characterization possibilities for the existing methods. The merge of the review characterizations is presented in the following figure.

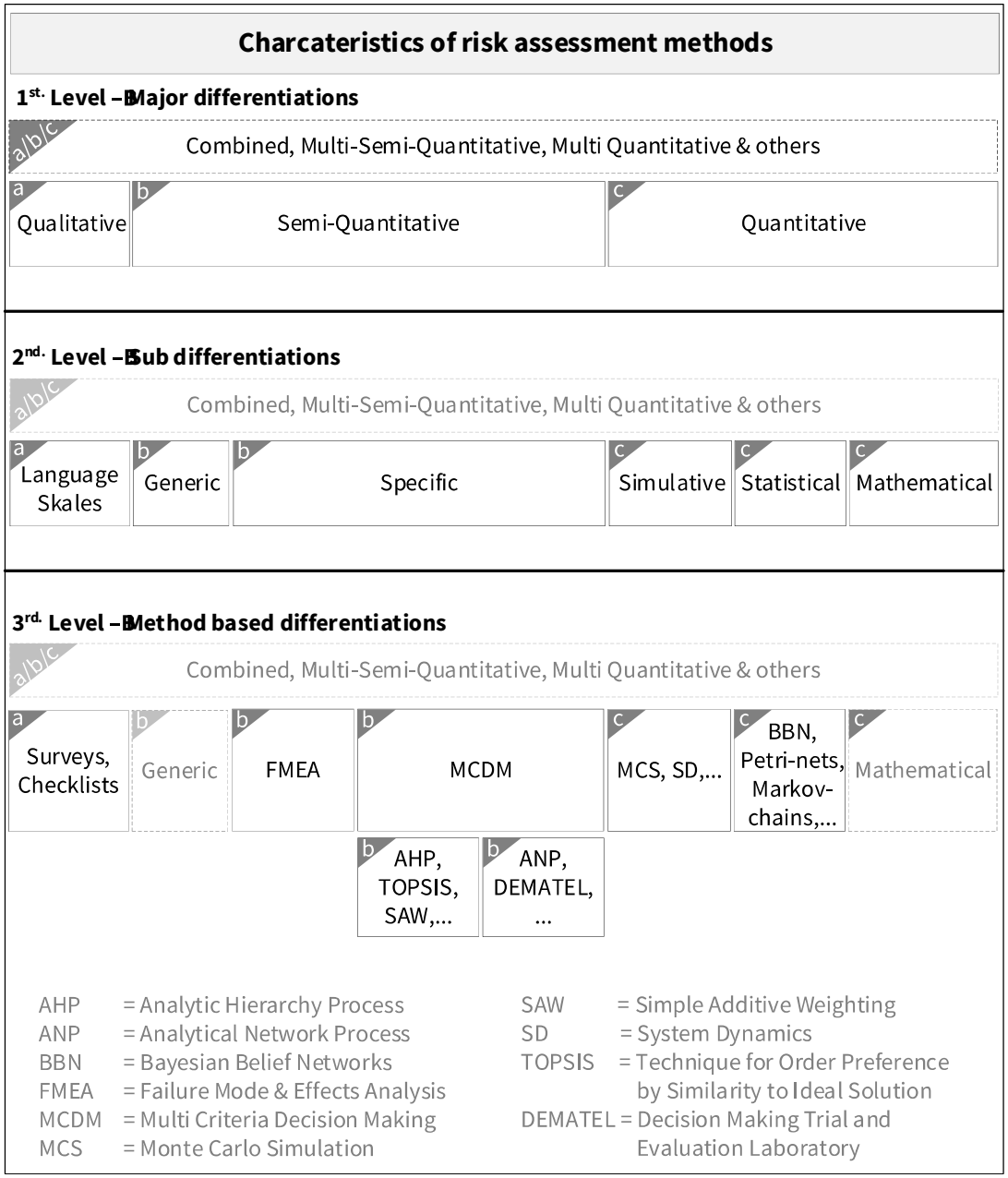


Figure 2: Overview of classified methods based on characteristics of risk assessment

Approach for Application-Specific Selection of Risk Assessment Methods

In the latest review, Tran, Dobrovnik and Kummer (2018) identified general approaches to risk assessment and SCR assessment methods. According to the scientific methodology, the identified methods are classified into qualitative, semi-quantitative, quantitative, and combined methods. (Tran, Dobrovnik and Kummer 2018) This classification covers the characteristics from most of the other reviews, and therefore, it is taken as the first differentiation level. Quantitative methods are further divided into simulative, statistical, or mathematical methods, whereby semi-quantitative methods are divided into generic and specific methods. Qualitative methods are not divided but described in more detail in levels two and three. The third level gives examples of the most common methods. In this level the methods may be further divided, in case a method contains subdivisions. If no further division is made in the third level, the category might not include common methods which fit for this universal approach. In some sources, further method modifications are presented but for the general overview, the characterization in the three levels is focused because the modifications are based on the presented approaches.

In qualitative methods, the risk assessment is carried out by verbal descriptions by language scales. Thus, risk assessment elements such as the probability of occurrence are estimated based on logical conclusions by experts or involved SC companies. (Neghab et al. 2011; Tran, Dobrovnik and Kummer 2018) Typical qualitative procedures are the execution of surveys and processing of checklists (Choong, Hamid and Chew 2018; Wildgoose, Brennan and Thompson 2012). There is limited room for action to get qualitative results, therefore, the variety of methods is low.

In addition to qualitative aspects, semi-quantitative methods also consider quantitative aspects (Manning and Soon 2013; Septiani et al 2016). A distinction can be made between generic- and specific methods. Based on quantitative methods, risk assessment is carried out using relative numbers in ordinal scales. The verbal scales are expressed by numbers. In generic methods, for example, the probability of occurrence is divided into very rare = 1, rare = 2, regular = 3 and often = 4. (Tummala and Schoenherr 2011) It follows that a ranking of risks is determined (Manning and Soon 2013; Tran, Dobrovnik and Kummer 2018). Next to the generic methods, specific methods are used to assess risks. A widespread specific semi-quantitative method is FMEA, in which, in addition to risk

identification, risks are evaluated by the probability of occurrence and detection, as well as the extent of damage. (Azambuja and Chen 2014; Bozdag et al. 2014; Kumar, Boice and Shepherd 2013) Normally a scale from 1 to 10 is used for the assessment (Bozdag et al. 2014). Furthermore, methods for risk prioritization like AHP, ANP, TOPSIS and other MCDM methods are used. (Cagliano et al. 2012; Ho et al. 2015; Rangel and Leite 2015)

Quantitative methods are used to evaluate risk elements systematically and analytically, for example with observations, theories and laws (Neghab et al. 2011; Tran, Dobrovnik and Kummer 2018). In contrast to qualitative methods, numerical scales form the basis and enable a more precise evaluation (Manning and Soon 2013; Tran, Dobrovnik and Kummer 2018). The extent of damage is assessed, for example, through financial losses and the probability of occurrence through data measured (Gisslen and Horndahl 2016; Landtsheer et al. 2017).

Further differentiation on quantitative risk assessment methods is possible in simulative-, statistical- and mathematical methods. Mathematical models describe formal relationships of variables, while statistical models like BBN, Petri nets, or Markov chains perform the risk assessment based on statistical distributions of the risk assessment elements. (Gisslen and Horndahl 2016; Kumar Sharma and Sharma 2015; Teerasoponpong and Sopadang 2016; Wan et al. 2013) With sufficient historical data, simulation models like MCS or SD are used to calculate the probability of occurrence and the extent of damage over time (Cagliano et al. 2012; Tuncel and Alpan 2010).

It is possible to combine methods like semi-quantitative and quantitative methods to minimize the disadvantages of individual approaches. Furthermore, the combination of semi-quantitative or quantitative methods is possible, which is called multi semi-quantitative or multi quantitative methods. (Käki, Salo and Talluri 2015; Kurniawan, Santoso and Kamal 2019; Lee, Yeung and Hong 2012; Marasova, Andrejiova and Grincova 2017; Nepal and Yadav 2015; Schaefer et al. 2019).

3.2 Assessment Elements

Chapter 3.2 deals with the focus of the different methods in terms of assessment elements which are used within the methods in order to assess a risk. The probability of occurrence, extent of damage, probability of detection, interaction between risks and the combination of risk assessment elements are taken into account, based on the most common elements used in the selected reviews (Tran, Dobrovnik and Kummer 2018; Heckmann, Comes and Nickel 2014; Rangel and Leite 2015). Figure 3 presents the chosen assessment elements and the individual allocation to the methods. The given overview can support SME in case the enterprises have already an idea about what kind of method elements and -characteristics would fit in their initial situation. A selection based on this level requires existing knowledge in risk assessment because the methods are divided based on their attributes and not on user requirements.

Method Lvl. 1	Quali-tative	Semi Quantitative			Quantitative		
Character-istics Lvl. 2	Language Skales	Generic	Specific		Simulative	Statistical	Mathematical
Risk Assess-ment Elements Lvl. 3	Survey, Checklist		FMEA	MCDM (AHP, ANP,...)	MCS, SD,..	BBN, Petri-nets,..	
Probability of occurence	X	X	X	X	X	X	X
Extent of damage	X	X	X	X	X	X	X
Probability of detection	X	X	X	X	X	X	
Interaction				X (ANP)	X	X	X
Combination (RI=1, RPN=2, Others=3)	X (1)	X (1)	X (2/3)	X (1/2/3)	X (1/2/3)	X (1/2/3)	X (1/2/3)

Figure 3: Connection between risk assessment characteristics and risk assessment elements

3.3 Application Criteria

To focus the user view within risk assessment and support the user perspective, it is important to understand what kind of criteria the user would have in mind to differentiate the existing methods and choosing the right one for the initial situation of the own SME. In this paper, these criteria are called application criteria because the focus is set on the input the company must give to get valid output.

This paper works with general application criteria, which fit most of the user requirements to simplify the procedure and to create a standard. Based on the research of the DIN ISO 31010 (2010) as an international standard as well as an empirical survey of enterprises by Ziegenbein (2007), the five application criteria usability, specific IT-necessity, information- / data origin, resource effort, and output accuracy are derived (DIN ISO 31010 2010; Ziegenbein 2007).

In the following section, these criteria are further described. Next to the definition, it is mentioned, how each of these criteria could be divided into maturity levels. The application criteria are chosen in a way, which allows SME to evaluate methods with existing knowledge and with a limited degree of complexity. Furthermore, the exact maturity level is always slightly influenced by the individual situation of the method user, which calls for a standardized allocation in the first place. These are the reasons why the different maturity levels are indicated mainly with a low, medium, or high level. Dividing the methods into two to three categories is sufficient to guide a company during the first steps of choosing an appropriate application-specific risk assessment method. A more detailed evaluation would require more background information and know how, as well as a more time-consuming evaluation what is not the purpose of the pragmatic approach.

The usability describes the level of knowledge and experience required by users for applying the risk assessment methods (DIN ISO 31010 2010; Manning and Soon 2013). The more complex a method is, the lower is the level of usability.

Qualitative methods like surveys or checklists are classified as simple methods based on the procedure by questionnaires and verbal descriptions (DIN ISO 31010 2010; Manning and Soon 2013). Generic semi-quantitative methods and FMEA are also evaluated as

simple methods based on the evaluation of the risk assessment elements using verbal and associated quantitative scales (DIN ISO 31010 2010). This leads to a high usability. With MCDM methods like AHP or ANP, the valuation structure is more complex. The assessment of risks is also easy by pairwise comparisons using semi-quantitative scales, but the final prioritization of risks is done by algorithms, which require user input and advanced application knowledge. (Rangel, Oliveira and Leite 2015) This leads to a medium usability. The usability of quantitative methods is classified as low, since users need mathematical, statistical, or simulation skills to apply the methods (DIN ISO 31010 2010; Manning and Soon 2013).

Regarding the IT necessity of the methods, a distinction is made between basic programs such as MS Office and specific software. Qualitative methods, generic semi-quantitative methods, FMEA, AHP, and ANP and mathematical methods usually require standard MS Office products such as Word and Excel, whereas for methods using simulations and statistics, specific software is recommended instead.

The origin of the required information can have an influence on the decision for a risk assessment method. Some companies generate a huge amount of data in their processes, and can therefore use methods, which require a good historical- or real-time data basis. Other companies do not have this opportunity and need to use methods with low data requirements. Qualitative data are primary data from interviews and questionnaires as well as secondary data from the literature. In the case of qualitative methods, the data can be collected e.g. by interviewing external academic- or industrial experts (Markmann et al. 2013; MeiDan et al. 2011) or internal SC participants, especially managers (Tran, Dobrovnik and Kummer 2018; Venkatesh, Rathi and Patwa 2015). Semi-quantitative methods assess risks based on experts, as well as mostly incomplete historical data. E.g. with group decision making, participants give their individual opinion, which is averaged over other opinions. (Khayyam and Herrou 2017) FMEA and AHP are useful methods when no representative data are available because identifying the risks with the greatest negative impact is often sufficient. The exact monetary value is not necessarily decisive. (Dong and Cooper 2016) Therefore, for qualitative and semi-quantitative risks, no exact historical data are required for risk assessment (Berle, Norstad and Asbjørnslett 2013; Manning and Soon 2013; Ziegenbein 2007). With

quantitative methods, the risk assessment is based on comprehensive data (Manning and Soon 2013; Ziegenbein 2007). This allows a precise assessment of the risks, as long as the data are correct. Access to the data is crucial, but not always possible. (Rangel and Leite 2015) Therefore, data are also obtained through simulation and statistical modelling (Berle, Norstad and Asbjørnslett 2013; Kumar Sharma and Sharma 2015). If necessary, expert estimations are also used for simulations to assume distributions, for example for the probability of occurrence (Berle, Nor-stad and Asbjørnslett 2013).

The resource effort is based on two dimensions: cost and time (DIN ISO 31010 2010). The cost and time effort for qualitative methods is low due to the conception, dissemination and result analysis of the survey compared to the other method groups. The method is quickly applied and evaluated at the discretion of the user. This is only given if questionnaires have an appropriate number of questions. Then the effort can be categorized as low. In addition, no further specialist knowledge is required during the preparation, which leads to no additional personnel costs for specialists. (DIN ISO 31010 2010; Manning and Soon 2013; Ziegenbein 2007) The resource effort for generic semi-quantitative methods can also be implemented in a time-saving and cost-effective manner by evaluating expert statements on the risks (Rangel and Leite 2015, p.6). The application of FMEA is conceptual due to the detailed decomposition of processes into failure modes and identification of control measures, therefore, time-consuming. Since the usability for the employees who work with this kind of methods is high, the need for additional expert expertise is lower. The increased time-consumption combined with the high usability and relatively low additional costs for specialized staff leads to a medium resource level (DIN ISO 31010 2010; Ghadge et al. 2017; Neghab et al. 2011). AHP is also more time-consuming due to the extended application knowledge, but the costs and personnel expenditure are relatively low as well, resulting in a medium resource effort level. With quantitative methods, the modeling of risks is associated with mathematical, statistical, and simulation knowledge, which results in increased time and personnel expenditure. Due to increased personnel effort and the necessary software, the time and costs of quantitative methods are high. (DIN ISO 31010 2010; Manning and Soon 2013; Neghab et al. 2011; Rangel and Leite 2015; Ziegenbein 2007)

Based on the data basis and the properties of the methods, the accuracy of the evaluation can be derived. Both qualitative and generic semi-quantitative methods make mainly use of the assessment of experts, taking into account little to nonconcrete data according to a less systematic procedure, therefore, provide a low output accuracy compared to quantitative risk assessment procedures. (Rangel and Leite 2015; Ziegenbein 2007) Semi-quantitative methods such as FMEA, AHP, or ANP follow a systematic and holistic approach, and the risks are compared with each other. The data are based on experts as well as partly incomplete historical data in FMEA. As a result, these methods are classified as medium. If a simulation is used as a quantitative method, a variance of scenarios can be evaluated. In addition, historical data are considered, and risks are assessed analytically. This results in a high degree of output accuracy. (Vilko and Hallikas 2012, p.592) The output accuracy of mathematical and statistical methods is also high due to the consideration of analytical principles based on historical data. (Ziegenbein 2007) Figure 4 presents the rating of the application criteria.

Method Lvl. 1	Qualitative	Semi Quantitative			Quantitative		
Characteristics Lvl. 2	Language Skales	Generic	Specific		Simulative	Statistical	Mathematical
Application Criteria Lvl. 3	Survey, Checklist		FMEA	MCDM (AHP, ANP,...)	MCS, SD,..	BBN, Petri-nets,..	
Usability	High	High	High	Medium	Low	Low	Low
Specific IT-Necessity	No	No	No	No	Yes	Yes	No
Information-/ Data Origin	Experts	Experts	Experts / Data	Experts / Data	Experts / Data	Data	Data
Resource Effort	Low	Low	Medium	Medium	High	High	High
Output Accuracy	Low	Low	Medium	Medium	High	High	High

Figure 4: Rating of the application criteria regarding risk assessment methods

3.4 Further Optional Criteria and Modifications

Next to the described criteria in Chapter 3.1 to 3.3 there exist sub criteria. These criteria can support the decision making for a risk assessment method after using the main criteria or support the output quality of the method itself. They are presented as optional selection criteria since it is not advisable to choose methods with these criteria in the first place. Some methods are proven in certain industries or for some specific risks. Sub criteria which can support the output quality of the methods itself are modifications in terms of numerical basis and assessment weighting.

Various articles dealing with risk assessment refer to specific industrial sectors or kinds of risks. In general, the application of the assessment methods is mostly independent of the industry sector or specific risks. However, a method already proven in the same industry or for similar risks might have a higher potential to fit for the own SME.

To use the advantages of different methods as well as to compensate for disadvantages, the presented methodological approaches can be modified (Tran et al. 2018). Using modifications, an extended number basis for semi-quantitative and quantitative methods or weighting factors for qualitative or semi-quantitative methods are used.

For the methods presented in the previous chapter 3.1, the risk assessment is performed by using natural numbers. Since the risk assessment, especially by expert assessments, has a certain subjectivity, which can cause inaccuracy, the number basis is expanded. Examples for that can be using fuzzy sets, grey sets, rough number sets, or others.

Next to the number systems also weighting factors can influence the output accuracy. The subjectivity of expert assessments in semi-quantitative methods reduces the accuracy of the assessment. By interviewing several experts and weighting the results, higher objectivity, and thus, higher output accuracy is achieved.

4 Application-Specific Selection Procedure

Chapter 4 presents risk assessment methods including a differentiation in categories. Figure 5 presents the main selection procedure. It includes five steps, to select a suitable method. In addition, optional selection steps are mentioned. These optional steps can help if the main selection procedure does not yield sufficient results.

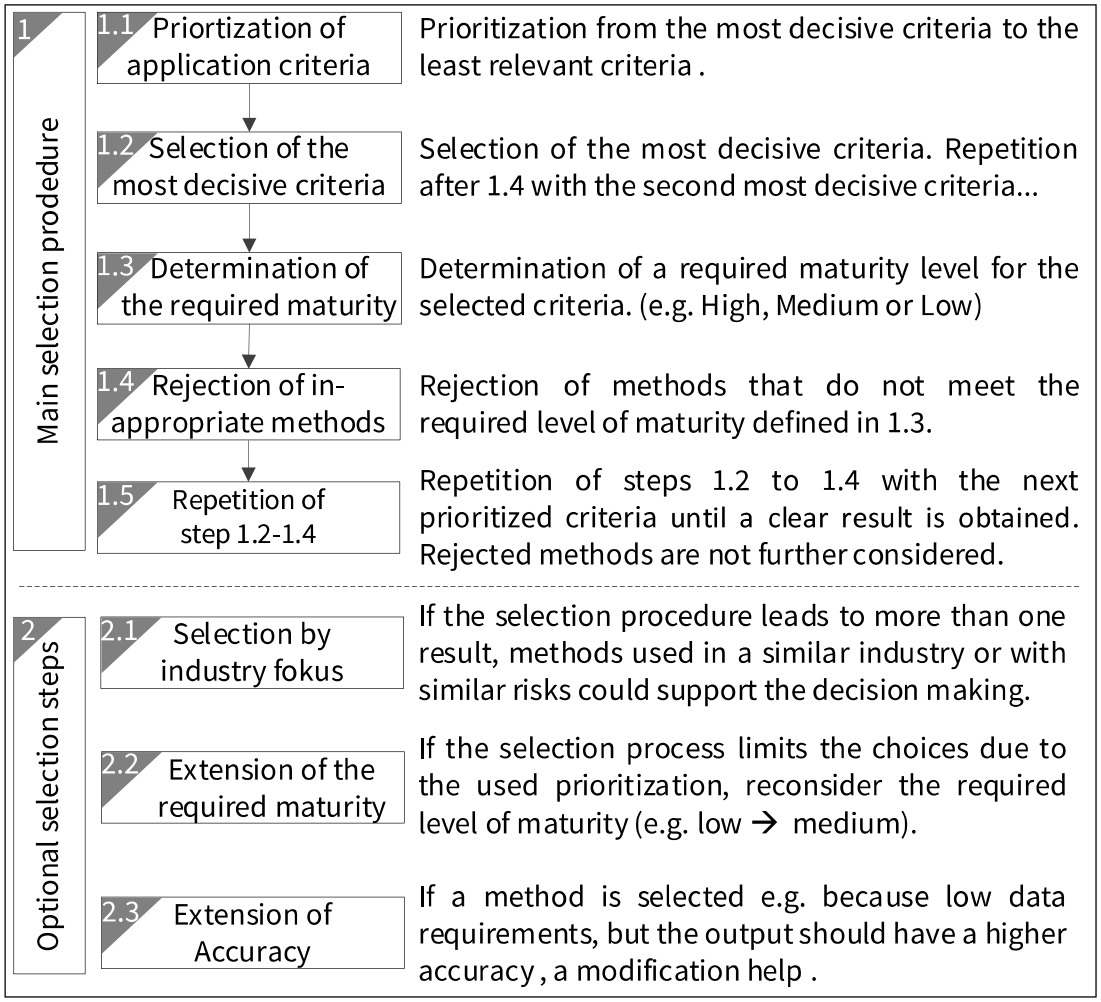


Figure 5: Selection procedure for identifying a suitable risk assessment method

To perform the selection procedure, Figure 6 gives an overview of the selection options.

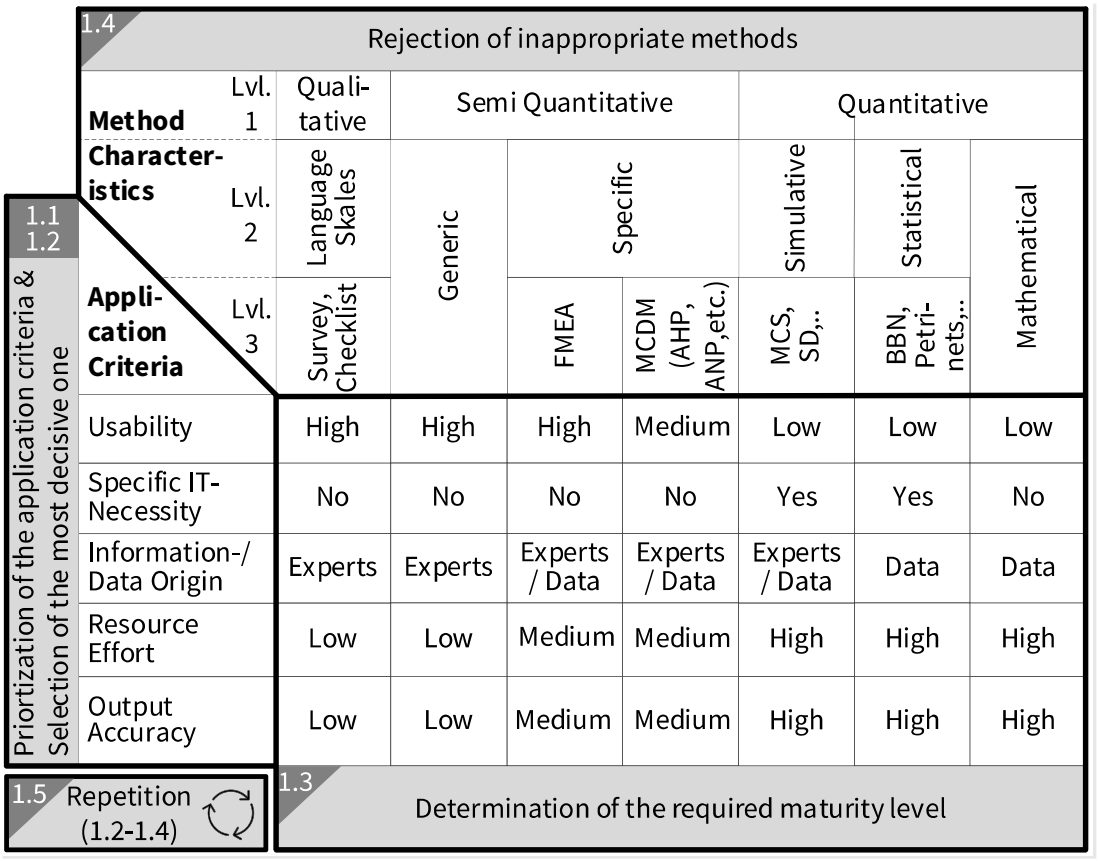


Figure 6: Visualization of the selection procedure steps

This figure helps to follow the selection procedure. In general, it is an allocation between the characteristics of the methods, including specific methods discussed in chapter 3.1 and the application criteria presented in chapter 3.3. Additionally, figure 6 highlights the main selection procedure steps 1.1 to 1.5. Since the selected application criteria will not be changed again for the further process, step five just includes the repetition of steps 1.2 to 1.4 with the following application criteria. This should help to raise knowledge regarding the common risk assessment methods by five application criteria. Furthermore, this approach supports companies in choosing the most suitable method.To avoid misunderstanding of the procedure, a short example is given: A fictive SME needs to deal with risks during the last months and decides to implement an assessment method to set a prioritization. First the management prioritizes the

application criteria. Since the SME has no experts regarding simulation or statistical tools and has just access to MS Office, the company decides, that methods with requirements for specific IT-tools should be rejected. That means for the application criteria “Specific IT-Necessity” all simulative and statistical methods are rejected. In this case, the urgency for acting regarding risk reduction is high, that is why the implementation of a method should be possible within a short time frame with low or at least medium effort. Based on the “Resource Effort” these requirements lead to a rejection of mathematical methods, due to the high resource effort. From now on, all quantitative methods are rejected.

For the selection of the third application criteria, the SME chooses the “Output Accuracy”, as some of the risks can cause huge losses, and the company wants valid results. Because the methods with the high level of output accuracy are already sorted out, only low and medium ranked methods are left. The company chooses the medium level methods and rejects the low-level methods. That results in a rejection of all qualitative methods as well as generic semi-quantitative methods. For the remaining methods, the criteria information-/ data origin is on the same level. That is why this criterion is not helpful for decision making.

The last criterion is usability, and since the company has time pressure and no experts for specific methods, the company selects the methods with a high level of usability. That leads to a decision for the specific semi-quantitative method called FMEA.

The SME should now gain know-how about this method. If the output accuracy will not fit the expectations, there is the opportunity to modify the method or combine with other methods. By following this procedure companies should get an idea about categories of risk assessment methods down to specific methods which should fit for the individual needs. To reduce the risk a company selects a wrong method based on individual personal decisions regarding the prioritization of the application criteria, the procedure should be executed by a selected group of relevant employees or should be done several times by slightly changing the prioritization and comparing the outcome. In case the result is still the same, the chance that the method will fit to the companies requirements is high. In case more than one method is the outcome the company should take both

methods into account for the further evaluation and make a decision after a detailed insight.

5 Conclusion

Risk management moves into the focus of many companies, e.g. due to increasing vulnerability and complexity, within the SC. The management of these risks becomes a critical capability of successful companies. Despite the wealth of research, some areas are not sufficiently revealed, yet. One research gap is the missing focus on SME and ways how these companies can identify the most suitable methods for their individual circumstances and needs regarding risk assessment.

This paper supports SME with the decision making for a suitable risk assessment method, even when the know-how regarding risk assessment in general and especially the existing methods is quite low. The developed procedure is supposed to lower the obstacles, companies encounter regarding the implementation of risk management in general.

The output enables an analysis of the methods in several ways. The aim of this analysis is to find criteria and characteristics which help to differentiate the methods for application-specific situations. Next to general characteristics like qualitative or quantitative methods, the included assessment elements like the probability of occurrence or the extent of damage are evaluated for each method or method group. Since these characteristics are still difficult for companies to relate to their individual needs, application criteria like usability level, specific IT-necessity or information- / data origin are chosen for the selection. At the end, a procedure is developed to present a way of using the application criteria to select the suitable risk assessment method.

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Impacts of the COVID-19 crisis on Inland Navigation

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Purpose: *The goal of this paper is to provide initial insights into the impacts of the COVID-19 crisis on inland navigation on both freight and passenger transport. It creates a starting point for further research and supports practitioners to prepare for future crisis situations.*

Methodology: *After a review of the literature, we prepared an interview guideline and conducted ten interviews with experts from the inland waterway transport (IWT) sector (i.e. freight and passenger transport). The interviews were coded and analysed using MAXQDA software. After the content analysis following the approach of Mayring (2014) we discussed the results and derived future research needs.*

Findings: *The COVID-19 crisis has both, positive and negative impacts on inland navigation. The inland navigation sector was affected by a reduction of transport volumes, the suspension of the passenger transport and requirements for crew changes or arbitrary regulations. A positive impact is that IWT is perceived as a reliable transport mode and customer bonding increased.*

Originality: *This paper shows initial impacts of the COVID-19 crisis for the inland navigation sector for freight and passenger transport. It provides future research needs which serve as a starting point to conduct in-depth analysis of individual impacts of the crisis.*

First received: 13. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Crises disrupt entire societies and are often accompanied by worldwide impacts (Farazmand, 2018). In general, crises lead to negative impacts such as a reduction in economic performance (i.e., GDP). The transport sector is usually hit by crises, as it correlates with GDP (Moschovou & Tyrinopoulos, 2018). Transportation is essential for supplying the population with their daily needs, such as food or medicine (Gray, 2020). Panic buying, which caused a worldwide stir at the beginning of the COVID-19 crisis, emphasized the importance of functioning supply chains and transport systems (Islam et al., 2021). Transport systems enable and support a wide range of activities, such as commuting to work, supplying households and businesses with energy and transporting goods to production sites or distribution centres. Therefore, they are essential for a functioning economy (Rodrigue et al., 2013).

Freight and passenger transport are carried out by different transport modes, such as railway, road or inland waterways. IWT is an environmentally friendly transport mode (Fastenbauer et al., 2019) that must be promoted more, according to the European Green Deal. According to the goals of the European Green Deal, the modal share of IWT in Europe should see a 50% increase by 2050 (COM(2019) 640 final, 2019). To achieve an increase of the modal share, it is important to demonstrate the reliability and crisis resilience of the transport mode. In our paper we will focus both on impacts and on strengths and weaknesses of IWT during the COVID-19 crisis, as this knowledge about strengths and weaknesses is essential to increase crisis resilience (Borca et al., 2021).

The goal of this paper is to provide initial insights into the impacts of the COVID-19 crisis on inland navigation for both freight and passenger transport. The research question guiding this paper is: RQ (1): How did the COVID-19 crisis impact freight and passenger transport using inland waterways?

The paper is structured as follows: after the introductory part, a theoretical framework is provided. Section 3 continues with the methodological approach of this paper, followed by results and discussion in section 4. The last section 5 will provide conclusions, theoretical and managerial contributions as well as the limitations of this paper.

2 Theoretical background

Borio (2020) describes the COVID-19 crisis using three words: uncertain, global and exogenous, meaning that it has not evolved due to previous financial imbalances. According to the definition by Sawada et al. (2011) the COVID-19 crisis is a natural crisis, meaning that its appearance did not involve any human action. As the COVID-19 crisis evolved due to the virus spreading it affected the majority of the world (Bambra et al., 2020; Borio, 2020; Moreira & Hick, 2021). Furthermore, several uncertainties, such as the speed of disease transmission or the incubation period, accompanied the beginning of the COVID-19 crisis (Kimhi et al., 2020). In order to protect peoples' lives from the virus, rapid initial actions were essential (Moreira & Hick, 2021). These actions differed between regions with measures being more or less strict (Bambra et al., 2020). Actions which were taken during a crisis are called a crisis response and represent a major part of a typical crisis management cycle (Fakhruddin et al., 2020).

Crisis management is generally carried out in four phases: (1) mitigation and prevention (2) preparation (3) response and (4) recovery (Fakhruddin et al., 2020; Spiekermann et al., 2015). The (1) mitigation and prevention phase is characterized by trying to avoid the occurrence of a crisis (prevention) and by taking measures, which help to minimize highly negative impacts of a crisis, before it occurred (mitigation). In the (2) preparation phase disaster plans are prepared to plan and optimize available resources and to agree on international collaboration. When the event occurs the (3) response phase starts and is considered the most important phase, which highly correlates with the other three phases. In the response phase actions take place to tackle the crisis in a coordinated way. The (4) recovery phase plays an important role, summarizing information from the entities involved which is used to help improve the preparation and response in future crises (Coccolini et al., 2020). If the response to a crisis (3) is inappropriate or important resources are missing, a natural crisis can lead to financial or social crises (Bambra et al., 2020).

Several uncertainties, the global spread of the virus, as well as the exogeneity of this crisis (Borio, 2020), are the reasons for the high degree of unpreparedness demonstrated by the bodies involved (Coccolini et al., 2020). This unpreparedness caused a shift in the

crisis management cycle: The cycle began with (3) response, followed by (4) recovery (1) mitigation and (2) preparation (Fakhruddin et al., 2020). As the COVID-19 crisis emerged due to a virus spreading which occurred in several waves and regions, the (3) response and (4) recovery phases are mainly not linear, as with other natural crisis e.g. caused by flooding (Fakhruddin et al., 2020). Responding to an event without being prepared for it often leads to uncoordinated actions. Therefore, a more integrated approach is needed for future crises (Fakhruddin et al., 2020). To increase the understanding of the response and impacts of the COVID-19 crisis, we will compare our results to the (shifted) crisis management cycle and confirm or reject it from the IWT sector's point of view.

3 Methodology

To investigate the impacts of the COVID-19 crisis for IWT we used a qualitative research approach. Through this approach the information about specific societal problems in order to reveal impacts which can barely be measured quantitatively and to include the personal opinions of the experts, can be obtained. Therefore, we conducted problem-centred and semi-structured expert interviews according to Mayring (2014) for collecting the information. Problem-centred interviews are open, so the interviewed person is able to answer without selecting from given answer alternatives, allowing us to obtain a personal viewpoint about the problem in focus. Furthermore, the interviews are semi-structured, which means that an interview guideline exists, which facilitates the focus on the problem (Mayring, 2014). Figure 1 summarizes the methodological approach of Mayring (2014) used in this paper.



Figure 1: Methodological approach of this paper (according to Mayring (2014))

The interview guideline was categorized by time in the past, present and future. We developed the interview guideline in a team of researchers together with experts from the IWT industry. The interviews were carried out between October and December 2020 with Austrian, German and French experts in inland navigation. As we aimed to obtain information about the impacts of the COVID-19 crisis on passenger and freight transport, we choose interview partners from both sectors. We conducted in total ten interviews, five with experts from the freight transport sector and five with experts from the passenger transport sector. The interviews were carried out virtually using MS Teams or by phone.

The interviews were recorded and afterwards transcribed. For the evaluation of the interviews, we used the MAXQDA software, which allows us to code the transcripts. MAXQDA enables the download of the coded, summarized information from the transcripts into a MS Excel file. This MS Excel file facilitates the qualitative content analysis based on Mayring (2014). For the content analysis, a summative approach was applied. This is useful e.g., for making comparisons or deriving essential statements. The evaluation of the content required a category system. The interview guideline was structured according to categories allowing us to synthesize the essential aspects of the expert interviews. We used these categories for the category system of the content analysis and to structure the Results & Discussion section of this paper.

4 Results and Discussion

The results are clustered in four subsections: the first describes the interviewed experts and the remaining three subsections were defined according to the category system of the content analysis in the past, present and future of the COVID-19 crisis.

4.1 Interviewed experts

We interviewed five experts from the freight and five experts from the passenger transport sector of IWT. Table 1 summarizes the experts, the sector, the size and location of the company.

Table 1: Overview of interviewed experts

expert	sector	company size	company location
EFT #1	logistics service provider	small	Upper Austria
EFT #2	logistics service provider	small	Lower Austria
EFT #3	port operator	medium	Lower Austria
EFT #4	steel production	large	Upper Austria
EFT #5	compound feed production	medium	Upper Austria
EPT #1	Excursion traffic	small	Vienna
EPT #2	Excursion traffic	medium	Vienna
EPT #3	Excursion traffic	medium	Upper Austria
EPT #4	Cruise ship navigation	large	France
EPT #5	Danube Tourist Commission	small	Vienna

EPT = Expert passenger transport;
EFT = Expert freight transport

Two of the freight experts are managers of logistics service providers which are specialized in IWT, working for small companies in Upper and Lower Austria. Two

interviewees are managers of production companies which use IWT regularly for transportation: One expert is a logistics manager of a large steel production plant, the other is a procurement manager of a medium-sized compound feed producer and both are located in Upper Austria. The fifth expert is the manager of a medium-sized Danube ports operator, located in Lower Austria.

Three of the passenger transport experts are employed at companies which organize excursion trips for passengers on the Danube in Austria, Germany and Slovakia. One company is small, the other two are medium-sized, all three are located in Austria. One expert is a captain at a large French river cruising company and responsible for the Danube area. The fifth interviewed expert has been working for the Danube Tourist Commission located in Vienna, which is well informed about the development of passenger transport on the Danube in general and particularly during the COVID-19 crisis.

4.2 The past: before the beginning of the crisis until summer 2020

This subsection contains questions about general preparation for crises, about the first impacts of the crisis and about a modal shift to or from IWT.

Before the COVID-19 crisis

Besides one freight expert, the four freight experts and all passenger transport experts agreed that the preparation for a crisis such as the COVID-19 crisis is not possible at all or only possible to a very limited extent. Contingency plans are generally considered as helpful up to a certain point. In fact, experiences must be gained to be able to prepare for future crises caused by a virus spreading. Five out of ten experts evaluated their own level of preparedness for the COVID-19 crisis as medium up to high. They argued that, almost everything that could be done to prepare for such a large, unknown crisis was done.

Measures to be prepared for crises range from a plan for pandemics (EFT #4), having a broad range of customers to ensure independence and avoid dependencies on a single customer (EFT #3). Another measure is to build monetary reserves to bridge the crisis to a certain extent (EPT #1 and #2). The other experts, two from logistics service providers

and three from passenger shipping companies claimed that preparation for the COVID-19 crisis was impossible taking in account their sector.

Regarding the extent to which companies were prepared for crises in general, a difference can be observed between shippers and freight/passenger transport companies: Shippers are basically prepared for different crises (e.g. by having crises plans or even designated teams) (EFT #4 and 5). In contrast logistics service providers (EFT #1 and 2) and passenger shipping companies (EPT #1-4) are primarily prepared for shorter-term unwelcome events, which appear at short notice, e.g. high or low water. Transport companies use so-called contingency to prepare for these unwelcome events. These plans include things such as possible route or programme changes in case a route cannot be operated due to disruptions.

Beginning of the COVID-19 crisis

Freight transport

The first impacts of the crisis hit the IWT sector in March 2020 with the general worldwide impact of a decline in global GDP. Besides the general decline in the demand for goods, the demand for certain areas increased. Two of the five experts reported positive impacts at the beginning of the crisis due to a higher demand for certain transports and services (EFT #1 and 3). In particular, RoRo (Roll-on/Roll-off) services (i.e. services which transport motorized vehicles e.g. cars and trucks by IWT) offered on the Danube were increasingly requested to avoid the border waiting times across Eastern Europe. Instead of travelling by truck to Romania or Bulgaria, the trucks were transported by vessel to a Romanian or Bulgarian port and from there travelled to the final destination (EFT #1)

Ports reported positive impacts from an increase in the demand for storage space at ports and thus, a shift to IWT. The COVID-19 crisis had increased the frequency of panic buying by companies leading to a shortage of storage space. Therefore, companies needed to rent additional storage space. Some companies which rented additional storage space at ports decided to transport goods by inland vessels, generating a higher demand for inland navigation (EFT #3).

In the steel industry, the demand for IWT declined at the beginning of the crisis. The decline was due to the weak order situation from the automotive industry. Some car

manufacturers plants in Europe were closed for a few weeks leading to a reduction in steel demand. (EFT #4) Panic buying had a negative impact on inland navigation, as raw materials were needed in a timely fashion for the production of goods. Therefore, instead of using the inland waterway vessel as usual, trucks were used for transport due to the higher transport speed (EFT #5). In general, IWT was perceived as a reliable transport mode, primarily because of its high availability (EFT #4 and 5).

The logistics service provider EFT #2 confirmed that there were generally less inland waterway transports at the beginning of the crisis. On the one hand the decline in IWT was due to a reduction in transport demand, and on the other hand it was due to arbitrary regulations. At the beginning of the crisis, there were different regulations per country leading to waiting times at borders. Besides national regulations, port operators, decided on their own regulations, with some ports reducing to one shift or to limit ship handling to daylight hours (EFT #2).

A major problem for both, freight and passenger transport was the change of crews. Usually, crews are changed every two weeks. At the beginning of the crisis, there were cases where crews remained on the vessel for two months because it seemed impossible to change crews due to the quarantine guidelines (EFT #2)

Passenger Transport

While freight transport suffered from lower transport demand, passenger shipping was affected much worse at the beginning of the crisis. Due to a decision by the federal government, passenger shipping was suspended for about three months. The official suspension of passenger shipping had varying degrees of influence on passenger shipping companies. EPT #3 reported, for example, that shipping was seasonally suspended over the winter before the crisis began, meaning that the official suspension of shipping in March 2020 hit them even harder, as the new season was supposed to start that very month.

Even if the passenger shipping industry was hit hard by the sharp decline of passengers, they recorded a few positive impacts. The positive impacts vary from an increase in experience for a future crisis (EPT #2), time to optimise internal processes (EPT #3) and retrofit the vessels with special filters (EPT #1). EPT #1 mentioned that the crisis was used

to strengthen customer loyalty through the installation of special ozone filters, which continuously decontaminate all surfaces.

Passenger shipping companies reported that there were limitations in place, once passenger transport was allowed again. EPT #5, for example, reported limitations on the number of passengers and crew, in some cases only 50% of the maximum number of passengers and 50% of the crew were allowed on a vessel. Moreover, passenger shipping companies were increasingly forced to change routes or programmes, e.g. vessels were not allowed to berth with passengers in Budapest for a while. Due to the limitations, necessary programme changes and frequent cancellations by customers, some companies were forced to end the season prematurely because of a lack of profitability (EPT #4). The absence of foreign tourists is another major challenge for IWT. Moreover, customers are more careful with their money, and thus less willing to participate in an excursion or a river cruise, which is often pricey (EPT #1).

Passenger transport report negative impacts on crew and staff. On the one hand, a large number of the crew were released or put on short-time work and thus made insecure; on the other hand, the existing crew had to adhere to strict hygiene and quarantine measures. EPT #4 reported, that the crew had to be in quarantine on board ten days before the start of the cruise. EPT #3 had to stay in close contact with the released staff, because they were very uncertain about the future and partly lost faith in the company. Table 2 provides an overview of the impacts for freight and passenger transport of the COVID-19 crisis on IWT.

Table 2: Impacts of the COVID-19 crisis on inland navigation

	positive impacts	negative impacts
Freight transport	in some cases modal shift towards IWT noticeable IWT is perceived as reliable	decreased transport volume problems with crew changes different national regulations different regulations by stakeholder group (e.g., port operators)
Passenger transport	internal processes can be revised gain of know-how for a future crisis increased customer bonding	suspension of passenger transport by federal government in Austria limitations of passengers and crew route and programme changes absence of foreign tourists inland tourists are not willing to spend money on excursions many staff released or put on short-time work hard quarantine measures for remaining crew

The results of the expert interviews showed a high degree of correlation with the literature we discussed in the introduction. Preparation for this crisis was hardly possible (Coccolini, et al., 2020; Fakhruddin, Blanchard and Ragupathy, 2020), which most of the experts confirmed. This unpreparedness, paired with many uncertainties(Bambra, et al., 2020) and the need for rapid action (Moreira and Hick, 2021) led to the uncoordinated behaviour of responsible parties, as confirmed by EFT #2. Bambra, et al.(2020) mentioned that the measures differed between regions, which was supported by EFT #1, EFT#5 and EFT #2. The literature and the experts confirm the research of Fakhruddin, Blanchard and Ragupathy (2020), which stated that the crisis management cycle was shifted in this crisis

and therefore began with the response phase instead of the mitigation and preparation phase. Fakhruddin, Blanchard and Ragupathy (2020) pleaded for a more integrated approach in future crisis preparation, which would lead to a more coordinated response, both nationally and internationally. EFT #2 confirmed that, claiming that clear regulations eased the work a lot and are therefore essential.

Besides the negative impact, the COVID-19 crisis also had positive impacts on freight and passenger transport. It is encouraging that this crisis has partly led to a modal shift towards inland navigation, which is indispensable in reaching the goals of the European Green Deal. One of the goals of the European Green Deal is for the European Union to become climate-neutral by 2050 and in order to achieve this, it is essential to create a modal shift from road to the more sustainable transport modes of rail and IWT. Passenger transport was undoubtedly hit harder by the crisis than freight transport, since cruises were suspended completely for a few months. As passenger shipping has experienced a strong boom in recent years (CCNR, 2019), there was an opportunity for the companies to build up financial reserves to survive the crisis, which all experts from passenger shipping agreed with.

4.3 The present: autumn 2020

The present discusses the change of the impact from the beginning of the crisis regarding its intensity and whether any new effects became visible as the crisis progressed.

The development of impacts in freight transport varies greatly. EFT #4 found that the demand for steel products in certain segments has developed from very low to very high leading to an increase in the demand for IWT. The increased demand due to panic buying has decreased again and in the meantime, the demand has stabilized (EFT #5). The situation with storage capacities in warehouses has not changed since the beginning of the crisis; warehouse storage is still running at full capacity (EFT #3).

Logistics service providers are less optimistic about developments, in particular reaching pre-crisis transport volumes. EFT #1, who at the beginning of the crisis described themselves as profiteers of the crisis, now describe a very strong decline in transport volume. In some cases, entire trips were cancelled for economic reasons. As an

emergency measure the remaining goods were transported using trucks. EFT #2 spoke of a decline in transport volume, but notes that the other negative impact concerning the regulations has been solved. At the moment, they are trying to avoid situations that are legally uncertain, e.g. changing crews on Hungarian territory and they are relying on the Danube Commission to sort these situations out for good.

For freight transport using IWT it is of major importance that sectors which transport a large amount of goods via the waterway show positive developments. That applies to the steel industry, since over 40% of the transported goods on the Austrian Danube are associated with this sector (via donau, 2018). The demand of other sectors stabilised or has not recovered yet. This is an excellent example, which demonstrates the importance of dividing the transport volume of a transport mode into various cargo segments. The division into cargo segments helps to find the critical factors and is useful for a better prognosis of further developments (Maresch, 2021). The statements of the experts showed how volatile and changing a crisis can be. Often companies are struggling to deal with volatility, as volatility often increases the complexity within corporate operations (Nürk, 2019), which makes the handling of a crisis even more difficult.

Three experts in passenger transport reported that they are running cruises in the autumn, but due to a lack of tourists and severe COVID-19 measures they had far fewer passenger than in prior years. EPT #3 added, that their company usually organized major events, such as company events or festivities along the Danube, which were cancelled due to the crisis. For the moment, the five experts reported negative development of the impacts, since passenger shipping has been suspended again for a certain period.

Up until now, the crisis has been progressing and its actions are much better coordinated than at the beginning, where the crisis hit the unprepared sector (Fakhruddin, Blanchard and Ragupathy, 2020). The first ‚recovery phase' began in early summer after most European countries prevailed over the first wave of the pandemic (Zhang, et al., 2021), which was followed by a new preparation phase for the next wave. This new preparation phase helped to improve the cooperation between authorities and improve the regulations (EFT #2).

4.4 The future: since winter 2020/2021

Freight shipping experts are more optimistic than the passenger shipping experts about the recovery from the COVID-19 crisis. While freight experts expect that a recovery from the crisis will occur in up to 12 months, the passenger experts rather assume up to 24 months.

Lessons learned

When it comes to the lessons learned from the crisis, the freight shipping experts raised several issues: It is important to diversify customers to avoid dependencies (EFT #1 and EFT #3). An honest and targeted exchange of information with customers and employees is essential to strengthen customer and employee loyalty. Moreover, contingency plans are useful, and it has to be ensured that employees are able to deal with these plans (EFT #5). The crisis has made people realize how essential the work of organisations such as Pro Danube International or the Danube Commission is to represent the interests of IWT (EFT #2).

An important measure is to raise awareness for contingency plans among the staff, since it is not sufficient to develop contingency plans in a particular team without integrating the employees (EFT #5). A good way to practice this is with the help of gamification. Gamification may help to retain the knowledge for a longer period (Putz, et al., 2018) and is able to improve problem solving skills (Lee and Hammer, 2011), which is particularly useful in times of crisis. By gamification we mean the use of game-design elements in a non-game-system context (Treiblmaier, Putz and Lowry, 2018).

The experts in passenger shipping learned from the crisis to be more cautious with investments in new buildings and to build up a stable financial reserve. Moreover, it is essential to also calculate profitability at the level of individual journeys (EPT #2).

Strengths & weaknesses

The answers varied regarding the strengths of IWT during times of crisis. Some experts emphasized the reliability of IWT, which was observed during the crisis (EFT #2 and EFT #5). Others added that spare capacities are particularly relevant for shippers and that the lack of border waiting times represents a great advantage (EFT #4). In addition, the mass

transmission capability and the low-cost transport of IWT were emphasised. The passenger shipping experts added flexibility in programme planning as a strength of passenger shipping during the crisis.

Experts evaluated the dependency on tourists and the more difficult crew changes as a major weakness of IWT during the crisis. The two experts from the production industry added the lack of responsiveness due to the long transport times and criticized the lack of unity in the inland navigation community. From the perspective of passenger shipping, the major weakness were local ties, which means that starting a cruise from a non-home port is associated with high costs.

The experts in the freight shipping sector were more optimistic than the experts in the passenger shipping sector about how long it would take for the recovery from the crisis. However, since passenger shipping experienced a boom several years before the crisis (Fastenbauer, et al., 2019), it might be possible that the positive trend will continue after the crisis. The literature on freight transport revealed that the recovery from crises can sometimes be very lengthy. The recovery from the 2008 financial crisis, for example, took many years and was not completely finished before the COVID-19 crisis emerged in some sectors (Chi and Baek, 2013; Islam, 2018).

Considering the strengths and weaknesses of IWT in this crisis, two experts observed the reliability of IWT as a strength and the slow transport speed and the low flexibility as a major weakness (EFT#4 & 5). Indeed, these qualities (i.e. speed and flexibility) were essential in this crisis. Thus, road transport has advantages over other modes of transport in this crisis due to its speed, flexibility and the possibility of door-to-door transport. It should be noted that each crisis is different and therefore other characteristics of transport modes become important. E.g. in the financial crisis, the transport price was important, which gave IWT an advantage compared to the other transport modes(Maresch, 2021).

5 Conclusions

The aim of this paper was to identify the impact of the COVID-19 crisis on freight and passenger inland waterway transport (IWT), as well as to identify the strengths and weaknesses of IWT during the COVID-19 crisis. We used qualitative research and conducted ten expert interviews with five experts from passenger and freight transport respectively. The results showed both positive and negative impacts of the COVID-19 crisis on the freight and the passenger IWT sector.

Besides the general worldwide reduction of transport demand resulting in a reduced transport volume on waterways, other negative impacts on IWT were largely due to inconsistent regulations on an international basis. These inconsistent regulations for changing crews or quarantine measures complicated the daily work of freight and passenger shipping companies. Additionally, major ports limited their working hours, which impacted IWT negatively. Due to panic buying and the resulting increase in production volumes, transport speed became a priority for many companies. To deliver products fast, particularly within countries, meant that road transport was the preferred option for transport, rather than IWT, which caused a reduction in demand for IWT.

A positive impact was the higher demand for IWT at the beginning of the COVID-19 crisis due to a higher demand for RoRo transports in order to avoid border waiting times. Another reason for an increased use of IWT was the use of storage spaces at ports. Companies which rented additional storage space decided to use the close-by waterway and transport their freight using IWT, generating growing demand for IWT. Moreover, IWT was perceived as an overall reliable transport mode, as the availability was excellent throughout the crisis.

Passenger transport suffered tremendous losses due to the governmental decision to suspend traffic for several months. When passenger traffic was allowed again, the lack of foreign tourists and the cancellation of events increased the financial losses. Limitations regarding the maximum number of passengers and crew members permitted on vessels, the different regulations and the lack of foreign tourists forced many passenger transport companies to end the season prematurely.

Hardly any positive effects were observed for passenger transport. Experts named an increase in experience and know-how for future crises and the possibility to analyse and optimize internal processes as positive impacts. Furthermore, in some cases the crisis led to an increased bond with customers.

When considering the strengths and weaknesses of IWT, reliability as a strength and the lack of flexibility and low transport speed as weaknesses were perceived as the most present during the COVID-19 crisis. Road transport, which offers a higher degree of flexibility and speed, was preferred for many products rather than IWT. Another major weakness is the lack of unity in the inland navigation community, in particular on an international basis. Indeed, the crisis demonstrated the need for international collaboration to deliver an appropriate crisis response for the IWT sector.

With our paper, we provide insights for the scientific community as well as the freight and the passenger shipping sector. This study gives an overview of the impacts of the COVID-19 crisis on IWT, which can be used to better anticipate or assess the impacts of future crises and thus may help practitioners to prepare for a future crisis by, for example, installing an appropriate crisis management structure. Furthermore, our paper serves as a starting point for further in-depth research and evaluation of the COVID-19 crisis. Further research can focus on the analysis of quantitative, statistical data to identify the fluctuations in transport volumes during the crisis and compare the transport modes to identify patterns and create foresights. Several limitations exist for our paper, leading to the need for further research options. First, our research findings were limited to the information gathered within the expert interviews. This is a rather limited view and could be expanded for future research. Second, our research focuses mainly on Austria, which is expandable as well. Third, the interviews were carried out within a specific timespan.

Acknowledgements

This paper is part of the research project REWWay, which was funded by via donau.

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Simultaneous Treatment of Risk and Resilience

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Purpose: *Supply chain management has a clear focus on risk management, but recent developments have shown that it is also important to pay attention to resilience. This paper introduces a systematic approach to simultaneously treat the two correlated quantities and can incorporate various notations of risk and resilience.*

Methodology: *A game theoretic model that allows simultaneous risk minimization and resilience maximation is proposed. Integration of existing supply chain risk and resilience measures is described to show its applicability. The intrinsic uncertainty of consequences of actions is explicitly taken into account by probabilistic payoffs.*

Findings: *The model provides a set of actions that provide optimal protection, depending the weight put on risk vs. resilience (i.e., how much weight is put on which of the two goals). The problem of putting such theoretical results into practice is discussed and illustrated with an example.*

Originality: *This work aims at improving existing best practice techniques to increase resilience by providing a systematic optimization method. It allows integration of existing resilience measures and is thus flexible to use.*

First received: 13. Apr 2021 *Revised: 29. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

Resilience has become a topic of high interest in the context of supply chains (Dubey et al., 2019). This is also due to recent incidents that caused disruption of flows, such as the NotPetya attack that heavily affected container logistics (Tills, 2018). The strong relation between risk and resilience is well-known, but a concrete description of the relation is very challenging to find. There are approaches that identify explicit relations when building a resilient supply chain (Wicher and Lenort, 2012) and approaches that use simulation to design a framework for risk, resilience, and performance (Macdonald et al., 2018). This paper uses a different approach that applies game theoretic methods to simultaneously optimize risk and resilience without the need to explicitly model the relation between the two quantities. The proposed method is very general in the sense that users can choose their own measures of risk and resilience to be used during the analysis. This increases both the willingness to apply the method and the understanding of the results.

The paper is organized as follows. Section 2 provides a short overview on risk and resilience in the context of supply chains, including some measures that may be used during the upcoming analysis. Section 3 describes how to set up the game theoretic model and how to perform the analysis. The approach is illustrated with a small example to demonstrate the workflow. Section 4 concludes with remarks on limitations and potential future directions.

2 Risk and Resilience in Supply Chains

This section summarizes different approaches of risk and resilience in supply chains (SCs), providing input to the optimization framework. Users are free to use their own risk and resilience measures but might like to have a look at current approaches and adapt their measures based on these.

2.1 Supply Chain Risk

A critical review on different definitions and measures of supply chain risk is provided in (Heckmann, Comes and Nickel, 2015) in order to close the gap in the literature regarding a definition of risk in the context of supply chain risk management. This review demonstrates that most authors work with informal concepts, and only few authors (less than 20%) use explicit definitions. While these explicit definitions all consider risk to be triggered by an event, the actual definitions differ. Some focus on probability and outcome, while others consider the deviation from expected behavior or the (in)ability to cope with consequences of an event. If an explicit definition is available, the next question is how to measure the defined risk. For example, if the likelihood of occurrence is part of the definition, the question is how to estimate the likelihood - quantitative based on empirical data or on quantitative based on expert assessment.

A more recent survey still states that so far there is no generally accepted definition of supply chain risk (Baryannis et al., 2019). Correspondingly, there are numerous measures of risk in the context of supply chain, depending on the perspective of the researcher, on the specific sector and on the circumstance, e.g., in light of the experiences during COVID-19 (Deaton and Deaton, 2020).

Existing supply chain risk definitions and measures are heterogeneous, not least due to adoption of approaches from related fields (Heckmann, Comes and Nickel, 2015). The game theoretic approach described in the following can integrate any of these concepts, but qualitative measures allow an intuitive understanding of the approach. The user is free to choose a risk definition and measure on his own, which should also increase the understanding of the results (which are described in terms of the chosen risk measure).

2.2 Supply Chain Resilience

The term resilience can be understood from various perspectives, and the understanding of resilience changes over time (de Bruijn et al., 2017). Resilience may focus on providing a certain level of service despite disruption, on recovery time after a shock, or on reaching a stable state over time. Resilience concepts may focus on specific threats (e.g., extreme weather conditions) or on all possible sources of disruptions, depending on the goal of

the analysis. In essence, most resilience concepts in the context of supply chains capture the ability of a system to recover from disruptions, but the ways to actually measure resilience differ a lot. A systematic review of supply chain and supply network resilience based on 84 studies has been conducted in (Datta, 2017), finding that detailed explanations are often missing.

In other domains, such as critical infrastructures, more precise concepts are available, but consensus is still missing. A finding of the EU Horizion 2020 project IMPROVER is that a crucial part of critical infrastructure resilience is the ability to provide a minimum level of service and quick recovery after a shock (Petersen et al., 2020). Supply chain resilience could be defined similarly. A more concrete measure is the resilience triangle proposed in (Bevilacqua, Ciarapica and Marcucci, 2017). This triangle is drawn by plotting the performance of the system after a disruption over time. The name stems from the fact that after a sharp drop in performance, the system steadily recovers during a certain time interval, so that the area above the curve has approximately the shape of a triangle.

The main challenges in addressing resilience, as in risk research, are uncertainties and interdependencies, and sparse data (Sun, Bocchini and Davison, 2018). Uncertainty and the increasing number of interdependencies hamper prediction, and limited availability of data limit the use of empirical methods. A decision support framework to assess supply chain resilience to disasters is presented in (Falasca, Zobel and Cook, 2008). The authors define resilience as the ability to reduce the probabilities of disruption and to reduce both the consequences of disruptions and the time to recover and measure these through three determinants (density, complexity and node criticality). These determinants are integrated in the resilience triangle, and the objective of the framework is to reduce the size of the triangle.

3 Optimization of Risk and Resilience

Considering risk and resilience optimization as a game between two players allows identification of strategies that simultaneously minimize risk and maximize resilience without the need to explicitly model the relation between risk and resilience. In the context of risk management, it is common to consider a worst-case scenario where the

attacker tries to cause as much damage as possible (Monga and Zhu, 2016). The main contribution of this paper is such a zero-sum game model. The approach is described on a high level in the next subsection and applied afterwards.

3.1 Methodology

On a high level, protecting a system can be regarded as a game between a defender, i.e., the operator or authorities, who wants to protect the system and an attacker that tries to cause damage to the system. The key components of the model are

- Strategies for the defender (player 1) and the attacker (player 2). For the defender, this includes all countermeasures that reduce risk and increase resilience, while for the attacker, the list includes events that threaten the system.
- For each pair of defense and attack strategy the payoffs need to be estimated for each goal, i.e., risk and resilience need to be evaluated for each scenario.

Digitalization has increased the complexity of such kind of analysis, since a precise prediction of a system's reaction is almost impossible. Therefore, classical game theory can be extended such that it allows distribution-valued payoffs rather than real-valued payoffs (Rass, König and Schauer, 2015). This way, the user no longer needs to provide crisp estimates of the quantity of interest but can provide his believes over various values. In order to keep the approach practical, the payoffs are proposed to be measured on a qualitative scale, e.g., a 5-tier scale, such that the distribution over the possible outcomes becomes a simple histogram. The optimization algorithm requires that both risk and resilience are measured on the same scale.

An algorithm to solve such zero-sum games with random payoffs has been implemented in the statistical software R (R Core Team, 2018) in course of the EU project HyRiM (Rass and König, 2018). It is based on the fictitious play algorithm (Berger, 2005) that imitates the game and records how often players choose which strategy. In the case of qualitative payoffs, the algorithm compares two payoffs by comparing the values in each category with increasing importance, i.e., it prefers actions with a lower likelihood of the highest risk. The main functions of the R package 'HyRiM' needed to set up and solve the game are described in Section 3.3.

In the remainder of this section, we demonstrate how to perform such a game theoretic analysis. First, the strategies of both players are defined, and the payoffs are estimated. Then the optimization is done using the statistical software R and the output is interpreted.

3.2 Actions to Reduce Risk and Increase Resilience

Once the goal of the analysis is clear (in our case risk minimization and resilience maximization), the next step is to collect all possible and relevant actions each player can take, i.e., define the set of strategies.

For the attacker, the set of strategies contains all actions that threatens the system. This includes both intentional attacks (e.g. malware attacks, as in the NotPetya case) and natural disasters (such as a flood). Since the attacker is an abstract representation of threats, the strategies should reflect the threats the user is most concerned about. It is not necessary to estimate the likelihood of occurrence in this setting, rather a likelihood assessment is part of the result of the analysis, as we describe at the end of this section.

For the defender, this list includes all actions that can be taken to reduce the risk or increase the resilience. Due to the correlation between the two quantities, a strategy will typically affect both risk and resilience to some extent. The model requires to assess the effects for each goal individually, as described in the next subsection.

Threats and protective actions against supply chain risks have been discussed in the literature (Rajagopal, Prasanna Venkatesan and Goh, 2017) and build the ground for the illustrative example. According to the review, the main concerns are disruption of the SC and operational risk (e.g., risk of damage during transportation). Frequently discussed counteractions are construction of a robust SC network design (SCND) and risk propagation analysis (RPA). SCND methods describe how a supply chain can be designed effectively to recover from disruptions. RPA analyses how risks propagate through a system and affect different parts, which helps to understand operational risks better.

For the illustrative example, these two threats are chosen as attack strategies, and SCND and RPA are selected as defense strategies, as shown in Table 1.

Table 1: Strategies

	Attacker	Defender
Strategy 1	Disruption	SCND
Strategy 2	Operational	RPA

Note that the enumeration of strategies does not reflect their relevance, the analysis selects strategies depending on their effects regarding the considered goals. Further, it is possible to include a “no action” strategy that describes the current state (i.e., evaluating whether a strategy reduces the risk or increases the resilience compared to the status quo).

The final task to set up the game is an assessment of the payoffs, that is, for each combination of attack and defense action the expected impact needs to be estimated for each goal. It is recommended to measure risk on a qualitative scale (Münch, 2012) to represent the fact that an exact assessment is hardly possible in practice. If enough data is available, quantitative approaches may be used as well. In any case it should be made clear how to deal with inconsistent data, i.e., wether outliers are removed, or different assessment are aggregated. In this model, we chose to include all data available (including potentially inconsistent expert assessments) and work with probability distributions over all possible values. Non-probabilistic approaches like fuzzy logic usually perform very well in practice, but the interpretation of the underlying concept is not always obvious. The decision on whether to use qualitative or quantitative data is up to the user, since it is often a question of taste. The optimization algorithm requires that payoffs are measured on the same scale for all the goals, which is not a limitation in our case, since resilience is equally hard to measure as risk. We suggest using a 5-tier scale, where the levels have different interpretations for the different goals. The payoffs are collected in two payoff matrices (one for each goal).

Since the algorithm that solves the game has been implemented in the context of risk minimization, it is important that lower levels refer to a better situation than larger ones.

In practice, this means that experts who do the assessments (not necessarily one person alone) interprets 1 as low risk or a high resilience and 5 as high risk or low resilience. The algorithm then aims at minimizing the maximal risk and minimizing the lowest resilience (and therefore increasing it). The payoff matrices shown below in Figure 1 and Figure 2 show the probability distributions over the 5 categories, i.e., the x-axis shows the categories and the y-axis the corresponding probabilities.

Based on the description of the defense strategies in (Rajagopal, Prasanna Venkatesan and Goh, 2017) and references therein, the payoffs for the running example are chosen based on the assumption that SCND reduces the risk of disruption more than RPA (see first column of the matrix in Figure 1) because disruptions are less likely to occur in a network with robust network design. Further we assume that RPA reduces the risk of operational problems more than SCND (second column of the matrix in Figure 1), because such an analysis might identify causes of the problems that can be resolved and hence reduce the risk in the future. Note that these assessments depend on the specific use case, this work is based on a researcher's best guess, but expert knowledge will be crucial in practical applications.

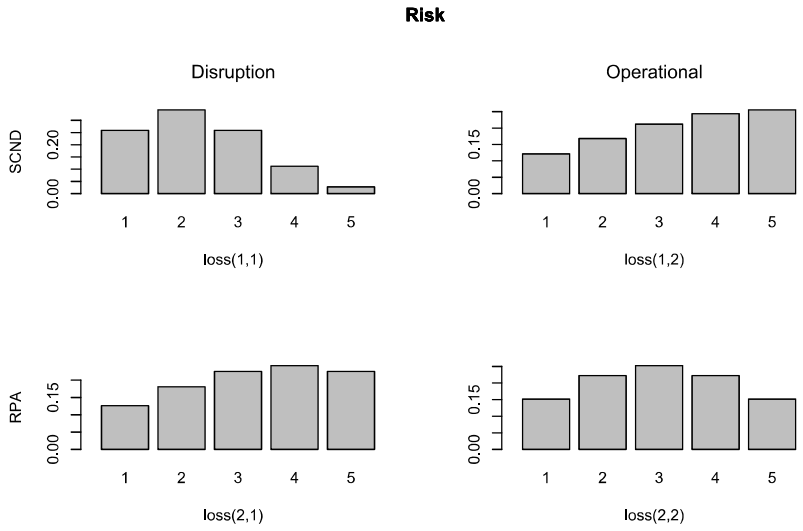


Figure 1: Payoff matrix for goal "Risk"

Similarly, it is assumed that SCND increases the resilience against disruption more than RPA (i.e., yields more likely lower values, see first column of Figure 2) while RPA increases

the resilience against operational problems more than SCND (second column of Figure 2). The concrete numbers in this example are artificial, and the assessment requires expert's knowledge in practice.

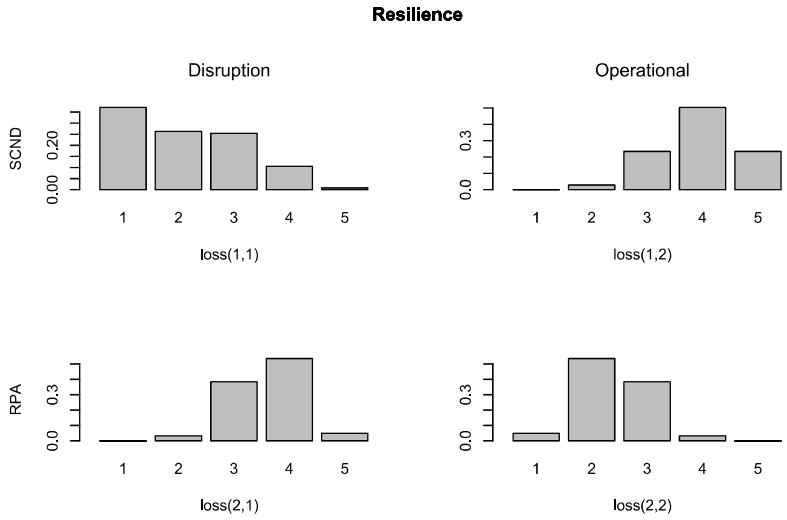


Figure 2: Payoff matrix for goal "Resilience"

3.3 Identification of Optimal Actions

Identification of an optimal choice among the possible strategies is done using the R package 'HyRiM' (Rass and König, 2018). The core functions of this package are:

- *lossDistribution*: constructs a loss distribution from raw data such that it fits the framework (in particular, all goals use the same scale); if necessary, smoothing is applied
- *mosg*: a Multi-Objective Security Game is constructed from the number of goals, number of strategies and a list of payoffs; description of goals and strategies are optional but recommended
- *mgss*: for a given game, this algorithm determines probability distributions over the actions of each player, indicating how frequently they should be used to get optimal results. Further, it provides a distribution over the expected damage, called *assurance* since this is the expected damage if the attacker acts in his best (the defender's worst) possible way, which will not always happen.

By default, the algorithm treats both goals as equally important. However, the user is free to adapt this by putting weights on the various goals and therefore prioritizing one over the other.

In case of the considered example, the R code looks as follows:

```
# load package HyRiM
library(HyRiM)
# number of strategies
n<-m<-2
# number of goals
d<-2
# description of strategies
defensesDescr<-c("SCND","RPA") # PS1
attacksDescr<-c("Disruption","Operational") # PS2
# raw data for payoff
obs111, …, obs122, obs211, …, obs222
# payoff distribution from raw data
ld111 <- lossDistribution(obs111, discrete=TRUE,supp=c(1,5),smoothing="ongaps")
…
ld222 <- lossDistribution(obs222, discrete=TRUE,supp=c(1,5),smoothing="ongaps")
# collect in list of payoffs
payoffs<-list(ld111,ld112,ld121,ld122, ld211,ld212,ld221, ld222)
# set up game
G <- mosg(n=2,m=2,goals=2, goalDescriptions=c("Risk","Resilience"),
losses=payoffs, byrow=TRUE,
defensesDescr<-c("SCND","RPA"), attacksDescr<-
c("Disruption","Operational"))
# compute optimal solution for chosen accuracy eps
eq <- mgss(G,eps=0.01)
```

The main result of the analysis is a guide on which defense actions should be used, i.e., which defense strategies should be played how often. The uppermost histogram in Figure 3 shows the recommended relative frequency of use for the defense actions.

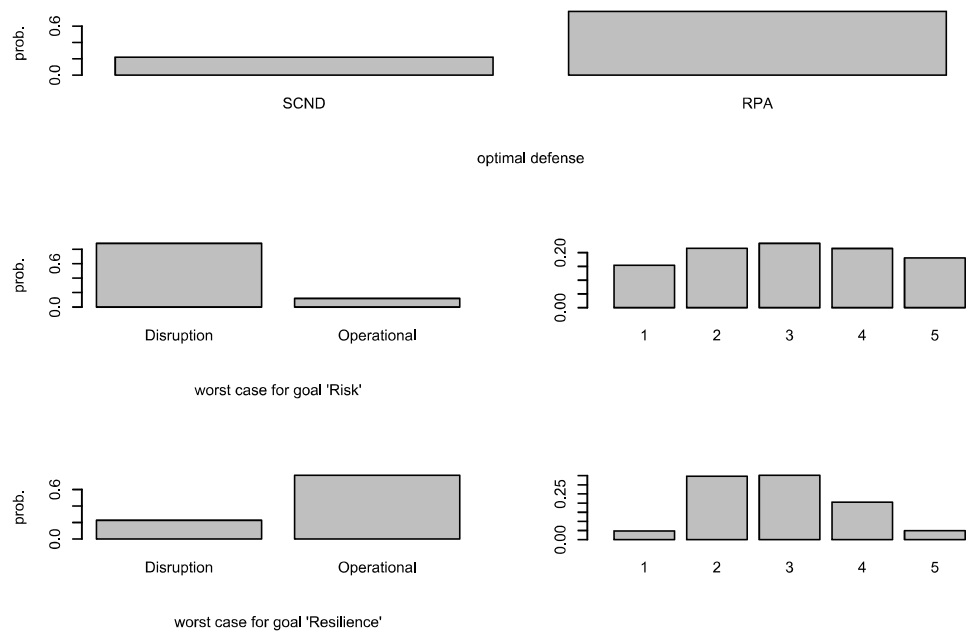


Figure 3: Results of game theoretic analysis

The practical implementation of such results depends a lot on the actual strategies. If they can be implemented with reasonable effort, they should be applied according to this relative frequency (e.g., in the case of quality checks, software updates etc.) In this concrete example, the analysis yields a frequency of 0.22 for SCND and 0.78 for PRA, so that on average SCND should be applied 22% of the time and PRA 78% of the time. Changing the network design might be costly, so that it cannot be done regularly. In this case, the numbers can be interpreted in terms of priority, i.e., applying RPA is more urgent than SCND. However, if it is not possible to switch between strategies in order to meet the relative frequencies in the long run, the defense is no longer optimal, and a different choice of strategies should be considered (the analysis needs to be redone in this case).

Besides instruction on how to act, the analysis provides information on the best actions from the attacker's point of view, i.e., on the worst-case attack from the defense's point of view. Similar as for the defender, the analysis provides relative frequencies over the attack strategies. However, this optimal/worst attack depends on the goal that the attacker has in mind. If he focuses on increasing the risk, his best action is characterized through the second row in Figure 3 (left side), if he focuses on reducing resilience his optimal choice is described in the last row in Figure 3 (left side). For both goals, the resulting payoff is given (right-hand side of second and third row in Figure 3). This should be understood as a distribution over the damage in case both the attacker and the defender play their optimal strategies. For the goal 'Risk', this attack most likely yields a risk of 3, but other risk levels are also likely to happen. For the goal 'Resilience', the optimal attack is very unlikely to yield a resilience level of 1 or 5, with levels 2 and 3 being most likely. These risk and resilience levels are reached if the attacker follows the optimal strategy, however he may not be able to do both attacks at the same time (if the optimal strategy profile differs for the two goals) or may not even be rational (e.g., in the case of natural disaster). In this case, the expected impact will be less bad. Therefore, the provided distribution is understood as an assurance, meaning that this is an upper bound to the observed values. The provided assurances are not valid any longer if the defender deviates from his optimal strategy given in the first row.

4 Conclusion

As every model, the proposed approach has its limitations, which at the same time show some potential directions of future work. From a modelling point of view, the approach is conservative in the sense that it considers the worst-case scenario. While this is appropriate for intentional attacks, it might be too strong for natural disasters, potentially resulting in spending more resources than strictly necessary. Further, it might be worth distinguishing agents that try to protect the system, i.e., have more than two players. From a practical point of view, open topics include identification of strategies (e.g., based on standards, maybe atomized) and the implementation of the results in practice. Finally, refinements for specific users might be useful.

Acknowledgement

This work was supported by the research Project ODYSSEUS ("Simulation und Analyse kritischer Netzwerk-Infrastrukturen in Städten") funded by the Austrian Research Promotion Agency under Grant No.873539.

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Disruptions and exception handling in Food Supply Chains

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The COVID-19 pandemic and resulting non-pharmaceutical interventions aspiring to reduce the spread of the virus, e.g., full or partial lockdowns, as well as social distancing measures, lead to increasing at-home consumption and panic buying. The resulting demand peaks for non-cooled perishable items hit the distribution systems of traditional brick-and-mortar retailers and have led to various out-of-stock situations on the shelves of ’‘Europe's retailers. If the impact of demand peaks during the COVID-19 pandemic on grocery retail warehouses are unaware, this can result in out-of-stock situations in the supermarkets. In this paper, we use a process-based discrete-event simulation model to develop and apply a simulation approach to shed light on the underlying mechanisms of grocery retail warehouses in order to predict the future behavior of the examined system and prepare for such external demand shocks. Our results show that both investigated scenarios of volume peaks have a great impact on waiting times for truck drivers and the time-depending utilization level of the warehouse dispatch area. We then derived optimal shift distributions by developing a supply chain resilience strategy varying the output quantities for order picking. Moreover, by that, we could reduce the utilization level in the warehouse dispatch area by nearly 20 percent. Our model can inform managers about the consequences of demand peaks on grocery retail warehouses. Furthermore, our methodology can be transferred to one-time disruptions, as well as to multi-wave disruptions besides COVID-19.

First received: 20. Apr 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

The COVID-19 pandemic has been causing a huge slowdown in many industries. Grocery retail is one of the few industries where sales were at a record high during, for example, lockdown situations, which has led to various out-of-stock situations. While cooled perishable items were the main growth driver for the traditional brick-and-mortar retailers in previous years, non-cooled perishable items led to demand peaks during the COVID-19 pandemic (Hobbs, 2020). The massive increase in demand hit the distribution systems of grocery retailers and led to empty shelves in supermarkets. The COVID-19 pandemic, as a new type of disruption, has been the first long-term supply chain crisis for the last decades and causes a lot of uncertainty in relation to demand, supply, and planning within the supply chain of brick-and-mortar grocery retailing. Therefore, this paper develops and applies a discrete-event simulation model to shed light on the underlying mechanisms of grocery retail warehouses in order to predict the future behavior of the examined system and prepare for such external demand shocks as a part of supply chain resilience (Ivanov, 2021c).

Reviewing existing research approaches examining the impact of the COVID-19 pandemic on logistics and SCM, we find research approaches that control the impact of COVID-19 on food supply chains, e.g., Barman, Das and De, 2021. Succeeding the consequences of COVID-19 on the food supply chain, the research community put focus on reacting and adapting the supply chain to the pandemic conditions (El Baz and Ruel, 2021; Ivanov, 2021d). While there are investigations about the entire supply chain within the distribution system, little is known about the impact of supply chain disruptions due to COVID-19 on the operational level of warehouse logistics.

Motivated by this research gap, the paper investigates the impact of time-dependent and varying output quantities of order picking and loading times on the utilization level of the warehouse dispatch area. Therefore, we examine the order volume of cooled perishable items as well as non-cooled perishable items.

We identify three research questions (RQ) for our study: (RQ_1) Which impact do demand peaks of non-cooled perishable items have on the warehouse dispatch area? and (RQ_2) Which impact do demand peaks of cooled perishable items have on the warehouse

dispatch area? In answering these RQs, we build on and extend the existing knowledge by constructing and using a discrete-event simulation model to investigate strategies for supply chains in the context of the COVID-19 pandemic within (RQ_3) How and to which extend are order picking volume variations a suitable tool to control utilization rates of dispatching areas?

This paper is structured as follows: the literature framework section highlights the relationship between pandemic caused disruptions and research in full range food retailing warehouses. Then, the third section describes the methodology adopted for the empirical research. The simulation study demonstrates and describes the model, assumptions, and experimental results. Our results, summarized in the findings, show that both investigated scenarios of volume peaks have a great impact on waiting times for truck drivers and the time-depending utilization level of the warehouse dispatch area. Finally, conclusions and an outlook on future research directions are presented.

2 Literature framework

2.1 Supply chain disruptions

Supply chain disruption management has become a significant interest of management science research (Hendricks and Singhal, 2005; Kleindorfer and Saad, 2005; Ivanov, et al., 2017; Chen, Wang and Zhong, 2021). Disruptions can occur in any part of the supply chain, including the upstream supply side, the intermediate manufacture processes, and the downstream demand side (Chen, Wang and Zhong, 2021). A local disruption at a supplier affects the entire supply chain as a ripple effect (Ivanov, Sokolov and Dolgui, 2014). The disruption-caused ripple effect could either result at the supply side and propagate along the logistics direction or originate at the demand side and spread negatively upstream, which would affect more companies in the supply chain (Ivanov and Sokolov, 2019). Li et al. investigated forward and backward disruption propagations within an agent-based model to describe the supply chain disruption propagation behavior (Li, et al., 2021).

2.2 COVID-19 as a supply chain disruption

COVID-19 affects the supply chain in two different perspectives: supply and demand. The greatest challenge in the supply chain during a pandemic is to get resources from suppliers and to guarantee the progression of movement from producers to customers (Alonso, et al., 2007). COVID-19 is characterized as a long-term supply chain crisis with uncertainty about the current situation and future developments. Furthermore, the supply chain faces a lot of problems, such as supply disruption or demand change (Ocampo, et al., 2016). Moreover, Ivanov defines COVID-19 as a super disruption which is characterized in Table 1:

Table 1: Characteristics of the super disruption COVID-19 (Ivanov, 2021b)

	super disruption (supply chain crisis)
impact	long-lasting impact with barely predictable scaling
scope	simultaneous disruptions in supply, demand, and logistics
recovery	is performed in the presence of the disruption and its unpredictable scaling
timing	simultaneous and/ or sequential openings and closures of suppliers and facilities

The paper on hand demonstrates that COVID-19 as a super disruption has a great impact on the order volume and resulting demand peaks. Furthermore, one can see that the volume is very difficult to predict. This has led to bottlenecks within the material flow of the warehouse dispatch area. The research community examines the impact of COVID-19 disruptions on the supply chain. As a new type of supply chain disruption Ivanov demonstrates the usage of simulation-based methodology to examine and predict the impacts of epidemic outbreaks (Ivanov, 2021a). Therefore, the research points out an analysis for observing and predicting both short-term and long-term impacts of epidemic outbreaks on the supply chain. The major finding of the different simulation experiments is that the timing closing and opening of different facilities at different echelons in a

supply chain is one of the most important factors predicting the impact of COVID-19 on that supply chain's performance (Ivanov, 2021a). Up-and downstream disruption durations are also very important for the performance of the supply chain (Ivanov, 2020). Further, Ivanov demonstrates the susceptibility of supply chains with postponed demand and shutdown capacity during pandemic conditions within a discrete-event simulation (Ivanov, 2021a, p.1-5). Therefore, he considers the after-shock risks according to different demands and capacity management during the pandemic (Ivanov, 2021a). Barman et al. (2021) investigate the impact of lockdown on the food supply chain summarizing recommendations on how to control and deduce the impact of COVID-19.

Besides demonstrating the impact of pandemic disruptions, the research community focuses on supply chain recovery and resilience. The recovery begins during the pandemic and is characterized by deep uncertainty (Ivanov, 2021a). Chen et al. develop a supply chain disruption recovery strategy considering product change under COVID-19 (Chen, Wang and Zhong, 2021). Moreover, Ivanov develops two strategies to avoid disruption tails within the supply chain. Therefore, a possible recovery strategy is demand smoothing over time in the post-disruption period. Additionally, a moderate capacity ramp-up prior to expected peaks of postponed demand is an effective leveraging approach for disruption tail control (Ivanov, 2021a). Besides the definition of recovery, there are numerous definitions of resilience in research. Resilience refers to the capacity of a dynamic system to adapt successfully to disruptions that threaten the viability, function, or development of the system (Masten, 2014).

2.3 Warehouse disruptions

Warehouses play a vital role for retail supply chains (Richards, 2018) and are responsible for receiving and storing items, as well as picking and shipping customer orders (Bartholdi and Hackman). Hence, disruptions can have various impacts on different warehouse operations. Our literature framework includes research about warehouse disruptions in general, as well as in a specific part of the supply chain in retail logistics. The more detailed investigation refers to typical warehouse processes of retail logistics storing, picking, packing, and shipping (Mohsen, 2002). Rana et al. examine the impact of demand disruptions on two warehouse perishable inventory systems during the COVID-

19 pandemic. First, the authors investigate the enforcement and ease of lockdown caused by COVID 19 when the owned warehouse is being vacated. Second, they examined the experiment using lockdown enforcement during the inventory dispatch from the owned warehouse and relieved as the items are taken from the rented warehouse (Rana, et al., 2021). Klumpp and Loske (2021) investigate the impact of information technology disruptions on retail logistics efficiency. Here, the authors apply the network data envelopment analysis to measure the impact of IT disruptions on the efficiency of operational processes in retail logistics using and comparing the efficiency of order picking and truck loading data (Klumpp and Loske, 2021). The literature review points on a research gap regarding supply chain disruptions in operational warehouse processes. There is a lot of existing research across the entire supply chain. The research community investigates the impact of supply chain disruptions of suppliers for example delay in delivery due to pandemic restrictions within the supply chain, but there is little known about intralogistic warehouse processes.

3 Methodology

The case study is developed in a German full-range food retailing warehouse, which is responsible for the complete and on-time delivery of roughly 400 supermarket stores. Considering the dynamics of demand-caused disruptions, we simulate the time-depending utilization level of the warehouse dispatch area for volume peaks. The quantitative simulation approach of this paper is based on the dataset of order picking and truck loading. Our empirical dataset utilized in the simulation model consists of N=13,488 transport units (roll cages) in the timeframe of 16.10.2020 – 23.10.2020. The non-random quasi-experimental study uses primary data of the companies Data Warehouse which has been validated by observation. More precisely, we used the barcode scan of every roll cage picked in the warehouse and transported to the dispatch area. Furthermore, the empirical data contains the time-dependent barcode scans to document the loading process performed by truck drivers for all transport units in the warehouse dispatch area. Therefore, the simulation model calculates the time-depending utilization in the warehouse dispatch area and demonstrates demand-caused

disruptions due to volume peaks. After simulating the different experiments based on RQ_1 high volume of non-cooled perishable items and RQ_2 consequences of the high volume of perishable items to the warehouse dispatch area of non-cooled perishable items, we analyze the dependence between the utilization rate and the disruptions in the warehouse dispatch area as a result. The utilization rate is defined by provided transport units in the loading lines of the warehouse dispatch area compared to the total capacity of the loading lines within the warehouse dispatch area. Finally, we simulate the consequences to the warehouse dispatch area by varying the output quantities for order picking within RQ_3.

Aspiring to answer the formulated research questions, we use a discrete-event simulation model within the simulation tool AnyLogic. AnyLogic is a multimethod simulation modeling tool to create, for instance, a 2D or 3D model (Tutorials AnyLogic Help, 2021). Discrete-event modeling is one of 3 types of modeling in addition to agent-based modeling and system dynamics. The characteristic of discrete-event modeling is that the modeler considers the system being modeled as a process (Borshchev, 2013). Therefore, we use predetermined process blocks made available in the simulation tool. We create a process flow adapted to the warehouse processes of the grocery retail warehouse. Different from agent-based simulation, the processes in the case study are well-known. There is a clear structure to be found which is to be modeled.

4 Simulation model

4.1 Problem context

The simulation approach considers the processes of order picking and truck loading within the warehouse dispatch area of non-cooled perishable items to investigate the impact of high volume of non-cooled perishable items and high volume of perishable items. The COVID-19 pandemic and daily fluctuating volumes make the utilization rate of the warehouse dispatch area and the impacts on delivery times of customers difficult to predict. Furthermore, seasonal peaks like Easter or Christmas enlarge the impact of high volume on the utilization rate. Demand peaks cause disruptions in the warehouse

dispatch area, the interface between order picking and truck loading. Figure 1 demonstrates the individual situation within the investigated grocery retail warehouse:

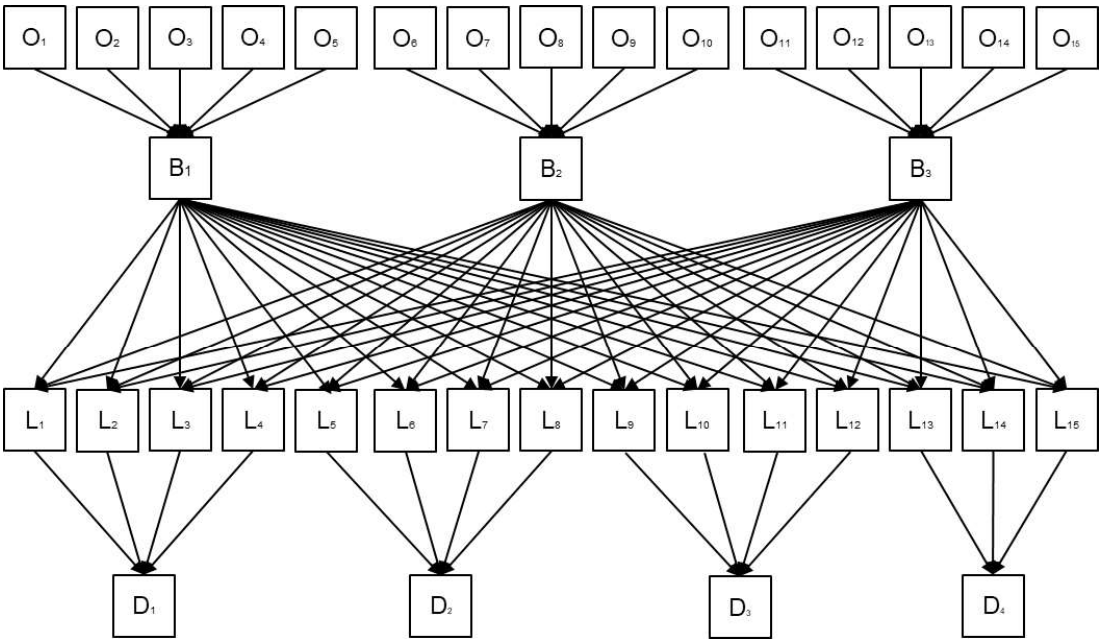


Figure 1: Material flow of the grocery retail warehouse (Gudehus, 2012)

O_n demonstrates the order picking zones separated in range-specific areas. After order picking, the transport units are placed in the buffer zones (B_n). At this time, the barcode of every transport unit is created. Furthermore, the transport units are placed in the loading lines (L_n) of the warehouse dispatch area. Each L_n has a capacity of 41 transport units (roll cages). The warehouse dispatch area consists of 39 loading docks and 2 to 5 loading lines per dock, depending on the respective area. The transport units of a customer placed in a loading line are loaded by truck drivers at the loading docks (D_n) according to the delivery time window. Resulting demand peaks due to COVID-19 and seasonal peaks cause disruptions within the individual loading lines when volume exceeds the capacity of 41 transport units. The simulation model demonstrates the mentioned time-depending demand-caused disruptions during the COVID-19 pandemic and seasonal peaks and displays the utilization rate. Volume peaks do not affect the structure of the investigated warehouse processes. It means that processes are not scalable, and there is a rigid structure of grocery retail warehouse processes during

demand peaks. Figure 2 demonstrates the material flow of the grocery retail warehouse within the created 2D model with the help of the AnyLogic simulation tool.

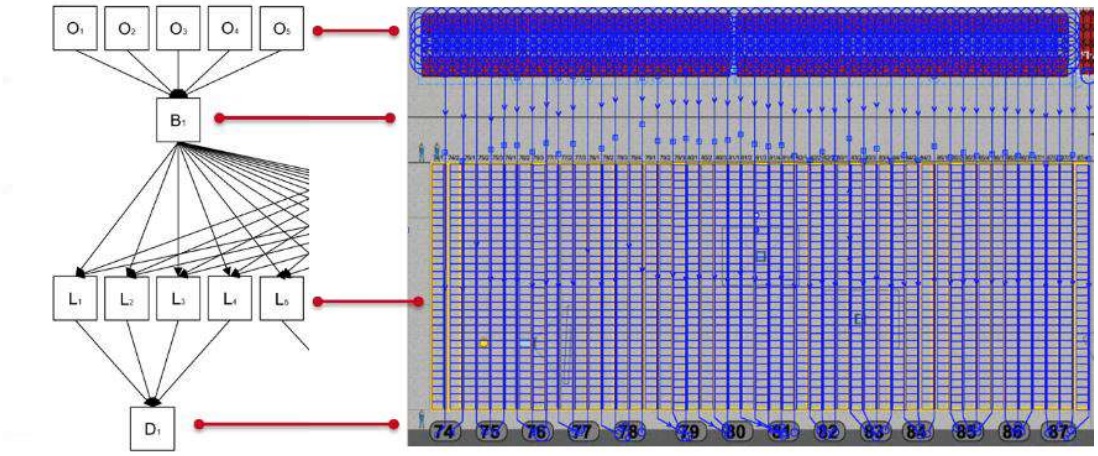


Figure 2: Simulation model from order picking to truck loading, created in AnyLogic 8.7.2

4.2 Model assumptions

We developed a discrete-event simulation model using the software AnyLogic. Because of model restrictions, the simulation focuses on 1 of 3 parts of the warehouse dispatch area. Furthermore, the simulation experiments have been limited to selected days due to the effort involved in the simulation model. Consequently, the model covers 14 loading docks, including 45 loading lines. We assume that the supply chain structure does not change during the pandemic period. Furthermore, to implement the data into the simulation model, we assume that a transport unit constitutes a roll cage. The simulation model is based on the time-dependent process, creating the barcode for each transport unit after order picking up to this time loading the transport units of the customer by truck drivers. The transformation of the processes within the warehouse dispatch area into the discrete-event simulation is shown in Figure 3.

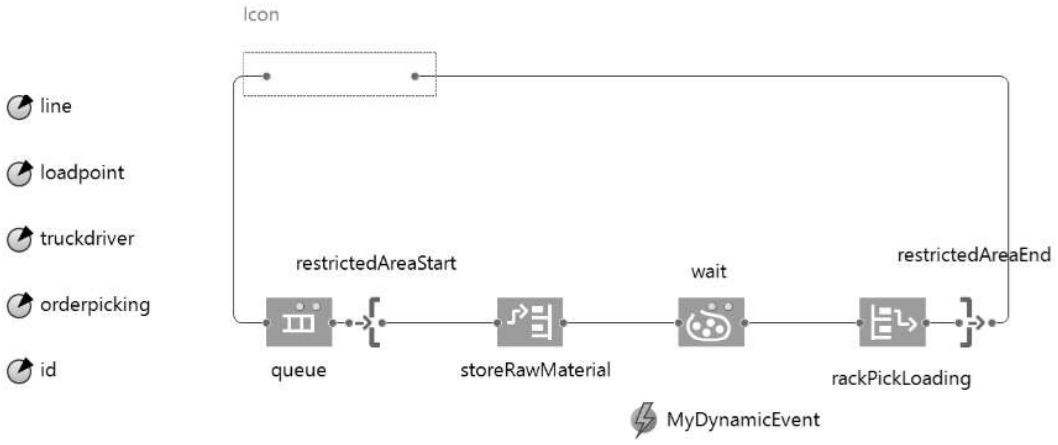


Figure 3: Process-flow from order picking to truck loading, created in AnyLogic 8.7.2

4.3 Parameters

The end of each picking process is documented with a timestamp for printing a barcode label containing all relevant information of a batch with all SKUs stacked on one roll cage (1). The sum of all batches assigned to one store, and, therefore, the total number of transport units per store, quantifies the total size of each order (2). Finally, the information flow at the end of the order picking process contains the loading line for the entire order (3). Relevant for the truck loading process is the information about the delivery day (4), which is also printed on the barcode label. As the order picking time depends on the respective time window of the store, we also use this information in our simulation approach (5). Last, to evaluate the length of stay for roll cages on the dispatch area, we quantify the material outflow through a time stamp documenting the loading time (6). To simulate the time-depending utilization level of the warehouse dispatch area, we need the following data.

Table 2: Simulation-relevant Data

Order picking	Truck loading
(1) Time of barcode generation	Delivery day (4)
(2) Transport units of customers	Delivery time window (5)
(3) Individual loading line	Loading time of barcode (6)

The data listed in Table 2 is part of different systems integrated and transformed into the Data Warehouse of the investigated grocery retail warehouse. The data warehouse export of Monday to Friday is evaluated for creating the simulation model. In combination with the process-based discrete-event simulation model shown in Figure 2, the data constitute the basis for the experimental research of volume peaks.

4.4 Validation of the simulation model

We validate our model in three different ways. We (1) validate the data from the companies Data Warehouse by observation within the warehouse dispatch area. Therefore, we observe the material flow on site and verify the collected data for the time of the barcode generation, placed in the correct loading line in the warehouse dispatch area, and the number of transport units as well as the loading time. Then (2) we validate the simulation model and its assumptions to the warehouse dispatch area, which we have observed in the examined company. We visually checked the dynamics of material flows through the simulation model. Finally (3), we validate the implemented data which we used for the discrete-event simulation in AnyLogic and the simulation experiments. The validated simulation model with real-context data in the period between Monday to Friday represents the basis for the non-random quasi-experimental study. The difference between implemented data and original data is the standardization of the transport units in the simulation model. The real-context data consists of different transport units of different sizes. The implementation of the data into the AnyLogic database requires the

standardization of the transport units to 1 (roll cage). To enable the accuracy of the simulation model, we consider the overall size of transport units for each customer.

Figure 4 demonstrates the utilization level of the warehouse dispatch area between the specified date.

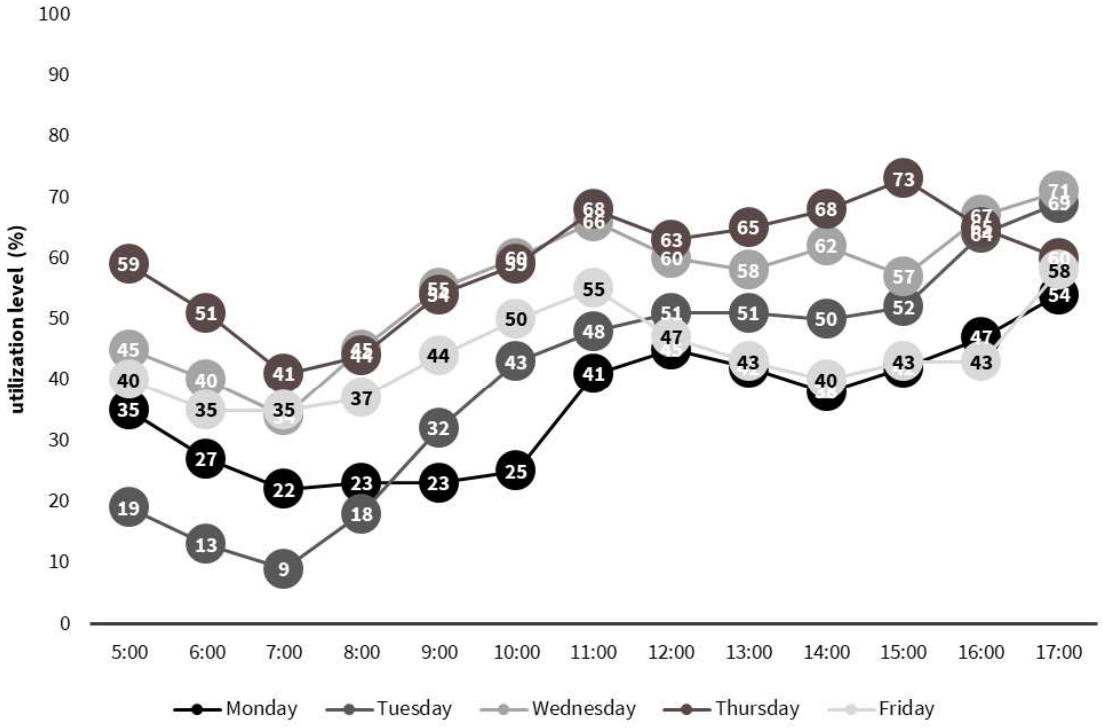


Figure 4: Utilization level of the warehouse dispatch area during COVID-19

The simulation between Monday and Friday demonstrates the percentage utilization level in a normal week during the COVID-19 pandemic. On Thursday, there is the most utilization during the investigated week. At 15:00, one can determine the highest occupancy. In the investigated warehouse, a disruption defines one or more overloaded loading lines due to a high volume of order picking and less truck loading of transport units. If the supply of order picking volume exceeds the capacity of a loading line of 41 transport units, one can notice a traffic jam at the buffer zone. A utilization level of more than 65 percent in total leads to multi-wave disruptions. The simulation run shows that the traffic jam at the buffer zone exceeds the capacity of the loading lines. In

consequence, the level of material flow in the warehouse dispatch area is only possible to a limited extent. This scenario affects the loading times of the truck drivers and delivery time windows that cannot be met.

5 Simulation Experiments

5.1 Seasonal Peaks during COVID-19

The non-random quasi-experimental study of high volume due to seasonal peaks during COVID-19 demonstrates the influence on the utilization level in the investigated dispatch area of non-cooled perishable items. Therefore, we used the percentage increase in volume at easter of the previous year to demonstrate the seasonal volume during the COVID-19 pandemic. We were able to determine an increasing volume of 10 percent on Monday, 25 percent on Tuesday, and 15 percent on Wednesday in the easter week of 2019. Furthermore, the volume was increased by the stated percentage within implemented data of our simulation model. By that, we simulate and predict the increase in volume during COVID-19 and additionally seasonal peaks on the warehouse dispatch area. The impact of demand peaks of non-cooled perishable items on the warehouse dispatch area is demonstrated in Figure 5.

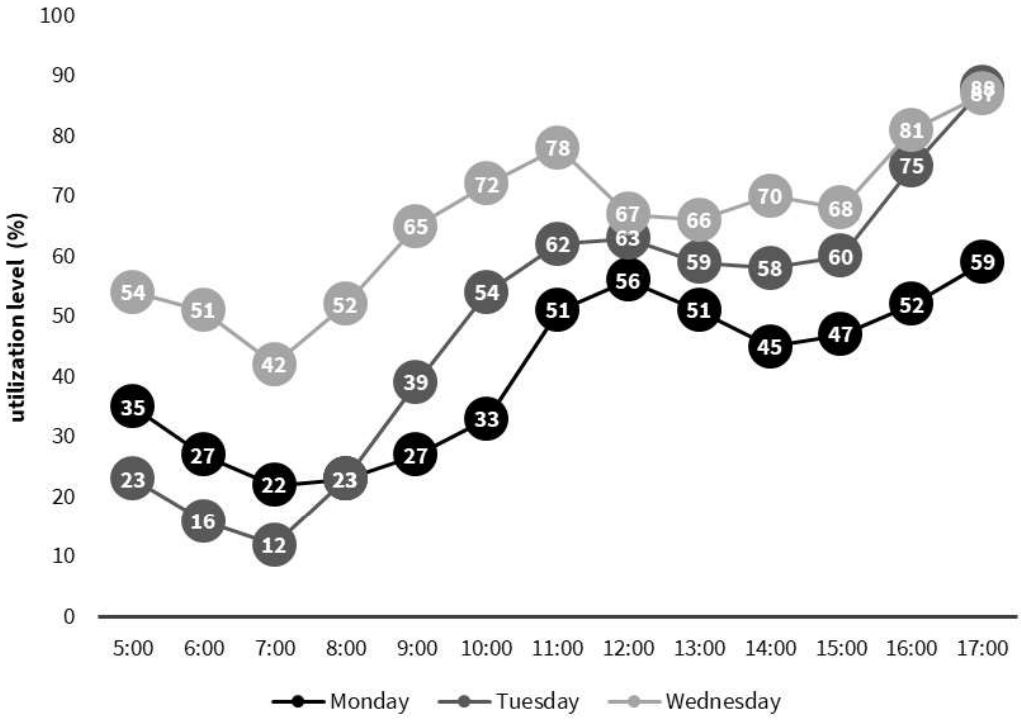


Figure 5: Impact of seasonal peaks on the utilization level

Figure 5 illustrates the experimental results for demand peaks and depicts that the utilization level increases due to seasonal volume. Moreover, the increasing utilization level on 21.10.2020 leads to disruptions in the warehouse dispatch area due to an increase of up to 16 percent.

5.2 Demand peaks of cooled perishable items during COVID-19

The non-random quasi-experimental study of high cooled perishable items volume during COVID-19 demonstrates the influence on the utilization level in the investigated dispatch area of non-cooled perishable items. High volume of cooled perishable items leads to delayed return times and, as a result, delayed loading times of non-cooled perishable items. Moreover, the transport units remain longer in the loading line contemporaneously the supply by order picking increases because of unchanged and

unscalable order picking. Consequently, disruptions occur due to capacity overrun within the loading lines. Therefore, the simulation model demonstrates the utilization level delaying truck loading $t+_{2h}$.

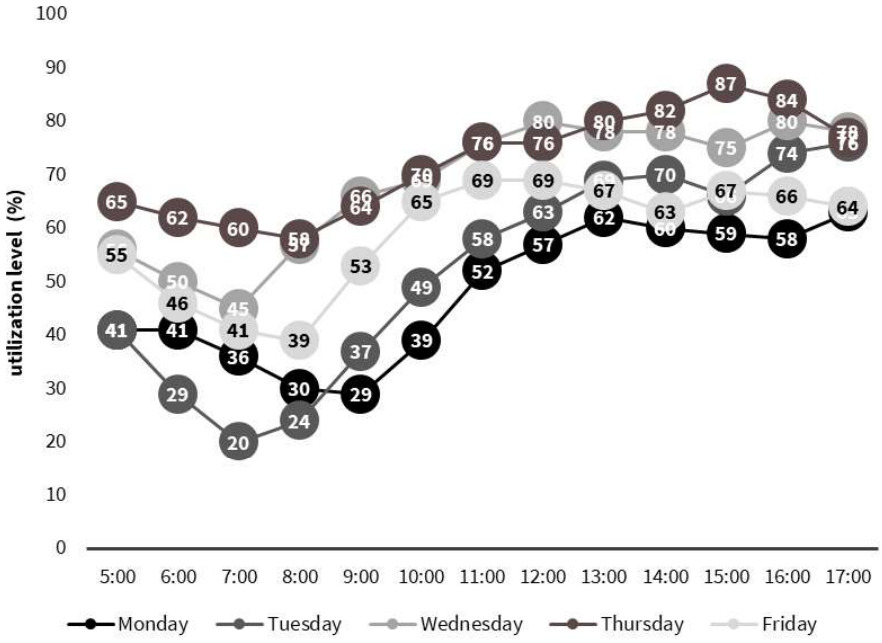


Figure 6: Impact of cooled perishable items on the utilization level

Figure 6 illustrates the experimental impact of demand peaks of cooled perishable items to the warehouse dispatch area of non-cooled perishable items. The delay in truck loading leads to continuously higher utilization. There is no relief due to delayed loading times which leads to disruptions between order picking and truck loading. The transport units remain at the buffer zone creating disruption tails in the process flow.

5.3 Supply Chain Resilience Strategy

Contrary to the simulation experiments for demand peaks, we investigate a strategy for supply chain resilience when volume increases during COVID-19 pandemic and seasonal peaks. We derived optimal shift distributions by developing a strategy varying the output quantities for order picking.

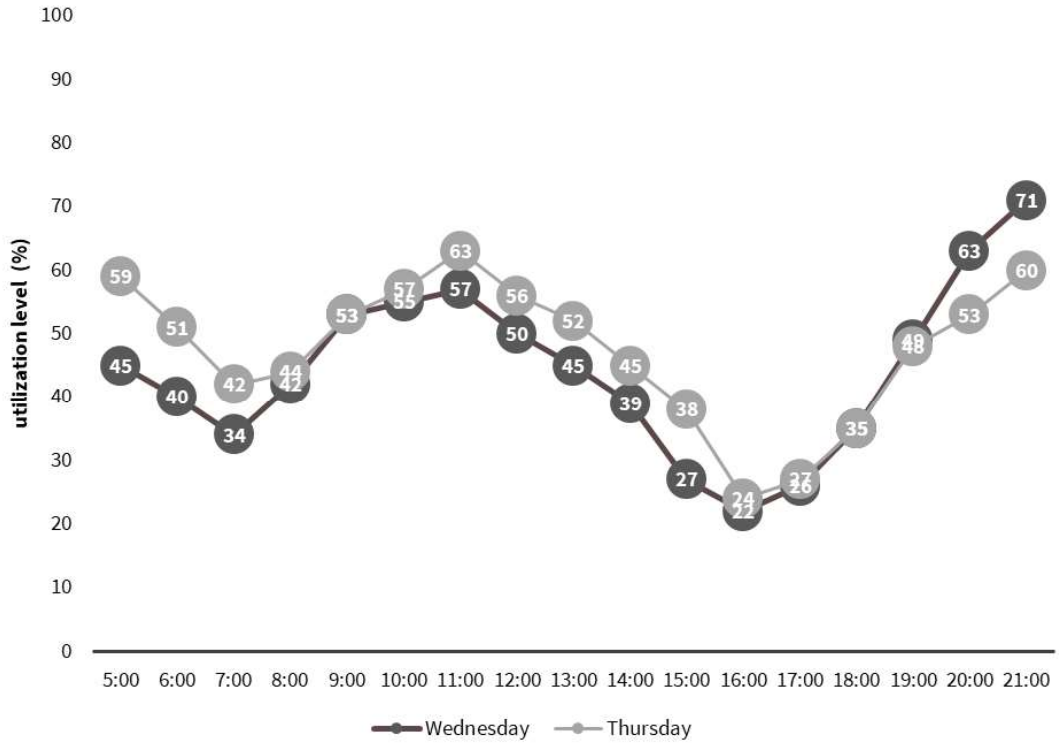


Figure 7: SC resilience strategy for demand peaks

Therefore, we investigate the supply chain resilience strategy on Wednesday and Thursday, the days with the most observed utilization level during the investigated week. We reduce the order picking volume per hour by implementing two shifts and distribute the volume over a period of 14 hours instead of 7.5 working hours. In the non-quasi experimental study, the first layer works from 7.00 to 15.30 and the second layer from 12.30 to 21.00. Figure 6 demonstrates the reduced utilization level due to lower order picking volume per hour. We can perceive a positive effect on the warehouse dispatch area by reducing the utilization level to daily peaks at 15 am by nearly 20 percent at both investigated delivery days. Furthermore, future disruptions during the material flow can be prevented by implementing two shifts and reduce the order picking volume per hour.

6 Findings

The model examined three different simulation experiments demonstrating the impact on the utilization level of the warehouse dispatch area. Aspiring to answer the formulated research question "Which impact have demand peaks of non-cooled perishable items on the warehouse dispatch area””?" a simulation experiment based on real-context data was conducted. Therefore, we added the percentage increase in volume during easter to the data collected between Monday to Friday. To provide deeper insights, we demonstrate the impact of demand peaks of non-cooled perishable items in Figure 6. We investigate high order picking volume due to demand peaks in the warehouse dispatch area. Moreover, the simulation model has shown that the time-depending utilization level increases up to 15 percent. Consequently, the simulation run demonstrates disruptions in the material flow. If the utilization is over 60-70 percent, depending on the situation within the warehouse dispatch area, no material flow can be guaranteed. Furthermore, the simulation model illustrates disruptions of multiple loading lines due to high utilization in the warehouse dispatch area.

The second research question has investigated the scenario of a high volume of cooled perishable items. Therefore, we aspire to answer the formulated research question "Which impact have demand peaks of cooled perishable items on the warehouse dispatch area””?". Therefore, we examine the impact of later truck loading times t+2h on the utilization level of the warehouse dispatch area. We observed a continuously high utilization rate within the simulation experiment. This can be explained by the strong inflow from order picking and the delayed outflow from truck loading. Consequently, the warehouse dispatch area shows disruptions during the material flow. The loading line capacity has been used up, but the order picking inflow remains unchanged. As a result, transport units remain at the buffer zone and cause disruptions. For that reason, a truck driver may not find customers' transport units in the loading lines, which results in long loading times and delayed delivery.

We then developed a supply chain resilience strategy to counteract the high volume during the COVID-19 pandemic and demand peaks. Therefore, we investigate the research question How and to which extend are order picking volume variations a

suitable tool to control utilization rates of dispatching areas”?". Subsequently, we are varying the output quantities of order picking by expanding the order picking volume on two shifts. By that, we could reduce the utilization level of the warehouse dispatch area, especially at time-dependent demand peaks. In addition, the disruptions in the material flow could be significantly reduced.

7 Discussion

The discrete-event-simulation model developed and applied in this paper demonstrates the impact of COVID-19 and resulting demand peaks on the utilization level of the warehouse dispatch area. Although the type of disruption may be different, e.g., increasing customer demand during Eastern or the COVID-19 pandemic, the stressor affecting the logistics system is the same. We operationalize this stressor by increasing order picking and transport volume modeled as an independent variable. At the same time, the utilization level of the warehouse dispatch area is the dependent variable.

The simulation model of the normal week based on data from a real application scenario showed the volatility within the different days during the COVID-19 pandemic. In addition, the time-dependent utilization level during a day is also shaped by fluctuations. The volatility makes it difficult to forecast the utilization level. Comparing the delivery day Monday to Friday, differences of up to 20 percent can be recognized. This is due to different factors like order volume, output quantities for order picking, and truck loading times. The problem of the warehouse dispatch area is the scalability and the inability to adapt the processes to volume peaks. This underlines the fragility of the examined logistics system, whose overall efficiency is highly affected by the stressor. Furthermore, the simulation experiments demonstrate that already a capacity of 60-70 percent leads to multi-wave disruptions within the material flow. In this regard, the capacity and utilization level of the individual loading lines must be considered in particular. Moreover, the disruptions lead to longer truck loading times and, additionally, to delayed delivery. Also, the transport units cannot be found in the individual loading line, so customers do not receive all of the ordered goods.

In summary, it is possible to forecast the utilization level of the warehouse dispatch area as the dependent variable by modifying the transport volume as an independent variable (stressor affecting the logistics system). Instead of forecasting absolute measures for the utilization level, our approach spawns insights about the relative impact of stressors causing an acceleration. Taleb (2014) illustrates this aspect of fragility with the following example of a traffic system. The driving time from the city center of New York to the airport increases by ten minutes when additional 10,000 cars enter the traffic system. Furthermore, another 10,000 cars increase the driving time by 30 minutes. Thus, we investigate an acceleration effect caused by the stressor (number of cars, independent variable) affecting the efficiency of the system negatively (increase in driving time, dependent variable). The absolute driving time remains unknown.

Our discrete-event simulation model does exactly the same: expressing the impact of stressors on the systems' efficiency in a relative rather than an absolute measure. We find that the acceleration effect caused by highly increased transport volume disrupted the underlying and highly fragile logistics system. Based on these results, we then derived optimal shift distributions by varying the output quantities for order picking. These shifts may be one possibility to reach a more robust system.

8 Conclusion

The paper has shown a way forward in analyzing the impact of COVID-19 and the resulting demand peaks to grocery retail warehouses. This was done by investigating order picking and truck loading through a discrete-event simulation in German food retail logistics based on order picking volume and truck loading times in the timeframe of Monday to Friday. The contribution of this paper consists of (1) the calculation of the utilization level within the warehouse dispatch area during the COVID-19 pandemic, (2) the impact of seasonal demand peaks, and (3) the high volume of cooled-perishable items on the warehouse dispatch area. Furthermore (4), we developed a strategy varying the output quantities for order picking to reduce disruptions within the process flow. The material flow is exposed to challenges due to the increased volume during the pandemic. Seasonal demand peaks or a high volume of cooled perishable items cause disruptions

within the material flow. A highly volatile order volume due to seasonal peaks in demand and short-term, weather-dependent increases in demand are contrasted with rigid network capacity. The simulation study sheds light on the processes of the warehouse dispatch area and calculates its utilization level. Our Model can inform managers about the consequences of demand peaks on grocery retail warehouses. Furthermore, our methodology can be transferred to one-time disruptions, as well as to multi-wave disruptions besides COVID-19.

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Analysis of the Suez Canal blockage with Queueing Theory

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Purpose: *The Suez Canal blockage in March 2021 delayed around $9.6bn of trade each day. The delay affected more than 400 vessels and likely disrupted further Supply Chain and transport operations even after clearing the blockage.*

Methodology: *The model of this paper has two goals: first, predicting how long the queued-up vessels need to wait until continuing their voyage; second, at what time the entire queue resolves, and a new service cycle continues with steady-state behaviour.*

Findings: *The model predicted that the queued vessels' behaviour, i.e., that the last ship will pass the canal five days after the clearing, which equals the number reported by the Suez Canal Authorities. AIS-data can further validate the model's input and output. The discussed model supports the decision-making processes by proving the tool to assess at what time circumventing the blockage is more beneficial.*

Originality: *Supply Chain Management literature already established models from Queueing Theory to evaluate the efficiency of services and infrastructure. However, the literature does not use queueing models to assess Supply Chain risk. This research introduces a queueing model to Supply Chain Risk Management to analyse the recovery of a disrupted transport route, thereby forecasting delays caused by disrupted transport routes.*

First received: 21. Apr 2021 *Revised: 18. Aug 2021* *Accepted: 31. Aug 2021*

1 Introduction

1.1 Motivation

The Suez Canal blockage in March 2021 delayed around $9.6bn of trade each day. The delay affected more than 400 vessels and is likely to propagate even further to liner trade and port operations even after clearing the blockage due to queuing processes. As Supply Chains (SC) became affected, companies discussed SC Risk Management strategies (SCRM) to mitigate the impact of the blockage; i.e., the global shipping giant Maersk warns about ripple effects lasting for weeks (Wagner, Macaya and Mahtani, 2021). Furthermore, the time of clearing was not evident during the blockage and alternatives like circumventing would take more than nine days. Therefore, the criticality of this canal for global trade has become eminent.

The mathematic discipline of Queueing Theory (QT) is well explored and established (Worthington, 2009). Some papers suggest applying models from QT to transport infrastructure, for example, in order to assess the internal procedures of crossing the Suez Canal (Griffiths, 1995). QT models are also present in the SC literature context to analyse the performance of SC operations under volatility of input parameters or demand (Bhaskar and Lallement, 2010; Van Woensel et al., 2008). QT models that provide a notion of risk in terms of statistic deviation from a service level objective are scarce (i.e., Goodfriend, H. and Pet-Edwards, 1991) and do not cover risk management.

1.2 Problem Formulation

Albeit, hundreds of waiting ships are not a performance issue but a transport disruption rippling SCs. Nevertheless, no published paper so far has applied models from QT in the context of Supply Chain Risk Management (SCRM), in which the recovery of SC services after a disruption occurred is of interest, which major review papers on SCRM and SC resilience highlight (Heckmann, Comes and Nickel, 2015; Hosseini, Ivanov and Dolgui, 2019).

Decision-makers would benefit from a prognosis of the delay of the vessels. However, there was no method at hand for stakeholders of the maritime SCs to predict the time

until the waiting vessels could continue their voyage in the Suez Canal (i.e., see HSN, 2021). Yet, each hour difference affects $millions worth of economic activities. The time the service becomes operational again depends on the Suez Canal Authority (SCA) procedures and the number of other vessels waiting. Given the uncertainty of how long it will take to clear the blockage and resolve the initial queue, knowing when the circumvention on the alternative route around South Africa becomes viable is also beneficial. A model from QT provides these answers.

1.3 Research Goal and Structure

The application of queueing models offers insights into the restoration of transport bottlenecks, which affect SC operations: This paper introduces a novel queueing model capable of simulating the events of the Suez Canal blockage. The model allows the deduction of the vessels' waiting times and recovery of the canal's usual service based on input parameters that reflect the situation, whilst the initial queue resolves. This model demonstrates the feasibility of answering research questions of SCRM with QT by predicting the recovery of the canal operation service for the waiting vessels. The internal processes of the Suez Canal, as well as vessel-specific routines, are neglected.

This paper aims to contribute to the literature of SCRM, more specifically concerning the notion of recovery, which is present in the SC resilience literature, by predicting the time until service becomes fully operational again after a disruption.

The paper is going to address the research goal with the following five steps. First, a literature review showcases the application of QT in the SC literature, and an overview of the SCRM literature will highlight the gap that QT can close. The following section formulates a QT model to simulate the situation at the Suez Canal blockage. Then, this paper presents the findings from the model for the motivating research question. The model discusses the method and findings regarding their validity, relevancy, and applicability. Last, this paper embeds the model into the broader context of the literature and names further research opportunities.

2 Literature Review

Supply Chain Management (SCM) literature applies queueing models in several cases to optimise logistics KPIs: Van Woensel et al. (2008) develop a vehicle routing problem with queues to optimise distribution processes in logistics. Bhaskar and Lallement (2010) model a three-stage textile SC with a series of queues to optimise delivery capacity by computing the minimum response time for delivering products to their destination. Souf-Aljen et al. (2016) use QT to simulate the impact of dredging works on port sea operations in a port while making forecasts on the port's throughput. In waterway transport, Wilson (1978) uses several queueing models to test the impact of lock capacities on congestion in the US.

Literature on the Suez Canal got first published in 1956, assessing the financial-economic impact of the canal (Baer, 1956)With the help of QT, Griffiths (1995) analyses the queues and delays at the entrance of the Suez Canal to maximise the throughput of ships and minimise queuing delays. Therefore, the author provides a deep understanding of the transport operations inside the canal with their QT model. (Laih, Tsai and Chen, 2014) publish a paper from a SCM perspective on the optimal pricing at the Suez Canal. Next, Sun and Laih (2021) propose a steady-state model to minimise queues at the canal entrance with a timetable and toll scheme and that takes the extension of the Suez Canal into account. Similar problem formulations considering arrival rates but relying on other methods exist: In the case of the Kiel Canal in Germany, Andersen et al. (2021) develop a metaheuristic to study the effect of uncertainty in arrival times.

The availability of transport infrastructure is of special interest in the context of SCRM because of SCs dependencies (Heckmann, Comes and Nickel, 2015), and other SC agents influence the infrastructure's service performance. If SC links become unavailable, the recovery aspect, the time until operations perform as usual again, is of interest from a perspective of SC resilience (Hosseini, Ivanov and Dolgui, 2019). However, applying quantitative, context-sensitive models with emphasis on the time aspect is still a gap in SCRM (Heckmann, Comes and Nickel, 2015; Qazi et al., 2017). Further research efforts could explore the application from a modelling/methodological side (Li et al., 2016; Hosseini, Ivanov and Dolgui, 2019). Also, further research is required to assess the effect

that the geo-location of the disruption has which is different for many SCs, i.e., based on their market distance (Bak, 2018).

This paper identified a research gap in the application of QT for SCRM and resilience. To the best of the author's knowledge, the SCRM literature has not considered applying QT to address research questions as of this date, and the QT literature has not addressed the potential to analyse risk in transport or SCM (used search engines include but are not limited to: Google Scholar, Scopus, academia.edu). More precisely, there is no literature estimating how long it will take to reach a steady-state behaviour after a risk event.

3 Model

The model of this paper has two goals: first, predicting how long the queued-up vessels need to wait until continuing their voyage; second, at what time the entire queue resolves, and a new service cycle continues with steady-state behaviour.

Queuing models are simplifications of reality, and the objectives of the models vary depending on the analysed system. QT has been originally applied to describe queues in telephone networks in the beginning of the 20s century and established as modelling methods of operational research since a long time (Worthington, 2009). Thus, Worthington (2009) proposes a new discipline of queue modelling to focusing on practical insights for managers (decision-makers) utilising queueing models because researched models become mathematical complex and challenging to implement.

The situation at the Suez Canal is as follows: During the blockage, vessels queued up and waited for the clearing. After clearing, vessels now enter the canal entrances and continue their voyage by being assigned to a convoy that achieves their goal. The convoy assignment depends on their arrival position in the waiting line. The North and South convoys are almost working independently due to the canal extension in 2016 preventing transshipment traffic; they start at the same time and contain about the same number of vessels each day. Therefore, the modelling of the situation gets simplified by aggregating the entrances altogether into a single service system with a deterministic service rate,

namely the convoy schedule and the cumulated arrival rates of new vessels at both entrances.

3.1 Model formulation

In the Kendall notation, the proposed model is the M/Dk/1 queue model considering a single queue ("…/1"). M denotes the exponentially distributed arrival rate of a new vessel, D is the convoy's batch-service with a deterministic service rate μ, additionally a fixed service time, and an average convoy capacity of k vessels. The waiting area for arriving vessels is hypothetically infinite, and new vessels arrive at an arrival rate λ according to a Poisson process. The arrival of a new vessel alters the queue process from state i to i +1, where i denotes the number of vessels in the system, including those currently assigned to a convoy.

Vessels are assumed to arrive individually in the waiting area and not in batches. The convoy assignment operates according to the principle “first come – first serve”, although different prioritisation strategies would be possible. The service convoys have a fixed capacity, and the vessel size does not matter: This model does not account for a variable service rate depending on the number of pilots from the SCA and guidelines like the minimum safety distance between ships sailing in the same convoy. The anonymous vessels are numbered and served according to their time of arrival in the queueing line.

This paper does not undertake to analyse the internal traffic of the canal. The internal services of the Suez Canal were investigated by (Griffiths 1995). This delineation is reflected in Figure 1, which draws a schema of the proposed M/Dk/1 model with the simplifying assumptions: the North- and South-Convoy get aggregated to a single service server to which vessels from the North and South waiting lines are assigned. Though implementable, the model does not consider the actual transit of the canal and continuation of the voyage.

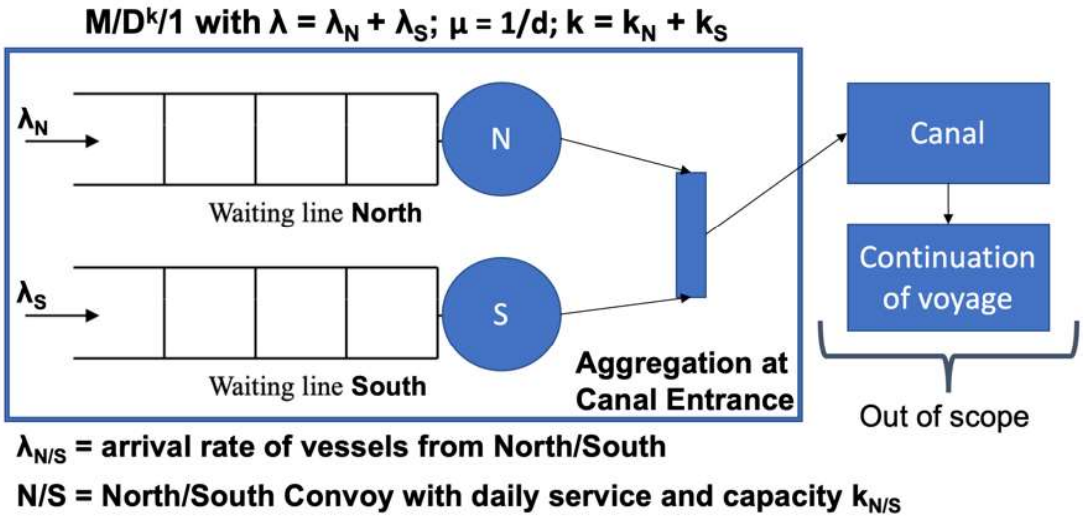


Figure 1: Schema of the $M/D^k/1$ model

For the steady-state, classic performance metrics are easily obtained. In the steady-state, the average arrival rate is less than the average service rate and service capacity – "business is as usual". However, the studied $M/D^k/1$ is initially not in a steady-state because numerous vessels queued up due to the Suez Canal blockage, whereas the service rate had been zero. Also, the time-dependent properties are of interest for this research, namely, to determine the initial queue's resolving. Thus, a transient model is required, which describes the busy period from the time of blockage when vessels start to queue up to when the entire queue becomes empty again, and business is as usual again.

With empirical data reported by news media (Greg Chang, 2021; Ankur Kundu, 2021), the model is parametrised as followed:

- λ: The arrival rate is 50 vessels per day.
- μ: two service convoys per day start from the two entrances with a constant service time of 11 hours with a service interval time of 12h for convoys.
- k: 85 vessels can pass the canal in convoy from the two directions.
- V_0: 494 vessels were queued and waiting in total at the North and South entrance at the time of clearing on 29 Mar at 3 pm, of which 72 are waiting inside the canal at the Great Bitter Lake.

3.2 Simulation and method validation

Time-dependent solutions often require sets of differential equations (Worthington, 2009); for a transient M/Dk/1 model, an analytical solution was published (Baek et al., 2016). However, the literature suggests that simulation results are sufficiently close to results from the analytical form (i.e., see Griffiths, Leonenko and Williams, 2008) while making them less mathematically complex and easier to implement (Worthington, 2009).

This paper uses the simulation approach due to the ease of application and better potential for modification. The simulation is conducted with the python simulation API SimPy, version 4.0.1 (SimPy, 2021). With this setup, a Monte Carlo simulation is performed to draw the queue model states from the distribution of the arriving vessels.

Consider an M/D^k/1 queuing system with infinite waiting room, arrival rate λ and deterministic service time 1/ μ with capacity k. V_0 is the number of the initial waiting vessels at the time of clearing t = 0. Let V(t) be the number of vessels at time t. Equation 1 depicts the time-dependent queue length probability:

$$Q_n^{(j)}(t) = \Pr[V(t,k) = n | V_0 = j], (\tau > t > 0) \quad (1)$$

where $n \geq 0$ is the state of the queue with $k = 85$, the batch-service capacity of the convoys, and $j = 494$ is the number of the initial vessels. τ is the first passage time of the M/D/1 queue defined as the point where the original queue becomes empty, meaning the Suez Canal can operate as usual again.

The time-dependent waiting time distribution of the vessels until their respective convoy starts is then, as equation 2 shows:

$$W_q^{(j)}(t,x) = Pr[T_q(t) \leq x | V_0 = j] \quad (2)$$

with q being the vessel number ε {0, ..., j, j+1, ...,maxV} with maxV, the number of the last vessel entering the system in the considered runtime period of the simulation model.

The conflict between the applicability of QT models and engineering model properties to reflect real system's behaviour arises, and this paper states many simplifying assumptions. Nevertheless, the simplistic M/Dk/1 simulation model obtains the

properties relevant for decision-making, which is according to the research goal to predict the behaviour of the queue of waiting vessels due to the Suez Canal blockage.

The findings consist of one random simulation simulating 14 days because multiple simulation runs do not change the characteristics significantly. The code is available on request.

4 Findings

Figure 2 shows the situation for the queued vessels, which are numbered according to their arrival in the system, at the time of clearing regarding their waiting time: The first 85 vessels transited the channel with the first convoy, whereas the convoy assignment serves the next vessels waiting in line in the following days. Thereby, the vessels accumulate waiting time equal to the time passing. This model omits the vessel's waiting time during the 6 days blockage before the clearing is easy to add.

The maximum waiting time of a vessel was 5.6 days. Afterwards, benefit from the diminishing queue length when the original vessels were processed. The 1089th ship, arriving 12.09 days after the clearing, encounters an empty queue and thus does not accumulate any waiting time anymore.

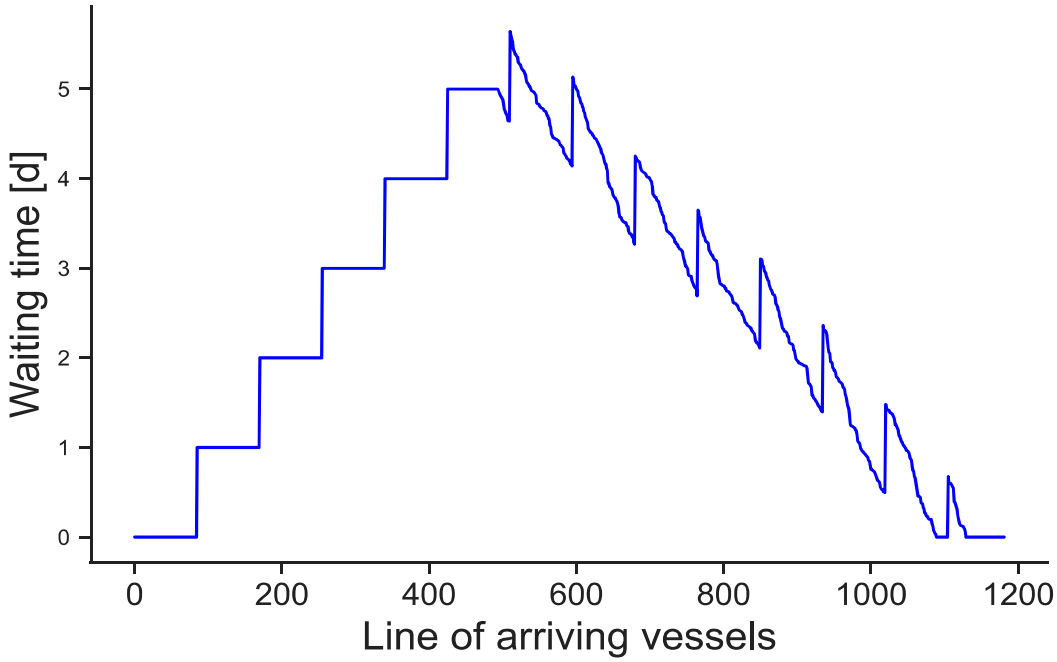


Figure 2: Average waiting times for initial queue length

Figure 3 depicts the queue length (brown line; left side) with an initial 494 waiting vessels at the time of clearing. The queue gets stepwise reduced as vessels get assigned to the convoys starting on day one after clearing. Meanwhile, the average waiting time of vessels increases as the backlog gets processed (blue line; right side). On day 5, the average waiting time reaches its peak and diminishes after that; the steep slope at day 12 means that the initial queue becomes empty, the average waiting time resets, and the busy period is over: the transport service through the Suez Canal has fully recovered. The findings imply that not only the initial 494 vessels got affected by the blockage but further 595 vessels in the next 12 days after clearing.

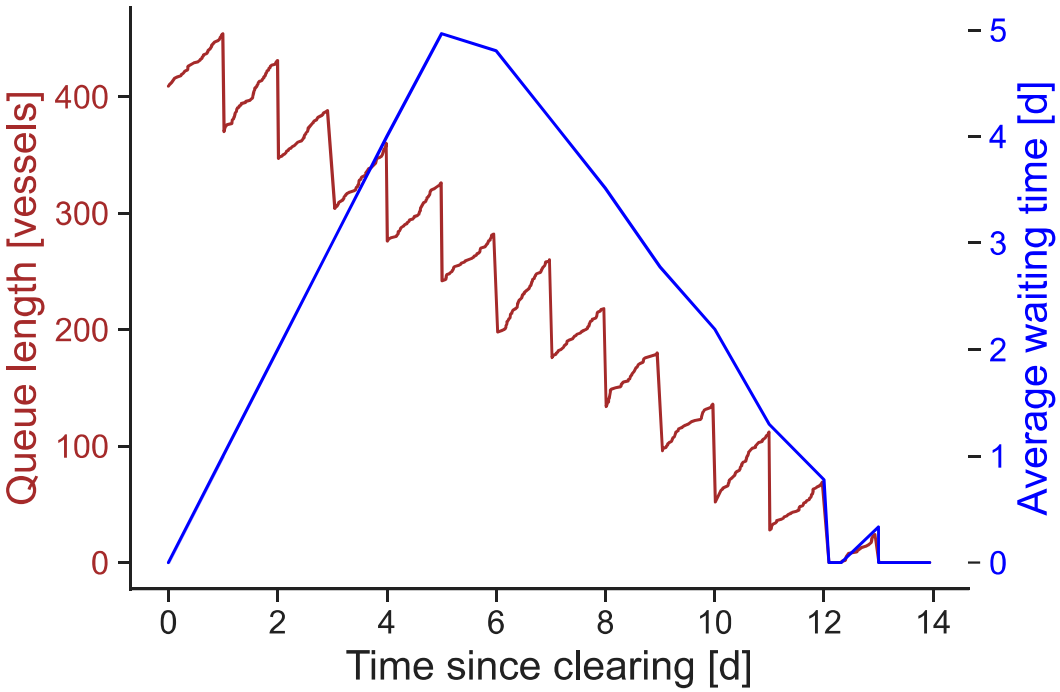


Figure 3: Mean waiting times for ships arriving since clearing at t = 0d

After examining the relationship between vessel position, queue length, and waiting time, Figure 4 depicts the prognosis of recovery depending on the point of clearing t = 0 and duration of blockage resembled by the initialising waiting vessels, which are calculated with a constant of 50 vessels per day of blockage. Note how the queue length in case of 2 days blockage (orange line) does not increase that steeply because most of the initial queue can already be assigned to the first convoy starting at day one after clearing. With the support of such a prognosis, a decision-maker can deduce risk mitigation strategies for their vessels with their estimated arrival and associated waiting time depending on the scenarios when the Suez Canal blockage gets cleared.

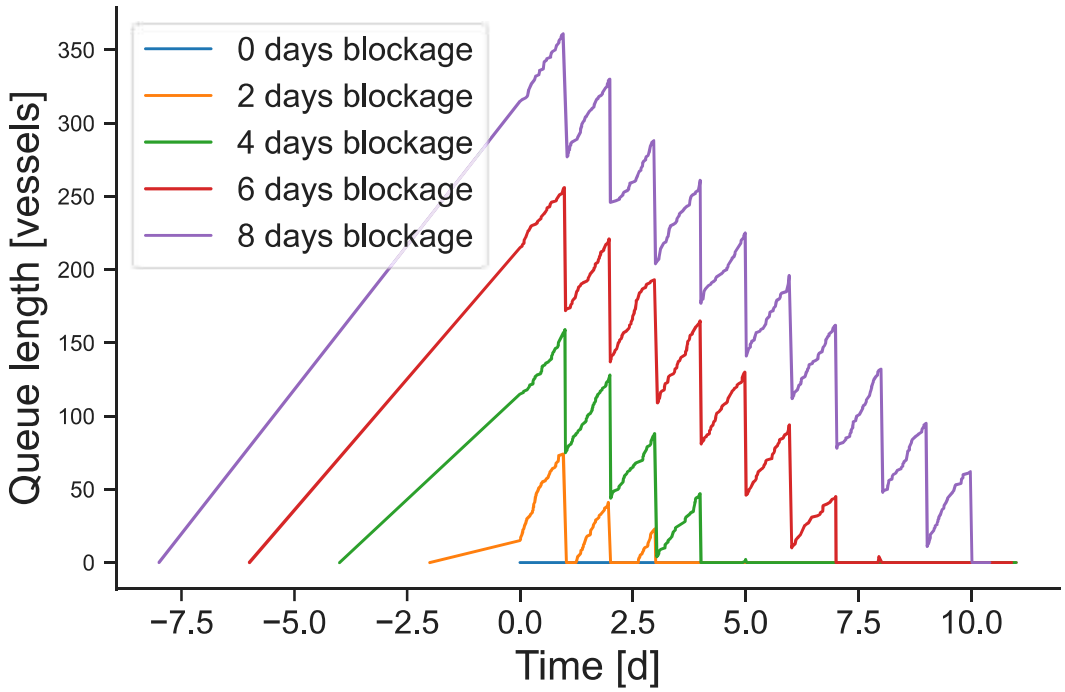


Figure 4: Resolving of vessels depending on initial queue length

5 Discussion

This paper computes findings close to the observations in reality: The model predicts five days until the last waiting vessel at the time of clearing passed the entrance; this is equal to the retrospectively announced five days by the SCA. The complete recovery of business-as-usual happens in 12 days. For the latter, the reported figures vary, depending on the source and definition of business-as-usual (i.e., 7 days by the SCA (Greg Chang, 2021), 10 days by Maersk (2021) and more than 11 days by (Kemmsies, 2021)).

The predicted behaviour regarding the queue length and vessel's waiting times are close to the reported numbers. However, the danger exists to cherry-pick the proper set of parameters that calculate the desired results observed. Using AIS-data allows for a data-based validation of the model by providing more precise arrival and service rates for the case of the Suez Canal and other situations where vessels with AIS-transponders are mainly present (i.e., see, Yang et al., 2019). Nevertheless, with the parametrisation from

news media, the model output reflects the determining behaviour of the waiting vessels and thereby reflects the notion that queueing models needs to rely on the weight of empirical evidence (Worthington, 2009).

This paper aimed to analyse the new aspect of recovery due to the risk event of the Suez Canal blockage. As stated beforehand, the model did not consider performance-based aspects of the Suez Canal case, which are already present in the literature. However, due to the compatibility of QT models (see Worthington, 2009), this paper's model and the queueing service model by Griffiths (1995) can be integrated into a holistic model integrating the risk and performance-based view. Furthermore, the formulation from QT allows consistency to other models from QT, thereby extending the model further by, i.e., further analysing port operations in the waiting vessels' destinations.

The simplistic $M/D^k/1$ model has been formulated to demonstrate the feasibility to model the behaviour relevant for decision-making after the disruptive risk event of the Suez Canal blockage. The model assigns each vessel in line with an associated waiting time, thereby anticipating the delay of the affected SCs that put cargo onto the vessel. A risk assessment of said SCs can use this value because decision-makers base risk mitigation strategies on the duration of the risk event (Heckmann, Comes and Nickel, 2015). Therefore, this paper's model contributes to SCRM research gaps as it provides a quantitative method with particular emphasis on the time aspect from which decision-points are derived (see Heckmann, Comes and Nickel, 2015).

6 Conclusion

This paper proposes applying models from QT to derive essential parameters relevant to SCRM: the behaviour of the recovery process after a disruptive risk event occurred. The proposed Queuing Theory model with a risk-based view extends the performance-based view of queueing models in the SCM literature by analysing the backlog queue and cycle until the busy period is over. The proposed method is novel to SCRM.

The $M/D^k/1$ model allowed a quick analysis of the Suez Canal Blockage and predicted a close estimate of when the queue eventually resolved with the associated waiting times

for individual vessels. In the case of infrastructure-based disruptions, the application of this model provides insights into the backlog behaviour and supports data-driven decision-making to mitigate risk effects by providing method-driven transparency. Stakeholders of waterway-dependent transport routes like the Kiel Canal can benefit from this model by assessing the associated time costs of queueing and deducing appropriate risk mitigation strategies like circumventing or modal shift.

The application of this model provided a quantitative method to gain insights into the Suez Canal blockage from a SCRM perspective. Moreover, a whole methodological toolset is presented to analyse the situation further with QT. Furthermore, applying queueing models brings along the performance measures and cost-optimising strategies transferred to decision-making in the context of SCRM.

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