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Christian M. Ringle (Eds.)

The Road to a Digitalized Supply Chain Management

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The Road to a Digitalized Supply Chain Management

Smart and Digital Solutions for Supply Chain Management

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(Editors)

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Preface

Digitalization is changing the way organizations manage their supply chain and their daily logistical processes. The development of digitalized solutions and industry 4.0 have created a completely new business ecosystem. Additionally, customers are demanding more innovative, more diverse and greener products. This creates numerous challenges for all actors in the supply chain; yet, they also present an opportunity to create solutions and practices that improve performance and productivity.

This year's edition of the HICL proceedings complements the last years' volume: Digitalization in Supply Chain Management and Logistics. All entities along the supply chain are challenged to adapt new business models, techniques and processes to enable a smooth transition into a digitalized supply chain management.

This book focuses on core topics of digitalization in the supply chain. It contains manuscripts by international authors providing comprehensive insights into topics such as industrial internet of things, digital factory design, risk management or aircraft fleet planning and provide future research opportunities in the field of supply chain management. All manuscripts contribute to theory development and verification in their respective research area.

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 2018

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

Part I

Advanced Manufacturing and Industry 4.0

Running the Machine Faster: Acceleration, Humans and Warehousing

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To reduce the lead-time, modern logistics seeks to respond faster by accelerating physical and information flows. However, what are the impacts on logistics workers of an ever-faster logic? The purpose of this paper is to examine the relationship between process acceleration and the autonomy of order pickers. The method is to use exploratory qualitative research, based on fifteen visits to different regional distribution centers (RDCs) in the retail supermarket sector. The contribution of this paper is to apply Rosa's (2013) social acceleration theory to the specific context of logistics warehousing and to demonstrate how speeding up order picking systems is a key driver of change that has an impact on worker autonomy.

Keywords: Acceleration; autonomy; warehousing; order picking

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1 Introduction

In France, the warehousing and transport sector employs 1.37 million people (Stratégies Logistique 2017) and the surface of the regional distribution centers (RDCs) of supermarkets now doubles in size every two years. Three reasons can explain this rapid growth in the sector: supply, internal capacity and demand. Firstly, on the supply side, the growth in world trade, maritime shipping and the trend towards global sourcing in the last forty years has resulted in more and more goods circulating that require an effective logistic industry to make them available to the final customer.

Secondly, technological advances enable the automation of processes and mechanization in RDCs. The demand for automated warehouse systems is worldwide. In the USA, forecasters expect the robotics market in warehousing and logistics to have increased more than tenfold to $22.4 billion by 2021, up from $1.9 billion in 2016 (Yale Materials Handling 2017).

Thirdly, on the demand side, the advent of e-commerce and omni-channel distribution has led to the further expansion of the sector, making the modern warehouse the place “where the virtual becomes physical” (Moore, 2018). Information technology now instantaneously relays point of sales information to the distribution center, requiring demand-pull systems to be more and more responsive. Indeed, following the acceleration of information flows, the acceleration of physical flows becomes essential in order to fulfil the demand promise.

Owing to earlier advances in communications technology and digitalization, accelerated information flows predate accelerated physical flows and this has impacted the order picking process in the intervening period. Pick-by-voice systems, introduced in the late 2000’s, were symptomatic of speeding up information flow technology, while we are only now seeing the installation of fully automated and mechanized warehousing systems more widely in the sector. The consequence of this desynchronization of the two flows has been borne by warehouse order pickers. Before the introduction of pick-by-voice systems, order pickers used their knowledge and skills to plan a route around the warehouse and stack their pallet in an efficient manner. With its introduction, algorithm–based software instruct workers via headsets which product to pick next: ”the savoir-faire of order pickers has been reduced to a physical engagement” (Gaborieau 2012, p.1). While process acceleration increases productivity, it can also have consequences for human operators.

Therefore, the research question is as follows: what is the relationship between the acceleration of warehouse processes in RDCs and the autonomy of order pickers? Fig.1 presents the research focus. We choose to focus on order picking, because it is an important and expensive warehouse operation that is either labor or capital intensive (Gu et al. 2007). As such, from a technical perspective it has been the subject of performance evaluation studies with a view to optimization (Gu et al. 2010). A research gap exists because, although studies into the role of humans in warehouses can be found from a sociological perspective (Gaborieau, 2012; 2016), logistics research into this subject is rare. One exception is a literature review by Grosse et al. (2015) which found that researchers' order picking planning models have focused on cost efficiency rather than on human operators. They describe the human factor as the "missing link" in order picking system design.

To explore this missing link and its relationship with process acceleration, we use exploratory qualitative research methods, involving 15 visits to warehouse sites managed by four brand name RDCs and two leading third party logistics providers. A questionnaire about order picking was administered at one of the sites and discussions were held with managers. We structure this paper as follows. Firstly we examine the literature related to acceleration theory, warehousing, desynchronization, dynamic capabilities and the notion of worker autonomy within the context of social sustainability. Then we explain the research methodology and present the findings and propositions. This leads to a discussion and conclusion.

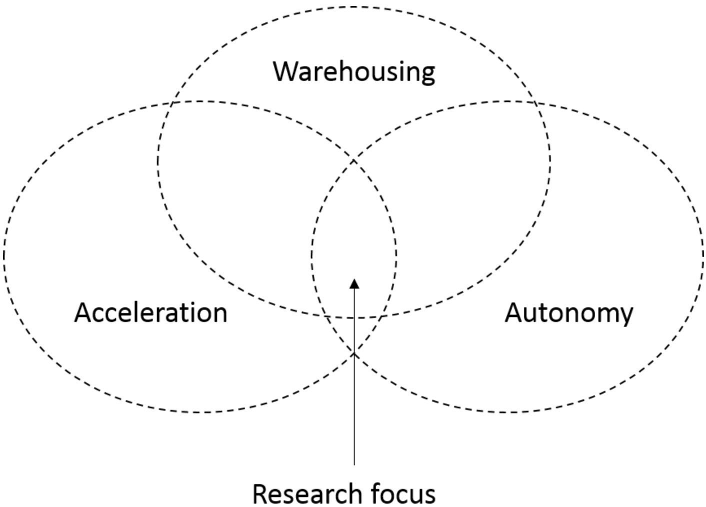

Figure 1: Schematic illustration of subject studied

2 Literature Review

2.1 Acceleration Theory

Writers have focused on speeding up movement as a defining characteristic of modern capitalism: “by far the greatest effect of industrialization…was to speed up a society’s entire material processing system” (Beniger 1986, p.427) and “everything that requires a long time lasts too long and everything that asks for time asks for too much time” (Rosa 2013, p.155). Underlying this drive for speed is a systems theoretical approach that concerns itself with “the securing of a ceaseless renewal of the elements of the system […] not static, but dynamic stability” (Luhmann 1996, p.79).

From the perspective of critical theory, Rosa (2013) has developed a theory of social acceleration that relates to three domains. Firstly, technological acceleration is found in production and transport and is defined as “the intentional acceleration of goal-directed processes” (2013, p.74). Secondly, the acceleration of social change is defined as a contraction of the present in all areas of life and a growing instability of our time horizons and expectations. Finally, the pace of life speeds up despite the increased free time that technological acceleration should enable, as a result of a scarcity of time resources. Importantly, he asserts that technological acceleration not only alters our experience of space and time (put simply, things seem to be happening more quickly), it also changes the quality and quantity of our social relationships. Acceleration can be viewed as the antonym of ‘depth’ in relationships. For our purposes, this analysis is interesting because it relates technological acceleration, on the one hand, to its possible impacts on humans, on the other. Before we explore this connection in more detail, it is necessary to consider acceleration in the context of warehousing.

2.2 Acceleration and Warehousing

Acceleration is an imperative of the modern RDC for three main reasons. Firstly, because the quantity of goods moving through a given site is steadily increasing, due to rising demand and the advent of multiple distribution channels. In order to maintain performance levels, there is no choice other than to speed up the order fulfillment process. Secondly, commodities (and above all perishable commodities) progressively lose economic value for the producer the longer they are in storage. The role of the logistic warehouse is therefore to minimize the time goods spend immobile and to speed up processing time, thereby reducing inventory costs through faster rotation. Finally, margins are tight and competition is intense in the supermarket sector, so advantage can be gained through investing in speeding up processes and replenishing supermarket shelves with the right products rapidly.

For these three reasons of growth, value and competition, the notion of stocks/stores/storage as something stable or fixed, or as provisions set aside until need arises, is now outmoded. Gu et al. (2006) define the major roles of warehousing as buffering and consolidation. We can add that the underlying logic of RDCs is movement, not immobility. In a picker-to-parts order picking system minimizing the order retrieval time is the main priority, since it has been estimated that order picking comprises as much as 55% of warehouse operating costs (de Koster et al. 2007). The sooner an order is ready for shipping the better. In order to speed up manual order picking, travel time and therefore travel distance around the warehouse has to be reduced to a minimum. This can be achieved by layout, grouping and storage assignment practices and by augmenting the work of the order picker by linking him/her to IT systems via headsets and microphones.

2.3 Desynchronization

However, warehouse acceleration risks the desynchronization of processes and functions (Rosa 2013) – a serious risk, given the importance of synchronizing flows for coordination, as advocated in the logistics literature (Simatupang et al. 2002). For example, speeding up warehouse materials handling will have an impact on inbound and outbound transport flows. Queuing and bottlenecks can occur because of improvements to one flow. Desynchronization, not only applies to material and data flows, but also to organizational functions: introducing an Enterprise Resource Planning (ERP) system, for example, will not produce the required results if the warehouse operations department is not appropriately trained in the new software. A reconfigured supply chain only operates at the speed of its slowest sub system with potentially dysfunctional consequences for the system as a whole (Rosa 2013).

Attempts to accelerate through automation and improved labor productivity always face risks, which are both technical and human. Because data processing and transmission now outpace material handling systems, the relative slowness of the latter becomes the weak link in the chain, demanding attention. Desynchronization and non-compatibility are an inevitable consequence of an acceleration of one part of the system, necessitating a holistic upstream and downstream vision of the whole system. For warehouse management, piloting parallel merging flows that function at different speeds becomes essential to avoid zero benefit from accelerating one of the flows.

2.4 Dynamic Capabilities

Efficient logistics increases the volume of transactions and availability of goods by managing time and eliminating barriers to circulation. The objective of a logistics warehouse is to minimize the lead time (the time taken from order reception to product delivery) by accelerating processing time. In the academic literature, a company's capacity to accelerate its supply chain is presented as "dynamic capabilities" (Teece et al. 1997; Beske et al. 2014). Specifically, Eisenhardt and

Martin (2000) define dynamic capabilities as "organizational and strategic routines by which firms achieve new resource configurations". Logistics capabilities help to build competitiveness for organizations. Therefore, in the highly competitive retail sector, where margins are tight, the capability to accelerate processing time enables a firm to gain a competitive advantage over another.

Helfat and Peteraf (2003) introduced the concept of the capability lifecycle to develop further this notion of dynamic capabilities. In the same way that products have a lifecycle of growth, maturity and decline, so too do capabilities. Therefore, logistics processes are capabilities that develop and eventually lose their ability to provide a competitive supply chain advantage. Acceleration theory, postulating that society is in an incessant cycle of speeding up processes, suggests that the lifecycle of logistic capabilities in the modern RDC is becoming shorter and shorter, as the organizational environment becomes increasingly turbulent and complex, requiring adaptability and regular reconfiguration.

Reconfiguring resources in the food industry is seen as essential, given the constant changes in consumer demands (Wiengarten et al. 2011; Trienekens et al. 2012) and the need to respond to them. Faster communications technology cycles and big data (Waller and Fawcett 2013) mean that firms seeking to maintain or gain market share, have to constantly monitor, evaluate and reconfigure their resources. The pull flow logic of demand chain management places the final customer as the driving force that the modern logistics warehouse aims to satisfy through product availability via multiple delivery channels:

"The implication of today's turbulent and unpredictable business environment is that demand chain solutions are required. That is, we need solutions that are flexible and capable of responding rapidly to structural change on both the supply side and the demand side of the business" (Christopher and Ryals 2014, p.29).

'Responding rapidly to structural change' involves accelerating warehouse processes. Yet the 'ever-faster' logic raises important questions about the social sustainability of the modern warehousing sector and the impact on the people who work in it.

2.5 Social sustainability and autonomy

This article considers the relationship between the acceleration of warehouse processes and the autonomy of workers. Of the three sustainability dimensions (social, environmental and economic), Ahmadi et al. (2017) show that social sustainability in supply chains has been under-researched, compared with environmental and economic sustainability. They conclude that this is "a research topic that will only gain in importance in years to come" (p.105). The importance of the human dimension as a research agenda is confirmed by Wieland et al. (2016) in data collected from 141 SCM researchers. After analyzing the difference between what should and what will become important, the people dimension of SCM was ranked the most underestimated research theme out of 35 subjects, followed in second place by ethical issues. They write: "Feedback from participants notes that supply chains are not "soulless machines," but complex socio-technical systems involving cognitive elements and impacted by face-to-face negotiations and conversations" (Wieland et al. 2016, p.207).

In a study of ten cases of sustainable supply chain management exemplars Pagell and Wu (2009) found that sustainable firms invest in human capital, aim to increase employee wellbeing, enhance organizational commitment and maintain a culture that values people and the environment. Workers in these organizations described their employers as thoughtful, caring, and committed. Varsei et al. (2014) evaluated the social performance of partners in a global supply chain. They focused on the four primary social dimensions specified in the Global Reporting Initiative (GRI 2012), namely, labor practices and decent work conditions, human rights, society and product responsibility.

2.6 Defining autonomy

In the warehousing context in France, where arguably, labor rights and systems of social protection exist, the focus for researchers into social sustainability is primarily on the experience of working conditions (Gaborieau 2012; 2016) and in the case of this research, on job autonomy. This has been defined as the degree of control that workers have over their own work situation (Brey 1999) and as spheres of independence that are directly or indirectly delegated by the organization to employees (Katz 1966).

In seeking to explain the paradox of disempowered industrial employees collaborating and engaging in a firm's activities, Katz (1966) argued that it was the undefined time left to workers within work time, to bring their culture into the bureaucratic workplace, which rendered the work tolerable for employees. In other words, worker autonomy engenders integration into an organization, through allowing a continuity between non-work life and the working life. Therefore, reducing worker autonomy in a tightly controlled work environment, with little time for association, could negatively affect worker commitment to the organization.

Importantly, Brey (1999) noted that even if organizations limit goal setting by workers, deciding on the means to achieve those goals can still provide autonomous spaces for meaningful and rewarding work. However, Brey describes three ways in which autonomy can be compromised. Firstly, monitoring and constant surveillance, enhanced by digitalization, remove moral autonomy and cause a loss of a sense of dignity and a perception of outside judgement. Similarly, task prestructuring by computer-defined systems imposes conformity on the employee and reduces his/her scope for freedom of action and decision-making. Finally, new computer systems create dependency on third parties, such as managers or system operators, who possess the necessary skills to install and maintain the technology, whereas the worker does not.

Vidal (2013) argues that there is a connection between an acceleration in the pace of work and low-autonomy work particularly in highly competitive sectors: the faster the process, the less time the worker has to decide what action to take or to communicate with colleagues. Where, as in the case of order pickers, a firm emphasizes and rewards the speed of a worker to complete a task accurately, little value is seen in allowing autonomous worker input.

This review of the literature relating to acceleration, autonomy and warehousing is summarized in Fig.2 below:

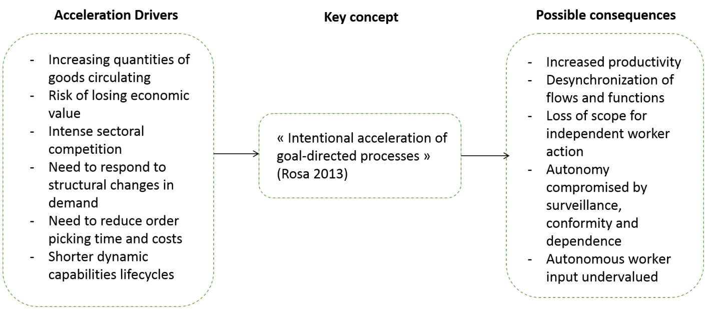

Figure 2: Proposed conceptual model for RDC acceleration

3 Methodology

Warehousing academic literature considers design, operation and performance evaluation, rather than understanding and contextualizing working conditions or the transformation of the modern warehouse. In a literature review of warehousing research, Davarzani and Norrman (2015, p.15) find that the "results of this study reveal a lack of reality-based investigations. Most of the scholars focus on quantitative research methods and mathematical modeling without any examples from real cases". They conclude: "that more empirical investigations should be conducted to understand and capture complexities of the real environment". Warehousing literature review articles (Gu et al. 2007; 2010; Davarzani and Norrman 2015) reveal an absence of theoretical frameworks and an emphasis on operational and technical solutions without reference to sustainability issues.

A systems approach rests on positivist assumptions of objective reality and independence from context. Such an approach, aimed at process optimization and improving productivity, encourages the progressive introduction of technological solutions, seen as neutral. Alternatively, complexity theory (Nilsson and Gamelgaard 2012) aims to take into account the diversity of human involvement in the organization of logistic processes.

The difference between the two approaches is made clear if we consider the question of self-organization or autonomy – to what extent is a worker able to plan his/her workload his/herself. For a systems approach, self-organization brings uncertainty and needs to be minimized. On the other hand, complexity theory recognizes that human intervention is an integral and inevitable part of the logistics process.

Table 1: Visits to warehouse sites during research

Firm	Sites and visits	Particularity of site
RDC A	3 sites and 4 visits	Ambient products only. Mechanized zone in each site.
RDC B	I site and 2 visits	6 warehouses for fresh, frozen and ambient products on one site, including large fully mechanized warehouse.
RDC C	I site and 2 visits	Site handling all product types, but shortly due for closure due to regional reorganization.
RDC D	I site and 2 visits	Ambient and fresh products. Site shortly due for closure due to regional reorganization. Order picking questionnaire administered here.
3PL A	3 sites visited once	3PL specializing in fresh and frozen products. Clients include leading supermarket brands.
3PL B	2 sites visited once	Client is a leading supermarket brands. One site due to close shortly due to contract termination.

The primary objective of this exploratory research is to consider the consequences of acceleration for the autonomy of order pickers. The research is based on 15 visits to different warehouse sites managed by six different firms (see Table 1) in France in 2017 and 2018, connected with the supervision of logistics students on internships. The selection of sites is random, since the logistics school receives offers of internships from firms and the researcher is allocated to supervise a certain number of students. Each visit to a site lasted between two and four hours and included a tour of the warehouse itself, detailed explanations of site operations and discussions with managers. After each visit, notes were made to keep a record of the principal observations. The research has been supplemented by discussions with and reports from logistics students on internships. Additionally a questionnaire was administered at RDC D that focused on managers' and order pickers' evaluations of pick-by-voice. The warehouses visited either handled frozen, fresh or ambient goods or in some cases all three types. The sites were also at different stages of automation and mechanization and had different strategies for their implementation. Supermarkets ran the majority of the sites visited, while specialist third party logistics service providers (3PLs) ran the minority.

4 Research findings

This chapter sets out four findings from this initial exploratory research, which are pertinent to the question of RDCs and acceleration and lead onto propositions, intended as possible future research directions. Table 2 sets out these propositions. The research initially focused on the impact of flow acceleration on worker autonomy. It has led to extra findings illustrating further consequences of acceleration on warehouse processes and organization.

Table 2: Summary of propositions

Concepts	Linked Propositions
Acceleration and autonomy	P1: Accelerating processes by intensifying an order picker's work rate reduces worker autonomy.
Desynchronization	P2: Desynchronization in warehouse processes is an inevitable consequence of speeding up flows, making global flow coordination essential.
Human Resources	P3: Process acceleration makes human resource management in RDCs more not less important.
Supply Chain	P4: Acceleration accentuates the role of RDCs as inward-looking, performance-focused and constrained logistics operations.

4.1 Accelerating order picking and worker autonomy

While other types of order picking exist (Richards 2011), the sites visited presented two types of acceleration of the order picking process. To start with the more recent, in France mechanized zones have been introduced in warehouses in the current decade, either as specific enclosed zones in a part of an existing site or as a whole building unit. These are defined as zones where all processes are mechanical and automated without human intervention in the sorting and picking process, except in a maintenance role. An enclosed zone handles heavier packages. It accepts full pallet loads, separates them and then prepares full pallet loads as ordered. While these specific zones have a high productivity rate, this is a capital-intensive solution to order picking and the return on investment is estimated at five years or more.

The second solution dates from the 2000's and is known as pick-by-voice software. A headset and microphone link order pickers to computer software, which determines the order of pallet preparation. BCP software estimate an increase in order picker productivity of 15% with pick-by-voice technology. However, it increases the workload, leading to concerns about risks to health (Anact 2010).

To ascertain the appreciation of pick-by-voice technology, a questionnaire was administered to 8 managers and 24 order pickers at RDC D. This revealed different evaluations of the pick-by-voice technology by the two groups. Managers' average score out of ten was 7.4, while workers gave a score of 5.1. Managers appreciate the technology because it enables tracking of activity, optimizes picking routes, reduces picking errors and improves productivity. From a human resource management perspective, it enables an accurate planning of the number of pickers needed each day. It also leads to better ergonomics for the worker, who now has his/her hands and eyes free.

The order pickers, on the other hand, found that the computer voice leads to a sentiment of dehumanization. During a visit to this site by the author, the manager asked a worker to explain how the headset and picking process works. He replied: "I just follow orders like an idiot". Order pickers using pick-by-voice also reported a feeling of being monitored and controlled; an increased workload leading to tiredness; limited possibility of communication between colleagues; a diminution of collective working; no global visibility of an order, making the job less interesting. The technology itself was criticized for frequent malfunctions, failures of the network, headaches and lack of comfort caused by wearing the headset all day and the regular repetitions needed to communicate with the software.

These findings confirm those of Gaborieau (2012; 2016) that pick-by-voice accelerates the pace of work, renders the work repetitive, reduces the opportunity for socializing and increases the weight carried per day. The first proposition relates to the human consequences of acceleration.

P1: : Accelerating processes by intensifying an order picker's work rate reduces worker autonomy.

4.2 Merging flows and desynchronization

At a site managed by RDC A, a manager presented the following problem of four different types of flow, operating at different speeds, both push and pull, some predictable and others not. These flows have to merge to be loaded onto the same truck, requiring piloting to minimize delays. The first flow is that of order pickers in pull flow using the pick-by-voice technology to stack pallets and deliver to the loading bays. The second flow is cross docking, where goods arrive from other RDCs of the same retailer for immediate dispatch to stores in the region. The third flow concerns special offers, launched by the centralized marketing department and operating in push flow.

Finally, the newly constructed mechanized zone, operating in pull flow, adds complexity to the site, for three main reasons. Firstly because there has to be a very careful selection of references that are suitable for this zone, which must respect both the specific materials handling criteria and the required pace of entry of goods into the zone. Secondly, because the zone handles 30% of references and the number of full pallet loads entering and exiting the zone is high, extra flows circulate within the same warehouse space. Finally, because the transfer of completed pallets from the mechanized zone to the loading bays is carried out by automatic guided vehicles (AGVs or robots). However, the route of AGVs from the mechanized zone to the loading bays crosses the "main highway" at the site and impedes the progress of order pickers and forklift drivers, whose pay is performance linked. (At another site of this group with the same configuration, this had led to incidences of sabotage of the AGVs by workers.)

Speeding up one flow or creating a new one and finding a solution to one problem - in this case that of heavy loads of 10 to 15 kilos, which can now be handled by the mechanized zone and not order pickers manually – has a knock on effect and sets up new challenges to be resolved. The shortening of dynamic capabilities lifecycles (Helfat and Peteraf 2003) suggests that the desynchronization of flows and the need to audit and pilot flows effectively are set to recur more frequently. The second proposition is about desynchronization. P2: Desynchronization in warehouse processes is an inevitable consequence of speeding up flows, making global flow coordination essential.

4.3 The roles of humans in warehousing

Changing flows in RDCs has an impact on the organization of work tasks. Because management realizes that order picking is an unattractive task, many of the sites visited had moved towards greater flexibility or polyvalence. In general, while order pickers were content to be trained to take on the role of forklift drivers, the inverse was not the case. One manager at RDC site D acknowledged this problem and refused to accept that staff could choose not to do order picking. It was clear that within the site requiring staff to do order picking as part of their different tasks had become a delicate issue.

Sites visited had different levels of temporary staff, reflecting the recruitment difficulties that affect the sector. At RDC site C, due to close in 2018 and be relocated, the percentage of temporary staff had reached 50% and was making the task of management in planning and organizing a workforce difficult. The best run sites also had the lowest levels of temporary staff. The overall impression from the visits to the 15 different sites was one of a sector undergoing rapid change. Some sites were due to close as part of a national restructuring programme. Other sites were in the process of introducing mechanized zones and robotic systems. RDC site B had recently completed a fully mechanized warehouse for full pallet loads, where the only humans are those in the truck loading and unloading areas and maintenance workers. Some managers were aware of the impact of these changes on workers and stressed the need for retraining, upskilling and recruiting more highly qualified staff. This leads to the third proposition that concerns human resources. P3: Process acceleration makes human resource management in RDCs more not less important.

4.4 The bow tie metaphor

The structure of a supply chain, in which RDCs operate, can be likened to a bow tie, as they are at the center of high volume inbound and outbound flows. (Most RDCs stock around 10,000 different product references.) Here, the main feature of the bow-tie metaphor is that there are complex and variable inputs or inbound flows, that a compact core accepts, then recomposes and distributes what has been stored to a wide variety of destinations. Two observations can be made about the impact of acceleration on the organization of the supply chain. Firstly, due to the need to accelerate and reconfigure processes, the pressure to reach performance targets, the difficulty in recruiting and retaining qualified staff and their position at the center of massive inbound and outbound flows, RDCs focus purely on the management of internal flows and arriving and departing transport. A 50,000m2 warehouse that serves as a conduit for many suppliers and customers only has contact with them in matters directly related to flow management, such as packaging problems. In concerning themselves primarily with their own logistics, RDCs exemplify the strict division of labor and functions along the supply chain and the rigid boundaries that characterize this sector of activity.

The second observation relates to what Carter et al. (2015), in their development of a theory of the supply chain, refer to as the “horizon or visibility boundary”. These authors suggest as a formal premise that: “the supply chain is bounded by the visible horizon of the focal agent”. Although RDCs are central nodes in the supply chain, they are more hidden from view than visible, bounded more by confidentiality and security than openness. Moore (2018) comments: “It is tempting to say that these buildings make the internet visible, except that their visibility is strictly limited”. It would be interesting to ascertain suppliers’ and customers’ level of knowledge of RDC operations, since they represent the next node in the supply chain. Furthermore, has the acceleration of processes in RDCs led to greater or lesser visibility of them by suppliers and customers? If the latter is the case and there is less visibility, following Carter et al.’s premise, can RDCs be viewed as part of supply chains or are they more accurately described as specialized constrained logistics operations. This leads us to the fourth proposition that relates to supply chain structure. P4: Acceleration accentuates the role of RDCs as inward-looking, performance-focused and constrained logistics operations.

5 Discussion and Conclusion

This exploratory research has shown that speeding up information flows through technology in labor-intensive order picking processes reduces worker autonomy and that process acceleration is an underlying logic of the modern RDC. In this final chapter, we discuss further the propositions made and consider where this might lead a warehousing research agenda.

To optimize information and physical flows the boundaries or borders, in the widest meaning of the terms, between and within firms have to be managed – boundaries between buyers and suppliers or between different departments within the same firm or between different zones in the same warehouse. For flows of goods and information to operate efficiently, boundaries have to be almost invisible or frictionless, soft rather than hard. The management of logistic processes across and within organizations aims to be seamless and the boundaries blurred.

Boundaries reflect the constraints imposed in the functioning of organizations and exist for purposes of control, channeling or connecting (Mezzadra and Nielsen 2012). However, process acceleration puts these boundaries under stress, disturbs established configurations, provokes desynchronization (P2) and requires the reorganization of different flows. The disruptive power of acceleration sets in motion a series of impacts, both positive and negative, anticipated and unforeseen, that bring into question the stability of existing boundaries (Hernes and Paulsen 2003). As Vakkayil (2012, p.206) has observed: “In constantly changing environments it is impossible to draw permanent lines of demarcation”.

We have noted that one of the imperatives driving acceleration in warehousing is economic value loss. Rosa (2013, p.163) describes the time goods spend in storage and distribution as time when “the realization of created surplus value is delayed”. He sees one of the basic systemic problems of capitalist economies as the need to maintain accelerated circulation to avoid such value loss. He argues that it is for this reason that logistics has to be more technically advanced than production – to ensure that the sphere of potential value loss does not negatively affect the whole value creation process and eventually, value capture.

Through applying Rosa’s theory of social acceleration to RDCs, the contribution of this exploratory research is to demonstrate that there is an ongoing tension between the systemic need for acceleration in logistics warehousing and the existing boundaries or constraints that have been negotiated and established in the supply chain and in the workplace. An example of these tensions, presented in this paper, is the autonomy of order pickers (P1), defined either as control over the work situation (Brey 1999) or as spheres of independence (Katz 1966). A future case study research agenda could examine in more detail how this tension between the established boundaries, which allow a degree of worker autonomy in warehousing and the imperative to accelerate is evolving. Additionally the nature of relationships between RDCs and suppliers/customers, and the changes to these relationships and supply chain structure associated with RDC process acceleration (P4) could be studied. Finally, by moving away from technical performance-based optimization of order picking systems, as suggested by Grosse et al. (2015), research could consider the future role of human resources in warehouses (P3) and provide exemplars of valuing human input.

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Supplier Integration in Industry 4.0 – Requirements and Strategies

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Cross-company networking is essential to successfully implement Industry 4.0. In this context, numerous new demands on suppliers arise leading to integration challenges that require specific integration strategies. While these topics are important in business practice, an aggregated holistic overview is still missing. Therefore, this article examines new demands on suppliers, challenges in the implementation process, and integration strategies for supplier integration in the context of Industry 4.0. Expert interviews with 15 different industrial companies from the sectors mechanical and plant engineering, electronics and electrical engineering, automotive, and information and communication technology serve as an empirical basis. This study provides insights into the challenges and strategies of supplier integration, helps academia to understand this topic, and indicates need for future research. Furthermore, this paper develops implications for corporate practice in the area of supplier management.

Keywords: Industry 4.0; Industrial Internet of Things; Supplier Integration; Integration Strategies

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1 Introduction

Industry 4.0 aims to establish intelligent, self-managing, and interconnected industrial value creation to ensure future competitiveness of the manufacturing industry (Kagermann et al., 2013; Kang et al., 2016; Lasi et al., 2014). Both research and practice have mainly focused on technological developments and the technical implications for value creation so far (Brettel et al., 2014; Emmrich et al., 2015; Kagermann et al., 2013; Kans & Ingwald, 2016; Kowalkowski et al., 2013; Liao et al., 2017; Rennung et al., 2016). Furthermore, almost exclusively large companies have been the focus of academia and corporate practice (Kowalkowsi et al., 2013; Radziwon et al., 2014).

Up to the present day, Industry 4.0 is primarily thought within the boundaries of a company and consequently present efforts aim at implementing the concept in a company. Yet, the predicted potential of intelligent interconnected value-added processes can only be exploited in its entirety by interconnecting companies and value chains resulting in networks (Kagermann et al., 2013; Lasi et al., 2014). Therefore, the implementation of the holistic concept Industry 4.0 also requires a holistic approach.

However, integration processes across company boundaries pose numerous challenges. First, such integration requires openness, willingness to cooperate, and compatible technologies on all sides (Kiel et al., 2017; Müller et al., 2018a). Second, the integration of suppliers requires, e.g., them to have the necessary infrastructure and drive forward the implementation of Industry 4.0. As suppliers are often small and medium-sized enterprises (SMEs), some might have neither the necessary resources nor access to the required knowledge (Icks et al., 2017, Müller et al., 2018b). Therefore, especially SMEs need to find adequate partners for cooperation (Müller et al., 2017).

The aim of this study is to analyze how to integrate suppliers in the context of Industry 4.0. The following research questions are proposed:

(1) Which requirements need to be met when integrating suppliers?

(2) Which challenges arise when integrating suppliers?

(3) Which strategies can be used to integrate suppliers?

Shedding light into the research object is important for several reasons. The way suppliers are integrated into the value creation process of a company has an impact on the extent to which possibilities Industry 4.0 can be used at all (Siepmann, 2016).

Supplier integration represents a source of differentiation and can therefore help to create sustainable competitive advantages. Last but not least, versatile, real-time-optimized, and autonomous cross-company value creation networks can only be established through adequate supplier integration, which is the overriding goal of Industry 4.0 (Bauernhansl, 2014).

2 Theoretical background

2.1 Industry 4.0

The term ”Industry 4.0” refers to a paradigm shift in industrial value creation. It is particularly widespread in the German-speaking world (Burmeister et al., 2015; Lasi et al., 2014), while the term ”Industrial Internet of Things” is particularly used in the Anglophonic world (Hartmann & Halecker, 2015; IIC, 2017). The origin of Industry 4.0 dates back to the year 2011 and was significantly influenced by the work of Kagermann et al. (2011) in the context of the Hanover Fair. Furthermore, they published implementation recommendations in 2013 in a final report of the Working Group Industry 4.0 (Kagermann et al., 2013).

In the age of industrialization, technical innovations repeatedly led to paradigm shifts that are called ”industrial revolutions” ex-post (Lasi et al., 2014). The first industrial revolution began at the end of the 18th century and was characterized by the mechanization of the value creation process and the use of water and steam power. Dated back to the beginning of the 20th century, the second industrial revolution was characterized by mass production through assembly line production, the application of the Taylor principle of division of labor, and the use of electrical energy. The use of electronics and information technology to automate and digitize production heralded the third industrial revolution in the 1970s. All industrial revolutions have led to an increasing degree of complexity of the production systems (Bauernhansl, 2014; Kagermann et al., 2013; Kelkar et al., 2014; Lasi et al., 2014).

It is predicted that the present economy is at the beginning of a fourth industrial revolution, summarized by the term Industry 4.0. This new paradigm shift is characterized by a digital interconnection and virtualization of the industrial value creation process (Bauernhansl, 2014; Kagermann et al., 2013; Kelkar et al., 2014; Lasi et al., 2014). For the first time in history, a change of paradigm is announced a priori (Drath & Horch, 2014). For this reason, Industry 4.0 is to be understood as a vision whose potential can be realized in the future (Drath & Horch, 2014, Lasi et al., 2014). However, as the technical foundations have existed for some time, while the practical implementation is only gradually developing, some scientists perceive Industry 4.0 more as an evolution than a revolution (Kagermann, 2014; Sendler, 2013).

Industry 4.0 is controversially discussed in science, hence no common understanding has emerged so far (Bauer et al., 2014). According to Bauer et al. (2014, p. 18), Industry 4.0 is a ”real-time capable, intelligent, horizontal, and vertical networking of people, machines, objects” and information and communication technology systems. Based on intelligent, digitally interconnected systems, people, machines, plants, logistic processes, and products can communicate and cooperate in real-time with each other (Platform Industrie 4.0, 2017). Industry 4.0 is ”a new level of organization and control of the entire value chain across the life cycle of products” (Platform Industry 4.0, 2017). The interconnection of the operational value creation process takes place across corporate functions, companies, and entire value creation chains (Kagermann et al., 2013). Therefore, a high level of standardization of interfaces between companies is required (Müller & Voigt, 2017).

Using new technologies enables the development of an intelligent value-added system within the framework of Industry 4.0. First, cyber-physical systems (CPS) result from the interconnection of embedded systems and link information technologies with mechanical and electrical components (Becker, 2015; Kagermann et al., 2013; Zhou et al., 2015). In addition, the collection, analysis, and use of large amounts of data play a decisive role and is subsumed among the term ”big data”. Finally, cloud solutions for storing and transmitting data via stable networks are used (Rüßmann et al., 2015; Bauer et al., 2014).

Research on the subject of Industry 4.0 is generally still in its infancy, which is particular true for the implementation across company borders and value creation chains.

2.2 Supplier Management and supplier integration

Supplier management is ”the design, management, and development of a company’s supplier portfolio and supplier relationships” (Wagner, 2002, p. 11). The aim of supplier management is to secure a company’s demand through an efficient supplier network and thereby contribute to the value creation (Helmold & Terry, 2016).

Supplier integration is a sub-process of supplier management (Helmold & Terry, 2016) representing a form of vertical cooperation (Möller, 2002). This implies close strategic cooperation with both key suppliers and customers in order to generate advantages (Schoenherr & Swink, 2012; Thun, 2010; Wiengarten et al., 2016). The goal of supplier integration is to design integration strategies, practices, processes, and behaviors in a collaborative, synchronized, and well-controllable manner (Zhao et al., 2015). Combining a company’s resources with the capabilities of its supplier and realizing joint activities can help to generate sustainable competitive advantages (Rink & Wagner, 2007). Shortening product development and product life cycles and the associated fast, flexible, and efficient production processes in the context of Industry 4.0 increases the importance of supplier integration (Hofbauer et al., 2016).

3 Methodology

3.1 Research design

The study follows a qualitative research design to answer the research questions (Gläser & Laudel, 2010). A qualitative design is characterized by considering and analyzing different perspectives and integrating the interviewees’ and researchers’ views (Flick, 1995). This design is particularly suitable for the research at hand because supplier integration in the context of Industry 4.0 is a very topical issue and little comprehensive knowledge is available (Kaiser, 2014).

Semi-standardized in-depth expert interviews serve as a data basis (Gläser & Laudel, 2010). All interviews followed an interview guideline and were conducted via telephone in German. On the one hand, the interview guideline was designed so that the interviewee was able to openly respond to questions and present his or her subjective perspective. The result was a natural course of conversation in which the interviewee could answer freely. In addition, the interviewer could follow up on certain questions or adapt his questions. On the other hand, a partial standardization of the interviews allowed to compare and evaluate the interviews (Mayring, 2015; Gläser & Laudel, 2010). After general questions, the experts were asked about their opinion on the topic of supplier integration in the context of Industry 4.0. The main part contained specific questions on the sub-topics (1) challenges with suppliers in the context of Industry 4.0, (2) expectations of suppliers as for Industry 4.0, (3) and adequate integration strategies. All interviews were audio-recorded and subsequently transcribed with the permission of the interview partners leading to more than 200 pages of text material. For confidentiality reasons, all interviews were anonymized.

3.2 Data sample

The data sample comprises 15 semi-standardized in-depth expert interviews. Originally, 46 companies were surveyed, and thereof experts from 15 companies were recruited for an interview, corresponding to a response rate of approximately 33 percent.

The surveyed experts come from a heterogeneous sample of companies, headquartered in the Federal Republic of Germany. The sample includes companies from the sectors electrical engineering and electronics, mechanical and plant engineering, automotive, and information and communication technology. These sectors were chosen because they are representative for the most important sectors in Germany, and as they are in particular, driving forward Industry 4.0 (Kagermann et al., 2013). The following figure shows the distribution of enterprises within the sample.

The size of the sample companies is heterogeneous. It varies in terms of turnover from approximately 150 million to approximately 80 billion euros and in terms of employees from approximately 3,000 to approximately 400,000 employees. All experts hold a position in either medium or upper management and have several years of business experience. The interviewed positions include nine representatives from purchasing departments, of which six are head of purchasing, two Chief Digital Officers, one Chief Executive Officer, one Chief Technology Officer, one head of external cooperation, and one head of supplier management.

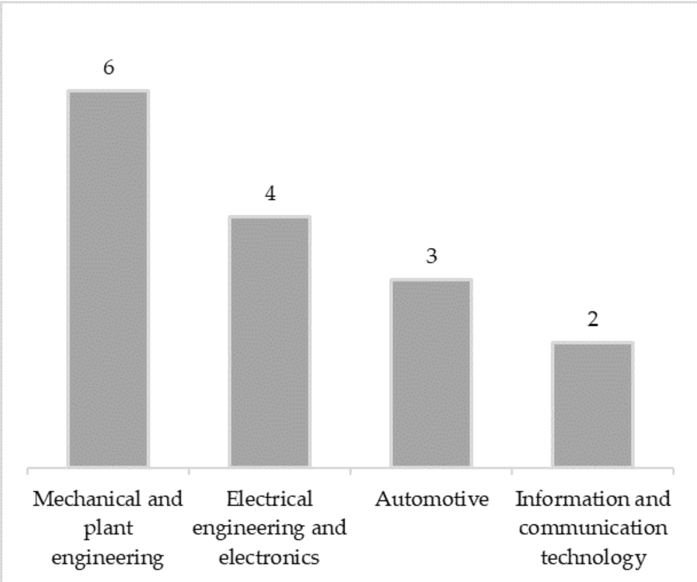

Figure 1: Sector distribution of sample companies

All interviews were conducted from April to June 2017 via telephone. In accordance with the interviewees, the interviews were audio-recorded and transcribed.

3.3 Data analysis

The interviews were examined using a qualitative content analysis according to Mayring (2015). Therein, the experts' statements are reduced to their core statements and, later on, paraphrased and subsequently generalized (Mayring, 2015). The paraphrases, which contain similar content, can be divided into few statements, which Mayring calls categories. The categories are formed inductively using a keyword analysis (Gläser & Laudel, 2010; Kaiser, 2014). The frequency analysis of individual nominations allows an interpretation and analysis of expert statements from which relevant research results can be extracted (Bogner et al., 2014; Gläser & Laudel, 2010; Mayring, 2015).

4 Analysis and results

4.1 New requirements for suppliers

The increasingly demanded ability to collect, store, and profitably evaluate data is mentioned by ten respondents to be new requirements for suppliers in the context of Industry 4.0. At the same time, the company representatives emphasize that many suppliers have paid little attention to this so far. Therefore, suppliers are demanded expand these abilities by the interviewees, even if those are just supplying parts or raw materials.

Eight respondents considered the creation of interfaces and the implementation of standards to be important requirements. Smooth interfaces are required especially for digital real-time data exchange, as mentioned by the respondents. From their perspective, suppliers need to be willing to adapt to customer-specific standards and interfaces, even if different standards exist among their customers.

The willingness to provide data as a requirement for their own suppliers in the context of Industry 4.0 was mentioned by six respondents. So far, data have often been published only if necessary and hesitantly, which should be done proactively in the future, according to the interviewed experts.

Five respondents named a cultural shift towards common, collaborative value creation within the Industry 4.0 concept as important. In the future, suppliers should no longer respect their own company boundaries as borders, but they should think and act beyond these borders, increasing partnership-based exchange. According to the interviewees, partnership and cooperation needs to be extended, replacing predominant competitive thinking.

The understanding of the shortening innovation cycles by Industry 4.0 to be an essential requirement was named by four respondents. Traditional industrial sectors, such as mechanical engineering, would have to rethink their way of creating value, in order to approach short innovation cycles like those of, e.g., the software industry. The interviewees regard this as an essential prerequisite in order to, e.g., produce cyber-physical systems or offer platform-based business models.

Three respondents described an increased orientation towards the common end customer of different supply chain partners. Consequently, the primary goal of value creation should focus on the common end customer and his needs, following the opinion of the interviewed experts.

4.2 Challenges of supplier integration

Nine surveyed company representatives named a high degree of complexity in supplier integration in the context of Industry 4.0. Inhomogeneous standards and differing requirements across industries hinder the implementation of Industry 4.0 across value chains. For example, different Enterprise-Resource-Planning systems must be harmonized in order to enable a global network.

The lack of resources on the part of suppliers as a hindrance was mentioned by eight respondents. These statements do not only refer to a lack of financial resources, but also to a lack of knowledge and work force.

Another eight respondents stated inadequate structures and interfaces as a challenge. In many companies, different departments work with different standards and a company-wide coordination does not take place.

The suppliers' uncertainty about the expected developments was described by five interviewees. Many suppliers do have a wait-and-see-attitude and, as for now, do not address the issue of Industry 4.0 proactively. This leads to a lack of competence creation instead of using time to gather information and define strategies for Industry 4.0.

Five respondents cited a lack of understanding, particularly as for the urgency of implementing Industry 4.0. This is especially true for SMEs. Instead, sectors would pursue the typical goals, e.g., mechanical engineering strives rather for improving mechanical quality, than preparing for future topics.

Another five respondents described issues of data security and data protection. Until now, issues of data security are not completely clarified from a legal perspective and the question of data ownership remains unclear. Further, concerns such as hacker attacks and espionage should be taken care of and secure encryption methods should be applied.

Challenges resulting from a changing balance of power were mentioned by five respondents. Suppliers would be afraid of losing importance in the future, as their competence is no longer of central importance in Industry 4.0. In addition, customers are concerned because suppliers could put more pressure on them and even completely bypass or replace them.

Four respondents described possible disruptions because of new competitors as a challenge. There are concerns in particular with regard to platform providers or data-based business models. These could create the core benefit for the customer in the future and thus degrade existing companies as suppliers or completely displace their business model.

A lack of willingness to exchange data on the part of suppliers to be an obstacle was also mentioned by four respondents. For example, there is a lack of understanding that data can only generate value in the future if it is exchanged across the entire value chain. At present, data is considered to be a trade secret and most firms disclose it whenever possible. However, a compromise must be found in order to create advantages for all partners within a value chain.

4.3 Integration strategies

Eight respondents described precise and comprehensive communication of common standards as an appropriate approach to supplier integration in Industry 4.0. Many suppliers did not know, which standards were required and which type of cooperation asks for which specific standard. It is therefore essential to clarify issues of standards and to make it easy for the suppliers to understand the requirements.

The establishment of digital platforms as a strategy for integrating suppliers is also mentioned by eight experts. The platforms could be used in different contexts, for example, in procurement, supply chain management, joint tool management, and product development. It is important to increase potentials through joint networking and to make them accessible to all partners in the value chain.

Six of the company representatives cited transparency in communication with suppliers as an essential approach. Thus, honesty and transparency are central points here. A clear presentation of the consequences following from a lack of co-operation and an honest communication are indispensable in order to cooperate with suppliers in the context of Industry 4.0.

Further, contractual security is an important issue described by two respondents. Suppliers need to have a reliable basis with a long-term perspective in order to be able to make the corresponding investments for the integration process. Since suppliers have to meet different standards for their numerous customers, they aim for keeping their customers for a long period of time, as otherwise specific investments would not payoff. Establishing long-term relationships is the only way to encourage the supplier's willingness to invest in Industry 4.0 and the integration process.

The creation joint business models was mentioned by two respondents. As suppliers can play a key role in new, joint business models in the context of Industry 4.0, this is a way to motivate the suppliers. For example, there are data-driven business models in which the supplier is responsible for data evaluation and is thereby offered an incentive to make investments.

Two of the respondents also mentioned common research and development activities. For example, joint development of Industry 4.0 components and software could help to qualify suppliers for Industry 4.0. It is in the hands of customers to help their suppliers to implement Industry 4.0 and to accelerate their efforts through corresponding demand.

The provision of resources was mentioned by a single respondent. Nevertheless, this integration strategy represents an interesting approach to support suppliers. For instance, specialists can be lent out for consultation and technical components can be made available at low cost or free of charge to speed up the implementation process.

5 Conclusion

This article presents the results of 15 in-depth expert interviews as for supplier requirements, challenges during the implementation process, and the adequate integration strategies for supplier integration in the context of Industry 4.0.

According to this study's results, key requirements include developing the ability to collect, store, and evaluate data, creating smooth interfaces, implementing standards, and creating a willingness to exchange data. In the course of the supplier integration, various challenges arise. The most important ones comprise coping with the high complexity, lacking in resource base, and having no adequate structures and interfaces. The new demands on suppliers and the challenges that arise in supplier integration can be classified into different fields of action that require specific integration strategies for companies.

In the future, important strategical issues are, among others, undertaking a comprehensive communication, establishing common standards, and maintaining long-term contractual security. These provide the basis for establishing strategies to face the challenges. Key strategies include creating digital platforms, carrying our joint business models, and undertaking common research and development activities.

It should be noted that the integration strategies presented by the interview partners reflect the status quo and include the strategic environment of the companies, which represents a limitation of the study at hand. Therefore, companies should review their own strategic options and their individual strategic environment to develop their own supplier integration strategies.

The study aggregates key information that is relevant to practice, as companies can use it as a starting point to develop successful supplier integration strategies in the context of Industry 4.0. Research can also use the results to develop the theoretical basis for future changes in supplier management caused by Industry 4.0.

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Scope for Industry 4.0 in Agri-food Supply Chains

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This study investigates the current capabilities and technologies adopted in the agri-food industry in Australia and the scope for transition to Industry 4.0. Data were collected from 360 firms representing suppliers, producers, manufacturers, wholesalers, logistics providers and retailers to represent a supply chain perspective. The technologies and strategies were grouped based on the various supply chain players against the maturity stages of Industry 4.0 as prescribed by Schuh et al (2017) in order to discern the integration efforts and degree of interoperability in the supply chain. We establish that upstream players tend to adopt technology mainly for internal operational efficiencies and B2B transactions. We propose that the individual orientation, interoperability and capabilities of these firms will need to be reassessed to derive a systematic plan for progression into a technology architecture for the overall supply chain. Despite the fragmented adoption of advance technologies evident at various points of value creation in the supply chain, we recognize and highlight the vulnerability of many small businesses and upstream players in the food industry who appear to be lagging behind in the fourth industrial revolution as well as the disruptive changes entailed to keep up and compete in the digital age.

Keywords: Agri-food supply chain; Industry 4.0; Maturity stages; Survey methodology

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1 Introduction

In the agri-food industry, logistics and supply chain management activities are deemed more challenging due to the need for time-based approaches, integral quality control and associated tracking and tracing systems of food products along the chain. These include meeting temperature control requirements, product perishability issues and the variability in agri-food quality (Soosay 2008, Sahin et al 2007). These products include grain, livestock (beef and dairy) and horticulture. Inter-organizational technology systems offer the potential to improve operational efficiency, responsiveness and traceability by supporting transactions and material flow more efficiently (Kim et al 2018, Johnston & Vitale, 1988). Consequently, integrative efforts are needed between supply chain members to reach new levels of competencies where firms can willingly share data and business applications.

Industry 4.0 requires supply chains to not only adopt modern technologies and engage in capability development, but also to transform their business models and network structures to achieve coherent vertical integration. This is likely to change traditional relationships between suppliers, manufacturers, wholesalers, retailers and customers. There are already some industries such as electronics and fast moving consumer goods (FMCG) adopting state of the art technologies and moving along the supply chain 4.0 continuum at present; while other industries are still lagging behind. There is concern that the diffusion rate of modern technologies in the agri-food industry has been much lower than anticipated, suggesting that their implementation may involve challenges or lack of collaboration (Costa et al 2013, Vlachos 2004, Salin 1998).

There are various empirical studies on supply chain technology adoption in the literature (Aydin & Parker 2018, Krishnan et al 2015). While the authors have established reasons why firms and some industries struggle with technology implementation, the theories, concepts and practices developed in the context of food supply chains need greater understanding as this industry faces distinct economic settings, such as market imperfections, heterogeneity of actors, information asymmetries, technology infrastructure, immature supply chain networks and the perishable nature of food products (Solanki & Brewster 2014, Xu et al 2004). As a result, this study examines the current capabilities, technologies and interoperability strategies adopted in agri-food supply chains and the scope for transition to Industry 4.0. The central research question is ’How is Industry 4.0

distributed across the stages of value creation in the agri-food industry in Australia?'

2 Theoretical Framework

Industry 4.0, also known as the fourth industrial revolution, is a collective approach to digitalization, interconnectedness and new technologies. It is increasingly gaining consideration from policymakers, businesses and academia worldwide. The term 'Industrie 4.0' became popular in 2011 with a Working Group offering the German federal government a vision for the future of industrial manufacturing. It subsequently formed part of the government's 'Action Plan High-Tech Strategy 2020' to ensure technological leadership with digitalization, smart factories and Internet of Things (IoT) (Klitou et al 2017). Industry 4.0 is expected to result in four long-term relationship paradigm shifts and changes to the landscape of European manufacturing: Factory and nature, Factory and local community, Factory and value chains (distributed and responsive manufacturing through collaborative processes, enabling mass customization of products and services); and Factory and humans. These will have impacts on technology implementation in a wider manufacturing and distribution environment (Santos et al 2017).

Schuh et al (2017) articulate that the fourth industrial revolution extends beyond ICT integration in industrial manufacturing to include transformations in organizations and their culture. Businesses will need to become more agile and adapt to changing environments. These authors prescribe the acatech Industrie 4.0 Maturity Index model which delineates the successive maturity stages for Industry 4.0. This model assists companies identify which stage they are currently at and their potential capability development and transformation to fully implementing Industry 4.0. The stages span from 'Computerization', 'Connectivity', 'Visibility', 'Transparency', 'Predictive Capability' to 'Adaptability'.

Industry 4.0 should not only be discerned at the organizational level, but will also revolutionize manufacturing supply chains with new products, services and business models through IoT from product design right through to customer delivery (Roblek et al 2016). For instance, it emphasizes the global network of machines in a manufacturing environment capable of exchanging information, knowing variations to be made to the product and being able to control each other. This is possible with collaboration between suppliers, manufacturers and customers to increase the transparency from when the order is initiated, manufactured and dispatched until the end of the product's life cycle. Hence, it is important to analyze how supply chains are impacted by Industry 4.0.

Supply chain networks today depend on a number of key technologies that enable integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement, smart warehousing, spare part management and advanced analytics (Schrauf & Berttram 2016). Lee et al (2014) highlight how technology is the key to 21st century global supply chain management for operational competitiveness. By tracking the evolution of supply chain technologies in the textile and apparel industry, these authors classify the technologies adopted in achieving superior supply chain performance and competitive advantage.

It is evident that digital networks offer higher levels of resilience and responsiveness with more efficient and transparent service delivery. Mussomeli et al (2017) report the shift from linear, sequential supply chain operations to interconnected, dynamic and integrated networks. Predictive shipping is another emerging concept, where according to Alicke et al (2017), a shipment which is already in the logistics network is matched with customer order at a later stage. Resultantly, demand management will need to be implemented at a more granular level using techniques such as micro segmentation, mass customization, innovative distribution concepts and more sophisticated scheduling practices. The emerging trends in Industry 4.0 can pertain to warehouse robotics, autonomous road transportation, logistics and technology services, supply chain social responsibility, the race for the last mile, and the rise of the virtual logistics team (O'Byrne 2017). Hence, businesses will need to reframe their business models and invest in how they can digitize their products and systems, starting with the supply chain. They will also need to reassess their capabilities, technologies and interoperability strategies in order to transition to Industry 4.0.

In this paper, we examine Industry 4.0 in the context of agri-food supply chains in Australia using the maturity phases from Schuh et al (2017) to understand the extent of technologies used by firms throughout the value creation. These phases are grouped as 'Computerization & Connectivity', 'Visibility & Transparency', 'Predictive capability', and 'Adaptability & Self-learning'.

3 Methods

Data were collected in three stages over a 12-month period as part of a larger study on supply chain integration. An online survey was sent to over 2,000 organizations obtained from various databases and industry associations. During the first phase, we collected data from suppliers, producers, manufacturers, wholesalers and retailers associated with the agri-food industry. Subsequently, we implemented a second phase of data collection after identifying the secondary players in the supply chain comprising input suppliers, packaging suppliers and third party logistics providers who also service the food industry. Input suppliers include firms who provide equipment, machinery, feedstock, fertilizers and other related products to farmers, growers and agri-food producers. Packaging suppliers include an array of firms who produce and supply paper, plastic, fibre containers, foam food trays, cartons, boxes, glass, closures, foil, film and other products used in the food industry. Logistics providers were largely transport companies, although some provided warehousing, light assembly and secondary packaging services. The third phase of data collection were reminders sent to firms in order to increase the response rate. As a result, a total of 360 usable questionnaires were received, constituting a response rate of 18% and where these firms represented a whole of chain perspective. These firms are illustrated in the following table showing their position in the supply chain as well as the firm size as prescribed by the Australian Bureau of Statistics classification. Majority of the firms were small and medium sized accounting for 74% of the sample population.

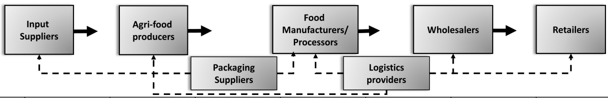
Table 1: Profile of firms

		n	%
Position in the Chain			
	Input suppliers	30	8.3
	Growers/Agri-producers	68	18.8
	Packaging suppliers	20	5.6
	Food Manufacturers	54	15.0
	Wholesalers	67	18.6
	Logistics providers	63	17.5
	Retailers	58	16.1
	Total	360	100
Firm size			
	Small (5-19)	81	22
	Medium (20-199)	186	52
	Large (>200)	93	26
	Total	360	100

In the survey, firms were required to rate the extent of usage for a list of technologies using a 7-point Likert scale (7 = to a very great extent; 6 = to a great extent; 5 = to a fairly great extent; 4 = to a moderate extent; 3 = to a small extent; 2 = to a very small extent; 1 = not at all). In this paper, we have categorized these technologies into four main maturity stages of Industry 4.0 using Schuh et al's (2017) framework. Table 2 depicts the means and standard deviations of the technologies. The reliability is reported using Cronbach's alpha which ranged from 0.76 to 0.93, indicating moderate to excellent reliability.

Table 2: Extent of technologies used

Items	Description	M	SD	α
Computerization & Connectivity				
		0.86		
CC1	Barcoding systems	5.31	1.14	
CC2	Customer Relationship Management	5.68	0.95	
CC3	E-business/ e-marketplace	5.76	0.98	
CC4	Electronic Data Interchange	5.76	1.00	
CC5	Electronic Point of Sale	5.73	0.97	
CC6	E-procurement	5.54	1.08	
Visibility & Transparency				
		0.93		
VT1	Global Positioning Systems	5.61	1.31	
VT2	Time Temperature Integrators	5.74	1.24	
VT3	Data Loggers	5.68	1.20	
VT4	Transport Management Systems	5.76	1.23	
VT5	Warehouse Management Systems	5.72	1.26	
Predictive Capability				
		0.87		
PC1	Enterprise Resource Planning Systems	3.85	1.42	
PC2	Manufacturing Execution Systems	4.12	1.32	
PC3	Radio Frequency Identification Systems	4.03	1.61	
Adaptability & Self-learning				
		0.76		
ASL1	Collaborative Planning, Forecasting and Replenishment	2.19	0.77	
ASL2	Efficient Consumer Response	2.07	0.78	
ASL3	Vendor Managed Inventory	1.99	0.82	



	Input suppliers	Agri-food producers	Packaging suppliers	Food manufacturers	Logistics providers	Wholesalers	Retailers
Computerization & connectivity							
Barcode	53.3%	29.4%	80.0%	24.1%	91.0%	76.2%	100.0%
CRM	20.0%	2.9%	60.0%	64.8%	34.3%	17.5%	75.9%
E-business	83.3%	86.7%	45.0%	77.8%	65.7%	12.7%	70.7%
EDI	0%	4.4%	0%	79.6%	28.4%	30.2%	81.0%
EPOS	30.0%	0%	0%	0%	0%	3.2%	100.0%
E-procurement	43.3%	41.1%	80.0%	90.7%	80.6%	15.9%	89.7%
Mean	*38.3%*	*27.4%*	*44.2%*	*56.2%*	*50.0%*	*26.0%*	*86.2%*
Visibility & transparency							
GPS	0%	0%	0%	0%	80.6%	49.2%	3.4%
TTI	0%	7.4%	0%	0%	44.8%	46.0%	12.0%
Data loggers	0%	16.2%	0%	13.0%	52.2%	30.2%	3.4%
TMS	0%	0%	15.0%	9.3%	80.6%	7.9%	0%
WMS	13.3%	0%	70.0%	9.3%	10.4%	39.7%	75.9%
Mean	*2.7%*	*4.7%*	*17.0%*	*6.32%*	*53.7%*	*34.6%*	*18.9%*
Predictive capability							
ERP	0%	1.5%	55.0%	79.6%	70.1%	66.7%	75.9%
MES	0%	0%	75.0%	77.8%	0%	0%	0%
RFID	10.0%	0%	40.0%	27.8%	80.6%	36.5%	79.3%
Mean	*3.3%*	*0.5%*	*56.7%*	*61.7%*	*50.2%*	*34.4%*	*51.7%*
Adaptability & self-learning							
CPFR	10.0%	0%	0%	44.4%	28.4%	3.2%	58.6%
ECR	10.0%	0%	0%	29.6%	0%	6.3%	60.3%
VMI	0%	0%	10.0%	44.4%	4.5%	0%	29.3%
Mean	*6.7%*	*0%*	*3.3%*	*39.5%*	*11.0%*	*3.2%*	*49.4%*

Figure 1: Technologies used in the agri-food supply chain

4 Findings and discussion

The range of technologies and collaborative strategies adopted depict varying levels of value co-creation, supply chain visibility and traceability. It is apparent that these organizations employ technologies and strategies to improve business processes and decision-making. In food supply chain operations, technologies are predominantly used as a means for communication and information exchange between partners, facilitating uninterrupted flows. Prior to information sharing, the technology used needs to be linked and integrated between their upstream and downstream members in supply chains (Bhatt et al 2017). For this study, we investigated the strategies, technologies and integration efforts between two or more companies to understand the degree of interoperability in the supply chain. Figure 1 presents a full picture of the technologies used and percentage of firms at the value creation stages in the supply chain.

Additionally, in order to further discern the realization of Industry 4.0 maturity stages for each group, we obtained the mean scores for the various technologies and initiatives based on the number of firms that adopted them.

4.1 Computerization and connectivity

Computerization is the basis for digitalization and encompasses the deployment of information technologies. This is the first step and basic prerequisite for Industry 4.0. At this stage, many of the technologies appear to be used in isolation either within the organization or to assist in digitally supported B2B processes and transactions. When firms replace their isolated technology usage with connected business applications, a shift to embedded systems is facilitated (Schuh et al 2017).

Our findings depict that barcoding identification technology was used at all stages in the supply chain. There is a lesser extent of usage by upstream growers, farmers and other food producers; particularly those dealing with fresh fruit, vegetables, meat and seafood which are generally sold by weight. This technology facilitates inventory control and information sharing with suppliers upstream through electronic data interchange (EDI) (Kinsey and Ashman 2000) and often integrated with Warehouse Management Systems (WMS) (Patterson et al 2004).

Electronic point of sale (EPOS) was found to be only used by input suppliers (30%), wholesalers to a small extent (3%) and all retailers (100%) in our sample. This technology is usually incorporated with barcoding, and allows food retailers, manufacturers and packaging companies to collaboratively discern purchasing patterns and develop new products (Cox & Mowatt 2004). Customer relationship management (CRM) appeared to be used throughout the chain as a strategy. It is believed that firms utilize data warehousing and mining techniques to segment customers for improved customers service and retention (Chen & Chen 2004, Cox & Mowatt 2004), which is particularly critical given the nature of the food industry.

The e-business enabled supply or commonly known as e-marketplace is becoming an increasingly popular business model for firms to source, trade and collaborate with chain partners (Howard et al 2006, Le 2005). Our findings depict that 87% of agri-food producers, farmers and growers were using this, arguably to diversify their business opportunities and enhance profitability. Such platforms allow firms to expand globally and enter new markets that were previously inaccessible due to geographical barriers (White et al 2007).

Electronic data interchange (EDI) is most used in manufacturers and retailers with 80% and 81% respectively. This computer-to-computer exchange of business documents in a standard format between supply chain partners enables firms to reduce transaction costs, improve information transparency, efficiency and achieve integrated efforts (Leonard & Davis 2006, Hill & Scudder 2002). EDI in the food industry is also known to reduce the bullwhip effect, although being a complex and expensive system to implement especially for many small businesses (Vlachos 2004, Kinsey & Ashman 2000).

E-procurement technologies include e-sourcing, e-auctions and EDI to trade with suppliers online. Our findings depict that this technology is apparent in all stages in the supply chain, and more so among packaging suppliers (80%), food manufacturers (91%) and logistics providers (81%). Firms can respond more effectively using real-time information to meet demand patterns and supplier prices, while reducing delivery times and procurement costs (Chibani et al 2018, William 2003). Many organizations operate e-procurement in the food industry to assist with JIT strategies.

Based on our findings, we draw inference that majority of the firms in our sample have embedded digitally supported processes and transactions for computerization and connectivity. Based on the mean scores, this is more apparent in retailers, followed by food manufacturers and logistics providers. We had expected growers and food producers to be less likely to be digitally connected owing to the nature of this industry; however, discovered that the wholesalers in our sample were the least connected.

4.2 Visibility and transparency

The second phase of maturity in Industry 4.0 is visibility and transparency. In the context of supply chains, we argue that this should extend beyond B2B transactions and result in end-to-end visibility. The real-time capture of events from several data points in the supply chain enhances visibility, based on information availability and quality. Schuh et al (2017) postulate that by aggregating this information and a corresponding contextualization, transparency is enhanced for faster decision-making. We identified four main types of technologies used in the food supply chain for this phase which are primarily in the area of logistics activities.

Global positioning system (GPS) was found to be used by 81% of third party logistics providers and 49% of wholesalers in our study. The use of radio signals from satellites is widely implemented to manage logistics and transportation activities. Firms can locate and monitor the direction of fleet operators and vehicles, further allowing for optimized vehicle scheduling and routing (Theiss et al 2005). This is also prevalent upstream in the food industry where food producers can collect data on crops, soils, environmental and climate data, and monitor the movement of livestock in paddocks, facilitating precision agriculture and farming practice (Opara 2003). However none of the upstream players in our sample adopted this technology.

Transport management system (TMS) on the other hand, was used to a greater extent by firms in the chain including packaging suppliers, manufacturers and retailers. As expected, a large proportion of logistics providers (81%) adopted this technology which is closely related with GPS. TMS optimizes distribution activities, particularly in the area of fleet planning, truck scheduling and vehicle routing (Pokharel 2005). The real-time information enables firms to monitor turnaround time, driver productivity and fleet utilization. It could further facilitate cross-docking in warehouses, which is highly pertinent in the food and grocery sector, where the timely flow of perishable products is critical (Apte & Viswanathan 2000).

Warehouse management system (WMS) is also another technology adopted throughout the chain except for growers, farmers and food producers. We establish that the sale of agri-food products occurs almost immediately or using JIT after harvest for optimum freshness and quality. Most growers and farmers do not have adequate storage facilities or keep much inventory. Retailers (76%) and packaging suppliers (70%) adopted WMS to a greater extent given the volume and variety of products they deal with. Surprisingly, WMS was only used in 25 out of the 63 wholesalers (40%). It equips firms with the capabilities in monitoring stock levels, the inbound and outbound flows of inventory and exact location of items stored in the warehouse. WMS captures data on product dimensions and characteristics to optimize warehouse space, personnel and material handling equipment (Patterson et al 2004). It is often interfaced with TMS, RFID and barcoding technologies to enhance logistics operations (Mason et al 2003). We argue that most food products tend to be highly perishable; hence their inventory management is critical at all stages.

Our findings highlight that time-temperature integrators (TTI) and data loggers are being used predominantly by logistics providers (45% & 52%) and wholesalers (46% & 30%). These devices or tags are placed within a storage container to record the temperature of food products throughout the distribution process. Data are used to monitor temperature stability, product quality or identify breaches at various points in the supply chain. This is critical for temperature sensitive or perishable food products. Such technology enables optimum quality, shelf-life and handling throughout the supply chain (Soosay 2008, Sahin et al 2007, Koutsoumanis et al 2005). However, only 7 out of 58 retailers (12%) in our sample had adopted this technology.

Overall, information integration is required for tracking and tracing, ensuring visibility and transparency in the chain to meet food safety and regulatory requirements. The mean scores shows a varied extent of visibility and transparency among various supply chain players. It appears that logistics providers adopt these technologies the most, followed by wholesalers, manufacturers and retailers. We discern that upstream players (farmers, growers and input suppliers) tend to adopt technology to a lesser extent as compared to downstream players; and that these were used mainly for internal operational efficiencies and B2B transactions. Our finding is also in line with Solanki and Brewster's (2014 p. 46) study on agri-food supply chains; where they confirm and highlight how the "flow of data is restricted based on a very conservative 'need-to-know' attitude such that information flows only 'one up, one down'". Moreover, due to cultural barriers and despite technological solutions, the firms do not appear to use or integrate data across the supply chain, "thereby greatly increasing the possibility of interoperability issues arising between supporting applications". Technology should be viewed as the key for SCM development and transformation of the food industry 'from dyadic, material management oriented relationships into complex, collaborative, networked, web-enabled, extended architectures' to enable visibility, transparency and food integrity throughout the chain (Akyuz & Gursoy 2013).

4.3 Predictive capability

The third phase of maturity lies in the ability of firms to use shared data from end to end supply chain partners to prepare for future scenarios. At a network level, the visibility and transparency of operational data, inventory levels and production plans provide focal firms with relevant and real-time information for supply chain decision-making. Unexpected events such as the bullwhip effect, forecasting errors, production variations or delays in distribution could be minimized to a large extent. These result in time-based approaches to reduce costs, waste, inventory and other supply chain inefficiencies. We identify three types of technologies in the food industry that are used to attain this predictive capability.

Enterprise Resource Planning (ERP) systems were evident in 188 firms or over half the sample surveyed. These consist of integrated modules that support not only various functions within the organization, but also across supply chain operations. The IT systems of suppliers and customers could be interfaced for seamless operations. Alongside ERP, there are also manufacturing execution systems (MES) used to manage factory operations and production systems. 78% of food manufacturers and 75% of packaging suppliers adopted this technology. MES controls the movement of materials from point-to-point, assigns and schedules resources, and tracks the costs and status of materials being processed (Beavers 2001). When production plans are shared with suppliers, retailers and wholesalers, the flow of food products in the supply chain could be better streamlined.

Radio Frequency Identification (RFID) technology was adopted throughout the supply chain in our sample except for agri-food producers. RFID in food supply chains can determine the location and history of products, which help to maintain quality and prevent breaches in food integrity (Van Der Vorst et al 2007, Opara 2003). When combined with other technologies, RFID equips firms with predictive capability to achieve reliable and accurate data forecasts, reduced inventory and labor costs (Wu et al 2006).

From the mean scores, the area of predictive capability shows a stark difference between the upstream and downstream activities. Manufacturers, retailers and logistics providers generally possess the capacity to engage in big data and supply chain analytics, given the extent of technologies adopted, scale and scope of operations. These firms are generally larger in size and have better resources to obtain value from large scale data to gain competitiveness in terms of demand volatility, cost fluctuations and inventory management. We argue that the utilization of supply chain analytics is still at an early stage in the food industry currently; but has the potential to assist in strategic demand planning, sourcing, manufacturing, logistics activities, inventory management, and overall network configuration to advance into a supply chain 4.0 continuum. The use of time temperature sensors, RFID, tracking devices and ERP systems generates big data for the supply chain, which serve as a new frontier for process improvement, demand management and decision-making.

Our findings show that upstream players in the supply chain are generally lagging in this maturity stage of Industry 4.0. Hence it is proposed that the individual orientation, interoperability and capabilities of upstream players will need to be reassessed to derive a systematic plan for progression into a technology architecture for the overall supply chain. Bryceson and Yaseen (2018) illustrate how various disruptive technologies have been changing the landscape of the agri-food industry including upstream farming and production activities. IoT systems are conducive to agri-food firms in environmental monitoring, precision farming, precision livestock and cold chain logistics. For example in livestock management, IoT technology coupled with RFID can be used for real-time monitoring of cattle health and behavior. These authors also emphasize how big data analytics can assist businesses overcome environmental degradation, food safety and food security. Smart farming is increasingly being used with tailored seed varieties, crop nutrients, pathogen monitoring, and improving crop yields and addressing food safety concerns. New types of data can be used to measure biophysical characteristics (such as climate, soil alkalinity, seed cultivation, fertilizer and pest control) from the paddocks and farms upstream through to food processing, facilitated storage and food retail downstream (Bryceson & Yaseen 2018). Additionally, smart packaging is gaining prominence in food supply chains today. They not only help to meet HACCP and QACCP requirements, but also detect real-time biochemical changes occurring in the food and its environment to help extend shelf life. Another feature of Industry 4.0 is blockchain technology which offers huge potential for food traceability solutions. This technology works as a technical schema of databases which could contain information of all activities, processes and transactions in the chain forming a digital form of fingerprinting; and through interoperability mechanisms, this could ultimately provide visibility and traceability of the product's entire life cycle.

4.4 Adaptability and self-learning

The fourth maturity stage occurs when firms are able to take corresponding measures autonomously based on shared data. According to Schuh et al (2017), this delegation of decisions allows for rapid adaptation to changing business environments. Applied at a broader level, we establish that the combination of technologies achieves supply chain agility for customization and responsiveness to end consumers. We considered various supply chain strategies and classify three initiatives for this category.

Vendor Managed Inventory (VMI) was the least adopted technology in 13% of firms only. It was apparent mainly in manufacturers (44%) and retailers (29%). VMI is a powerful initiative based on technology integration and established transparency and visibility. Upstream suppliers or manufacturers are authorized to monitor retailers' real-time inventory levels and replenish accordingly (Waller et al 1999).

Its low uptake in the food industry could be attributed to the effects of inventory holding costs or high shortage penalty costs (Ru et al 2018). Closely linked to this initiative is efficient consumer response (ECR) applied in the food industry to alleviate supply chain inefficiencies. Once again, this was apparent mostly in food manufacturers (30%) and retailers (60%). This initiative requires retailers to share point-of-sales data with supply chain partners for not only better store assortment, promotion, product development and replenishment (Harris et al 1999), but also better financial and operational performance (Martens & Dooley 2010).

Collaborative Planning Forecasting and Replenishment (CPFR) is another shared IT system to project demand patterns. These were adopted by over half the retailers (59%), followed by manufacturers (44%) and logistics providers (28%). By using real-time data in the supply chain, this initiative facilitates demand forecasting, inventory management, production and replenishment planning, and order fulfilment (Hill et al 2018). CPFR is critical given the price points of food commodities, time-sensitivity, perishability and shelf-life. In this context, firms make autonomous decisions on a breadth of areas including timely supply, food production, processing, wholesale, distribution, marketing and retail. Our findings suggest that these factors are highly considered by downstream players due to their proximity and reliance on end customers and food consumers' demand preferences. This is further confirmed by the mean scores, showing the disparate heterogeneity in the supply chain for adaptability and self-learning. The other stages in the supply chain (input suppliers, agri-food producers, packaging suppliers, logistics providers and wholesalers) had very low values for this maturity stage.

These three powerful initiatives applicable in the food industry require the establishment and mastery of the first three maturity stages. This fourth maturity stage of adaptability and self-learning represents an autonomous supply chain. Characterized by robotics and automated networks, the concept of autonomously delivering products is becoming a reality. Heard et al (2018) claim that connected and autonomous vehicles (CAV) will be embraced first in the food distribution industry, given the interplay between transportation logistics, food perishability and cost. Enabled by logistics innovations and e-commerce, these authors state that autonomous trucks could one day displace grocery stores, and change the business model of distribution by delivering ordered foods directly to consumers instead. Similarly, MES and ERP systems have been around for a while; and possess the intelligence to organize and control manufacturing processes and job sequencing. They mandate using appropriate technologies, achieving streamlined visibility and transparency across supply chain partners and facilitating the autonomous and continuous adaptation to changes individually at the firm level as well as collectively as a network of partners.

5 Conclusions

Considering an end-to-end supply chain model, we deem the autonomous supply chain to be far from achievable in the food industry at this stage, given the presence of traditional labor intensive methods in some farming and agri-food production activities, especially for fresh and perishable food produce. Despite the fragmented adoption of advance technologies at various points in the supply chain (such as in manufacturing and logistics), we establish that agri-food supply chains still have a long way in reaching this milestone for Industry 4.0. This is because a true autonomous supply chain does not require human intervention (River Logic 2018).

Industry 4.0 requires firms to develop agile capabilities for rapid adaptation to changing business environments where customization and responsiveness come into play to fulfil end consumers' needs. We argue that the technology infrastructure provides integrated, empowered and more responsive decision-making; hence enabling a new frontier for customer receptiveness and market changes. The evolving and dynamic nature of food consumption means that customers expect high quality sensory properties, more variety and better food security (Castro & Jaimes 2017). Additionally the perishability of food products requires more advanced handling, transportation and storage solutions that requires firms to be flexible, efficient and responsive. Today's supply chain transformation involves the use of digital technologies, predictive analytics and artificial intelligence. To compete and survive, firms must embrace new business models, digital transformation and interoperability aspects. With this in mind, supply chains of the future should be viewed as an autonomous ecosystem of firms rather than traditional linear structures.

6 Limitations and further research

This study has several limitations, which must be taken into account when interpreting the results and their implications. Firstly, it presents preliminary findings from a larger study on supply chain integration in the agri-food industry. Notwithstanding that, it extends our knowledge on the issues relating to the impact of relevant technologies with respect to different stages of the supply chain and their activities. It uncovers the breadth of technologies used and the impacts of technology interface in agri-food supply chains. Secondly, we acknowledge the reliance on cross-sectional data, which measured technology adopted at one point in time that has weaknesses in establishing any causality inferences. Also market factors and stakeholder pressure may differ for various food groups. Further research could be more informative by investigating market configurations pertaining to the types of food products (e.g. fruit, vegetables, meat, seafood) and proximity of chain members to end consumers. Additionally, by employing a larger dataset, there is scope to perform measurement invariance across supply chain nodes and/or multi-level analyses. These could then provide better insights into the technology interface at specific points in value creation in the supply chain in more detail. Additionally, we recognize that our sample comprises a significant proportion (74%) of small and medium enterprises which is characterized by the food industry predominantly. We do not intend to generalize our findings, but highlight the vulnerability of many small businesses and up-stream players in our sample who appear to be lagging behind in the fourth industrial revolution as well as the disruptive changes entailed to keep up and compete in the digital age due to their size, resource constraints, scope and scale of operations. Despite these limitations, this paper offers discernment to supply chain researchers and practitioners by illustrating the maturity phases of Industry 4.0 in the context of agri-food supply chains in Australia.

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Advanced Scientific Algorithms in Digital Factory Design Applications

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In contrast to manual procedures, research constantly develops modern computerized factory design approaches applying concepts of Industry 4.0. Nevertheless, literature hardly reveals their practical application. A market review analyzing recent software applications shows that they still focus on simple and outdated algorithms, resulting in limited support for facility arrangement. This study further analyzes the use of scientific approaches implemented in software applications for factory design and suggests new research directions to increase their practical applicability. Therefore, we conducted a semi-structured interview study investigating four layout design software developers. Applying an iterative approach, semi-structured and guided interviews were performed, coded, grouped into categories referring to similar phenomena, and interpreted to provide proposals for future research. The results indicate that innovative, automated methods are met with skepticism, although their performance is considerably superior to traditional approaches. The interviewed developers for factory design software reveal certain features they expect from modern approaches emerging from research to ensure successful implementation.

Keywords: Factory layout design; Software applications; Metaheuristics; Interview study

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1 Introduction

Manufacturing companies are constantly faced with major challenges shaping their requirements for success, such as new production technologies, shorter product life cycles, as well as frequent changes in market dynamics. Certain situations may compel companies to make major changes to their manufacturing sites, affecting the arrangement of facilities and equipment in the plants. This common problem is referred to as the ”facility layout problem” (FLP) in literature. There is substantial prior research starting from the 1960s (Anjos and Vieira, 2007).

During the last decades, a trend towards metaheuristics and algorithm-based optimization of the arrangement problem has evolved (Ahmadi et al., 2017). Nevertheless, the practical application of scientific methods, particularly their software implementation, within design projects is scarcely mentioned. However, in the context of Industry 4.0 and Smart Manufacturing, advanced software applications are gaining importance throughout all subject areas in manufacturing companies and constitute a worthy area for optimization and further research (Bracht et al., 2018).

In a recent paper, Klausnitzer et al. (2017) conducted a case study to investigate the application of scientific algorithmic methods in practice. Users of software applications, consulting engineers in this case, and a scientific institute specialized in factory design were interviewed. Their key findings are that advanced mathematical methods are not applied to factory design projects due to the users' unawareness of extant superior methods and lack of algorithmic support regarding the applied software solutions. These findings add impetus to the research of this paper.

Whereas Klausnitzer et al. (2017) focused on users of factory design applications, we suggest that investigating developers of factory design applications might produce interesting findings. It can be safely presumed that the developers of software applications in digital factory design have a profound knowledge of methods and trends in their field of interest and have a high affinity for scientific methods. To the best of our knowledge, there is no empirical research on the approach applied by software engineers to develop the applications as well as the impact of scientific research on these development procedures. Furthermore, the evolving trend towards metaheuristics has produced various scientific algorithms for the FLP that produce promising results but little is known about the value the software developers for factory design applications give these algorithms.

Therefore, this paper aims to answer the following research questions using a market review followed by a multiple semi-structured interview study:

- How do modern software applications methodically support the factory design process?

- How does scientific research affect developers of those applications?

- Why are advanced scientific algorithms adopted by software developers for factory design?

Our contribution is two-fold: From a theoretical standpoint, we provide insights from practice, in particular the needs and wishes that software developers have regarding scientific methods to encourage their implementation in factory design applications. Researchers are able to focus on specific aspects that will make their methods usable outside of the field of research. From a practical standpoint, we aggregate the recent developments in science and highlight important future developments as noted by leading representatives of software developing companies.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of the literature concerning solution methods for the facility arrangement and digital factory design applications. Section 3 describes the methodology adopted for the empirical research. Section 4 presents the findings from the market review as well as the interview study. Section 5 provides recommendations for practice, section 6 our conclusions. The limitations of the study and opportunities for future research are discussed in section 7.

2 State of Research

The basic process of factory design as defined in VDI (2011) or Grundig (2015) consists of the following planning phases: Target planning, concept planning, detailed planning, execution planning, and implementation. A large amount of research considering the FLP focuses on the concept and detailed planning phases, where several layout variants are generated to minimize the material handling effort as a function of travel distances. The first steps include determining the functions of facilities, dimensioning of required areas, and the arrangement of the facilities within the area. Subsequently, the block layout variants need to be refined with real life requirements considering structural conditions like walls and pillars, as well as ergonomic and logistic requirements. Favored layout variants are then designed according to specific conditions and restrictions such as facility details and orientation.

The step of arranging the facilities can be reduced to an algorithmic process that solves an optimization problem as it depends on material flow intensities and closeness ratings (Drira et al., 2007; Tompkins et al., 2010). Popular procedural approaches for factory planning and solving the FLP (e.g. Schenk et al., 2014; Grundig, 2015) still focus on outdated and simple algorithmic methods, such as the approaches of Schwerdtfeger (Kettner et al., 1984) and Schmigalla (Schmigalla, 1968). These methods illustrate flow relationships between functional areas to arrange them according to a determined pattern. Specific facility areas and real-life requirements are taken into account subsequently. The solution quality largely depends on the experience of the layout planner as well as trial-and-error.

Other approaches to solve the FLP are mathematical methods that lead to optimal solutions. However, the FLP is known to be NP-hard (Garey and Johnson, 1979), resulting in computational intractability for most of the practical problems, due to the large number of facilities to be arranged. This led to the emergence of heuristics and, more recently, metaheuristics, such as genetic algorithms, tabu searches, or simulated annealing. They are suitable for large problems that can be solved in a short time with solution qualities near the optimum, although the optimum cannot be guaranteed (Drira et al., 2007). In contrast to the traditional methods, modern approaches consider a variety of requirements like area constraints, material handling points, path design, and multiple floors in one single step. A concurrent approach to the arrangement of facilities and the design of real life requirements can significantly improve the quality of the layout solutions and the productivity of the user. Within a short time, several layout variants can be generated and evaluated without the follow-up work or a costly replanning of infeasible layouts obtained during a sequential process.

To support the design process for the FLP there are several factory design software applications. The selection of the suitable software application depends on the specific problems, data, information and defined goals (Schenk et al., 2014). In the context of Industry 4.0/Smart Manufacturing, advanced applications supporting the ”digital factory” are entering the market. Digital factory is a network of digital models, methods, and tools integrating a continuous data management system that aims for holistic planning, evaluation, and improvement of structures, processes, and resources of a factory.

It allows for collaborative planning to consider the experience of various users, which further contributes to an improvement of solution quality and approval (VDI, 2008). The digital factory applications can be categorized into three main groups that are briefly presented in the following:

Tools for visualization: CAD (Computer Aided Design) tools are used to visualize facility layouts and draft well-detailed drawings that are easy to create and to change in a short time. CAD tools are widely utilized in all kinds of manufacturing companies worldwide. However, standard applications like AutoCAD rarely provide scientific methods to support the layout design procedure (Grundig, 2015).

Simulation tools: Simulation tools are used to study the dynamic interrelations of manufacturing systems. The manufacturing system can be optimized by creating and analyzing different variants to select the best alternative (Arnold and Furmans, 2009). In recent years, CAD tools have been coupled with simulation tools to create layouts based on CAD data directly using standard 3D components. The complexity of the software applications and the needed expertise to generate a coherent representation of the real process flow from a static visualization is still one of the main challenges of simulative factory design (Schenk et al., 2014).

Virtual reality tools: Intuitive applications like virtual reality and augmented reality tools are receiving an increased interest regarding layout design. They are able to construct a direct or indirect view of real-world environments augmented with additional haptic or visual information (Schenk et al., 2014). 3D modeling and optimization of whole factory floors is simplified. So called ”participative planning tools” combine two-dimensional representations as in CAD tools with three-dimensional representations for a better visual experience and cooperative collaboration in project teams. In addition, users are provided with evaluation and optimization components (Jiang and Nee, 2013).

In summary, new and innovative mathematical methods like metaheuristics pose several improvements and advantages over more simplistic methods from a scientific perspective. They are able to solve large problems quickly with solution qualities near the optimum and concurrently integrate several design aspects that have been solved in a sequential process so far. However, the software applications are still focusing on features that support the manual design process without the use of advanced algorithms. This gap motivates the investigation of the development procedures of software applications, the underlying intentions, used scientific methods and the assumed but unclear scientific impact on the procedures.

3 Research Methodology

As there is no comparable research so far, we used an approach of rather explorative nature. First, we conducted a market review to identify promising software applications for facility layout design that use scientific methods to arrange facilities in the manufacturing sites. Therefore, a systematic search was conducted using web databases, project descriptions and scientific articles. We then classified the identified software applications after a thorough review and analysis (see section 4).

Second, we conducted a multiple semi-structured interview study with experts from a subset of the identified software engineering companies. The semi-structured interview design allows flexibility to adapt to specific but initially unknown circumstances in practice (Yin, 2009). To analyze a representative sample of cases for the area of interest, the concept of theoretical sampling was used (Eisenhardt and Graebner, 2007). Therefore, four software engineering companies took part in the interview study. The cases develop and distribute software applications with implemented scientific methods, especially in factory design. Although the number of interviews is relatively small, in the limited field of facility design software solutions the selected cases and the findings are representative and can be theoretically generalized (Meredith, 1998). The organizational characteristics of the examined software companies are shown in Table 1.

Cases A, B and C represent software engineering companies of different size. Cases A and B are small companies operating in Germany with less than 15 employees. In contrast, case C constitutes a large company with headquarters in Germany and the USA and employing over 9,000 people. In order to investigate the layout design methods applied by a scientific organization, we also interviewed an institute of a university (case D). The interview partner of case D has developed a design software application and distributes it as a freelancer.

Table 1: Outline of the cases (Organization)

Case	Employees		Customers		Contact with Science	Interviewee
	Number	Degree course	Sectors	Regions		
A	11	ME/IE,CS	All	Worldwide	Software used in university courses	Managing Partner
B	12-15	ME/IE,	Automotive	Worldwide	Practice journals and associations (VDI)	Director
C	9.000	ME/IE,CS, E	All	Worldwide	University work-shops, confer-ences	Technical Specialist
D	20	ME/IE	All	Germany	Software used in university courses	Research Associate, Freelancer

* ME/IE =mechanical / industrial engineering, CS = computer science, E = economics

Besides the distribution of software, all cases provide workshops and training courses to teach their customers as well as consulting services around layout design. The interviewed cases employ a highly skilled workforce with university degrees mainly in the fields of mechanical and industrial engineering. The customers of cases A to D operate in all sectors and industries around the world, though most are manufacturing companies. A comparison of project figures is complex since all cases stated that project durations and budgets differ depending on the specific customer needs. However, most projects range between a few days for basic training workshops to about three months for additional consultancy and may be extended by several months for major planning support.

Only case A actively cooperates with universities and scientific institutions regarding facility design projects. The interview partner of case B sporadically reads journals and uses the mutual exchange of information in associations like the Verein Deutscher Ingenieure (VDI) to stay up-to-date. There is no active collaboration considering the development of the software application with scientific institutions. This also applies for case C. Nevertheless, the interview partner takes part in workshops at universities and is a speaker at certain professional events. The academic institution of case D collaborates with colleagues from the same university in projects where they often utilize the software application. Further feedback comes from several other universities that use the software application for teaching and project purposes.

After the investigation of general characteristics, we applied an iterative approach for data collection, coding, and analysis (Eisenhardt, 1989). For preparation purposes and the appropriate selection of interview partners in the case companies, we provided the interview partners with a questionnaire prior to the interview as an extract from the guidance document. During the interview, we used the guidance document to focus on all relevant aspects. The data from the transcribed interviews was coded using MAXQDA 2018 to detect important aspects from the transcript.

All statements were grouped into categories referring to similar phenomena. According to a deductive-inductive approach, main categories were established prior to the interviews whereas subcategories were created from the investigation of the first transcript. In a first step, the text passages were grouped into the main categories. Organizational aspects like staff structure, company size, and customer features were grouped in ”Organization”. The second main category ”Software” covered aspects like application range and development procedures.

”Layout Planning” included the implemented scientific methods for facility design and all comments regarding advanced mathematical methods.

The ”Link to Science” was further analyzed in a fourth main category including the information approach towards current development and an assessment of the mutual exchange with scientific institutions. After the inductive determination of the subcategories, the whole document was grouped according to a differentiated system of categories (Kuckartz, 2014).

The analysis was carried out case-by-case first and completed with a comparative analysis. The resulting conceptual model represents a common understanding of phenomena regarding the cases. In addition to the interviews, we used company websites and provided material by the interview partners (brochures) to triangulate the interview data. The final reports were sent to the interview partners for validation purposes and to maintain participant engagement.

4 Findings

4.1 Market review on software applications

Table 2 illustrates the identified software applications and respective methods, features, and limitations. The software applications were then grouped into four categories and visualized in Figure 1. The two aspects of interest for this classification are the degree of integration of all planning tasks into the basic planning process of factory design (e.g. VDI, 2011) and the provided scope of functionalities for the arrangement of objects in the factory layout.

Table 2: Identified software applications and their respective scientific methods, features, and limitations

Tool	Scientific method for facility design	Features	Limitations
AutoCAD	none	Widely used in the industry; enables a digital representation of possible real world systems	Only supports trial-and-error for facility arrangement without any quantified evaluation
G-MAFLAD	Branch-and-Bound (exact)	Considers facility dimensions for a first block layout variant	Users need to provide certain feasible arrangement sites for each facility; no material paths considered; limited import/export features
FACOPT	Simulated Annealing / Genetic Algorithm	Considers facility and factory (incl. gates) dimensions for a first block layout variant	Provides block layouts without considering material paths or real life requirements; not commercially available
VIP-PLANOPT	Simulated Annealing + Local Search	Considers facility dimensions; extensive configuration options (dimensions, shape flexibility, factory floor)	Considers predefined material paths via blocked areas in the layout; scientific method not fully disclosed

SIMOGGA	Genetic Algorithm	Considers various input data (factory floor, material paths, facility dimensions)	Only usable for cellular layouts with redundant resources; needs an initial solution to start upon
MALAGA	Greedy Heuristic	Integrated plant model; connection to simulation software (Plant Simulation by Siemens)	Facility dimensions neglected for first steps of factory design, dimensions need to be manually applied subsequently
Tecnomatix Factory Design	Graphical Method	Connection to various related software modules (Plant Simulation by Siemens)	Needs an initial solution to start with an optimization; no consideration of material paths and input/output points
SketchUp MF-VO	Graphical Method	Plugin for 3D software ”SketchUp”; presentation, analysis, and optimization of material flow; considers paths	Solution method provides recommendations for arrangement that need to be applied manually
visTABLE®touch	Greedy Heuristic	Combined tool for visualization and layout design; considers paths; quantified evaluation	Solution method provides recommendations for arrangement that need to be applied manually

Although three identified applications used metaheuristics to arrange objects in the factory layout (VIP-PLANOPT, FACOPT and SIMOGGA), these applications are unable to connect with other commercial applications and therefore cannot be widely used. They only offer partial support for the factory design phases providing first block layout variants that need further fine-tuning, and were therefore entitled 'specific tools' in Figure 1. Comprehensive tools with a modern, user-friendly graphical user interfaces like visTABLE®touch or the SketchUp MF-VO Plugin still use simple but outdated methods, such as the method by Schmigalla (1968) or the method by Schwerdtfeger (Kettner et al., 1984).

4.2 Interview Study

Cases A, B, and D provide a single software application while case C provides several applications specified for different sectors. The mechanisms that led to the development of the software applications are similar in all cases. At the time of development, no product was available on the market which offered the functionalities that the interview partners needed for their projects. This led to in-house developments of software applications appropriate for the specified design projects after which cases A to D started offering their applications for sale to other engineering companies. The software was then increasingly enhanced in order to improve customer-orientation and user-friendliness. However, hardly any developments considering advanced scientific algorithms were adopted from contemporary scientific contributions. On the contrary, it is apparent that software developers are familiar with the general layout planning procedure of dividing the design task into several feasible smaller design steps (e.g. Schenk, 2014; Klausnitzer et al., 2017).

All cases use simple methods in their software applications to arrange objects in the sites. Case A uses greedy heuristics (related to the method by Schmigalla (1968) and the method by Martin (1976)) to optimize existing or initial layouts. Case B uses a modified approach of the method by Schmigalla (1968), while case C is currently testing an algorithm for a generative design of layout variants to generate a feasible layout variant. Case D uses the graphical method by Schwerdtfeger (Kettner et al., 1984) to arrange facilities. The interviewees are consistent in their skepticism towards the use of modern algorithmic approaches and stated that advanced algorithmic approaches are too difficult to apply in factory layout design. Moreover, the additional effort of implementing and applying the metaheuristics in comparison to simple heuristics does not represent a favorable

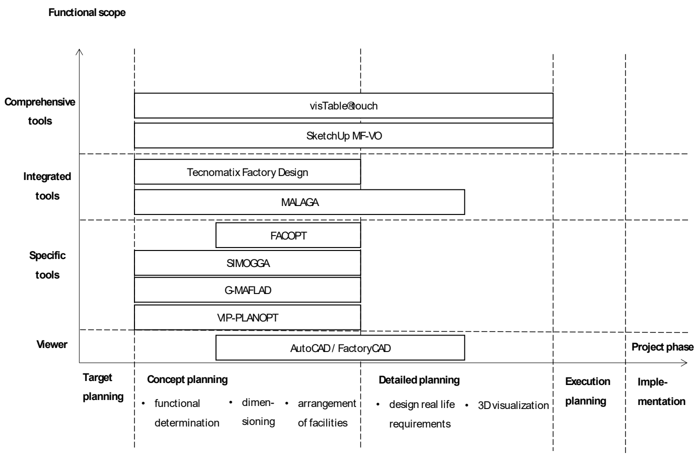

Figure 1: Classification of reviewed software applications for facility layout planning

cost-benefit ratio. Interviewees A and D further criticize that metaheuristics still only produce an initial solution for the layout problem. This solution has to be subsequently adjusted to real life requirements that were not considered by the algorithm.

The general skepticism about novel approaches suggests a lack of knowledge considering the existence of advanced algorithms. In all cases, the employees are usually mechanical and computer engineers. Advanced algorithms regarding the FLP as a long-time challenging discipline of operations research are usually not focused on these fields of study. Therefore, the interviewees are not aware of the considerable benefit in the quality of the layout solution and the potential of optimization of the overall planning. Since the traditional planning procedure suggests a top-down approach where restrictions are considered step by step, the planning process might run up against infeasible intermediate layout solutions several times that require multiple setbacks and replications of previous planning phases. In contrast, advanced computer supported layout design approaches can integrate several design elements and restrictions simultaneously within a single planning step. This leads to feasible layouts with respect to the considered restrictions and planning details. If such an algorithm is implemented within a software application, it is able to produce several layout variants within a few minutes that can be qualitatively and quantitatively evaluated and modified by the user. As discovered in this study, current software applications often only automate the relative arrangement of facilities using the approaches of Martin (1976) and Schmigalla (1968). Both approaches do not consider any restrictions, not even the areas of facilities and the planning areas. Therefore, solutions obtained with current applications frequently get stuck in infeasible intermediate solutions that require time-consuming replanning.

As regards the scientific education and the lack of implementability of advanced methods, interviewees A and C noted that the general quality of education has decreased and that it is difficult to find qualified employees capable of implementing advanced algorithms. This is enormously important for software developers like cases A to D since the software as well as the algorithms evolve continuously according to the design tasks. Moreover, interviewee B noted that there is a general lack of time to proactively enhance the software application. All interviewees are still occupied by the daily business of layout design projects due to their origins as software providers.

With regard to the customer’s capabilities in factory design and planning, all interviewees are consistent in their observation that the majority of customers do not grasp the relevance of factory design. Particularly interviewees B and C noted that the customers are not aware of the overarching objective of minimizing the material handling effort in the layout design as a considerable contribution for long-term efficiency and success.

Instead, objectives like a resemblance to existing testimonial factory layouts or low alteration costs are prioritized, resulting in low layout performance and a redesign early on. In addition, only a few users of software applications use factory design methods correctly and consistently due to a lack of expertise and constant time pressure in the planning process. This difficulty could also be overcome by the use of advanced approaches in software applications for digital factory design. Interviewee A believes that with new Big Data analytics there is an opportunity to gain a deeper understanding of the impact of factory design methods on decision makers. Interviewee D foresees a shifting focus from simulation to Big

Data applications. The digital factory and the associated trend towards constant redesigns caused by the volatile markets, new technologies, and changing legal conditions must therefore trigger a rethinking of the users towards a consistent and transparent planning approach.

Moreover, interviewee B sees a nascent conflict between the planning department and the IT department. An adoption of advanced algorithms that integrate design aspects of several planning phases would result in major changes in the well-established planning procedure in all cases. Thus, the IT department is increasingly seizing more planning responsibility and decision-making power from the factory designers. Additionally, all interviewees hinted that layout designers want a transparent and comprehensive layout planning procedure. They are skeptical about layout solutions that are generated automatically by pushing a button. These statements can be summarized as general acceptance problems concerning advanced algorithms.

Despite the general wariness about advanced layout design approaches, particularly interviewees A and B showed strong interest in these methods and in a close cooperation with specialized scientific institutes. Especially interviewees A and C assume that metaheuristic solutions will play a greater role in future developments, which is closely related to the further increasing computing capacity.

5 Recommendations for Practice

As a result of the conducted study, it is clear that the software developers are currently not focusing on advanced algorithmic approaches. They are not aware of their existence, possible benefits and implementation and showed therefore a general suspicion. A closer collaboration with universities would pave a direct way for the implementation of promising methods and would facilitate superior software applications. Therefore, scientific institutions like universities have the task to change and modernize their factory design courses. They should enhance the strong engineering view with findings from operations research that has focused on the layout design problem for more than 60 years as a separate stream of research (Koopmans and Beckmann, 1957). Students need to be better prepared for the future challenges of factory design resulting from digitization. This includes training in software applications in support of the entire planning process. Additionally, the focus should shift from CAD systems to specialized factory design applications that consider the overall production planning process and the connected logistic processes.

Software providers often serve as consultants in layout design projects and therefore focus on employees with engineering skills. They should also consider employing specialists skilled in operations research to continuously develop the design software and to implement advanced approaches.

In order to solve the acceptance problems, interviewees A, B, and D noted that automated layout design solutions could be valuable if they are used for orientation purposes and in comparison to manually designed layout solutions. Hence, the customers' acceptance will increase and advanced scientific methods can be positioned and marketed as a key feature of the software application. Interviewee C states that a complete replacement of previous simple, greedy methods by metaheuristics is conceivable. Moreover, interviewee C noted that software solutions are generally acceptable if they are user-friendly without time-consuming training and difficult settings.

Interviewee B further recommends well-prepared key users for the usage of advanced solutions in software to ensure a correct use of the generated layouts. The key users should be guided through the design process while automatically focusing on the overarching aim to minimize the material handling effort. Simple and intuitive software usability as well as certain adjustment possibilities would further improve customer acceptance.

According to all interviewees, future software applications should support the entire design process. This also requires interface functions to export the solution into common data formats for further visualization and simulation. Interviewee D noted that integrating the algorithms into a three-dimensional planning procedure is of further importance. Since the interview partners were concerned about the decreasing influence of the users in case of implementing advanced algorithms in the software, literature suggests implementing expert systems (García-Hernandez et al., 2014). These advanced approaches allow for the consideration of the user's experience at several planning steps.

6 Conclusions

There are a significant number of publications in the scientific area of facility layout design, with an apparent trend towards metaheuristics and algorithm-based optimization of the arrangement problem. Although these advanced methods offer several advantages over traditional methods from a scientific perspective, our market review indicated that current design software still uses these simple and outdated methods in the applications. The prevailing part of the design task remains with the designer without any software support. This answers our first research question regarding the methodical support of factory design processes in software applications.

In order to investigate the reason for this practice-research gap and to identify future research direction, we further conducted a multiple interview study with experts from software engineering companies and a scientific institution that distributes a self-developed software.

As regards our second and third research question, our study showed that all investigated cases are connected to science to some extent and apply a similar general layout planning procedure that is well-known in manufacturing engineering research. Current advances in advanced algorithmic approaches from the scientific area of operations research are not affecting the interviewed software developers due to the fact that the case companies

— lack knowledge regarding the existence of advanced algorithms, caused by the scarcity of employees familiar with operations research;

— lack knowledge regarding the implementation, due to the decreased quality of the staff's education;

— lack knowledge regarding the usage of advanced algorithms, due to the use of the software by customers unskilled in layout design;

— expect problems of acceptance, since advanced algorithms that automatically solve design problems would shift reasonability and decision-making power from the designer to the IT department.

Even the scientific institute, with an anticipated deeper understanding of scientific advanced methods, still uses simple algorithms and reveals the same findings as the other cases. This suggests that the research communities (engineering and operations research) are segregated, although they focus on the same topic from different viewpoints.

This study further derived recommendations for practice in light of Industry 4.0, besides the motivation for an intensified cooperation of software developers and scientific institutes from different disciplines:

- software engineering companies should employ staff with specific operations research skills;
- the education of mechanical engineering in the field of manufacturing design should integrate specific operations research issues;
- advanced algorithms should be made user-friendly and be implemented as complementary features at first, until the customers have gained trust in these features.

7 Limitations and further Research

The results of this study are analytically generalizable in terms of correlative validity; however, there are some limitations. The validity of this interview study is within a clearly defined scope:

- Software manufacturers with branches in Germany, specialized in layout design software and services;
- Customers from the manufacturing industry (SMEs to multinationals);
- Individual consultation and fulfillment of customer requests within the projects.

Future research using a larger sample size with diverse industries and firm characteristics would improve reliability of this interview study. An approach which involves interviewing software manufacturers with an international focus should also be expedited in order to validate the findings.

Additionally, we indicate some recommendations for research in order to focus the research for a better applicability of findings in practice in the imminent trend to Smart Manufacturing and Industry 4.0:

The interview partners described several features that they expect from an advanced approach to be implemented in their software. Interviewees A and B demand real-time capabilities of the solution method to make use of the benefits of collaborative planning. Interviewees A and C consider several minutes as a time requirement for a sophisticated solution to be acceptable in terms of collaborative planning.

This allows for a discussion of often uncertain input data and the following solution evaluation in collaboration. Moreover, if the algorithm produces several layout variants, interviewee C expects a recommendation for a preferred layout variant. Interviewee D emphasizes the relevance of a comparison value with traditionally obtained solutions to classify the solution quality. Therefore, the software should be able to calculate the material handling effort expected from the obtained layout variant and should further enable the user to define customized evaluation criteria.

Besides the objective function aiming to minimize the material handling effort, several main restrictions were identified in the interview study that should be taken into account by researchers when developing a metaheuristic:

- Facility shapes
- Facility orientations
- Dimensions
- Path and aisle design
- Fixable functional areas
- Structural conditions, e.g. walls and pillars

Most scientific approaches already satisfy several of these requirements since they are often rather fast, evaluate an adjustable quantitative objective function value and satisfy most of the required restrictions. However, there are only a few approaches that consider three-dimensional layout information (Barbosa-Póvoa et al., 2002) and the material path system (Friedrich et al., 2018). To the best of our knowledge, there is still a lack of scientific approaches that explicitly consider the aisle design.

In order to make their findings better accessible for practitioners, scientific institutes should proactively support the comprehensibility throughout the research process. Researchers are moreover advised to publish their findings considering layout design in practice-relevant journals in addition to scientific journals.

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Additive Manufacturing in Supply Chains – The Future of Purchasing Processes

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Additive manufacturing is one of the leading production technologies when it comes to the efficient production of individual parts. This paper explains how additive manufacturing will influence purchasing processes and network structures of producing companies in future supply chain networks. Therefore, an exploratory research of relevant literature and recent studies in a systematic literature review is conducted, giving an overview of how additive manufacturing will change the processes of purchasing. Traditional purchasing and modern processes affected by the implementation of additive manufacturing are compared, in order to point out differences and new requirements. In the future purchasers have to extend their knowledge of additive manufacturing, to integrate this production technology into their sourcing strategy in an effective way. Technological knowledge and capabilities, supplier relations and internal integration of purchasers need to be improved, to make use of benefits e.g. reduced inventory. This exploration of the impact of additive manufacturing is focused on purchasing processes. Therefore, this paper investigates one special field of the supply chain layer, which is the unique characteristic of this submission. The findings are based on a literature review of studies and specialized literature, an analysis in collaboration with companies was not executed. Additive manufacturing has great advantages in many fields, but it cannot be integrated in supply chain processes with a significant leap forward. The sourcing strategy has to be changed; employees have to be trained, to interact with the new supply chain members and to learn which components can be manufactured additively.

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1 Introduction

Additive Manufacturing is going its way from a pacemaker to a key-manufacturing technology. A lot of high technology companies spot the benefits of additive manufactured parts. At the moment, most of these parts are prototypes, spare parts or individualized consumer goods, but in the near future, taking the evolution of markets into consideration, more and more individual additive manufactured parts will be produced to enable individualized mass production (Zeyn, 2017). In this scenario, the decision to print additively or to produce a part conventionally has to be made during the purchasing process, preferably only in a matter of seconds. The velocity and the quality of this decision process will be a commercial advantage of companies acting on a globalized market. (Johannknecht and Lippert, 2015; Gress and Kalafsky, 2015)

A number of up-to-date studies and articles describe the trends and current developments in procurement. They do all point out digitalization as one of the main aspects influencing the future position of Purchasing & Supply Management (PSM) and the roles of purchasers (e.g. Kushner, 2015; Nowosel, Terrill and Timmermans, 2015; Pellengahr et al., 2016; PricewaterhouseCoopers, 2014). Digitalization, individualization and increasing autonomy as basic principles of Industry 4.0 also have an extensive impact on Purchasing and Supply Management (PSM) (Pellengahr, Schulte, Richard and Berg, 2016). Due to these facts and also because of the ongoing digitalization in production and administrative processes, the purchasing processes in companies will reach a new technological level.

On the one hand, digitalization is represented by new categories. Firms purchase digital products, services, and hybrid components. In order to acquire the demanded technical expertise, it is even more important to collaborate with other company functions. Purchasers have to be involved in product development processes on an early stage. New categories, e.g. related to additive manufacturing, will have to be procured with new sourcing strategies while others might lose importance or even disappear from the purchasing portfolio. (Arnolds, Heege, Röh and Tussing, 2016; Pellengahr et al., 2016; PricewaterhouseCoopers, 2014; Schuh, Aghassi, Bremer and Graw, 2014)

On the other hand, digital transformation causes not only technological advances and new requirements but also organizational and process-related changes. The administrative purchase-to-pay process will mostly be automated, as digital technologies help in the facilitation process. Further automation of transactional procurement decreases involvement of employees in purchase-to-pay and releases more personal resources for strategic tasks (Kushner, 2015; Pellengahr et al., 2016; Scharlach, Schuh and Strohmer, 2014; Drake, 2012). The purchasing staff members have to develop from former administrators to innovation managers, controlling data analysts and engineers in one person.

The network structures of future supply chains containing additive manufacturing as a production technology will refine and even different network partners will change their position and scope of duties. The value of data and their transfer through the supply chain network will be a new key performance indicator for effective supply chains. (Mellor et al., 2014; Zeyn, 2017)

Data for additive manufacturing processes will contain all information which is needed for an implementation in the production process. They will not only contain construction data but also parametric data and specialized settings for the building process in 3D-printers e.g. temperatures, feeding velocity and material advices. Taking this into consideration, one scenario could be that network partners that were not considered to produce goods can be enabled to execute additive manufacturing processes. (Zeyn, 2017)

A great example for this are forwarding companies that are able to become a producing network partner. The storing and distribution of goods will not be their main business area. The producing of parts on their 3D printers will become an important function for the supply chain network. All the parts that caused high storing costs for companies and that were no particular fast sellers can then be produced additively. As an example, these are parts that are only needed sporadically and were stored for the customer satisfaction, so that they have spare parts for a long period but also parts that had to be stored for legal regulation (e.g. aviation industry). (Mellor et al., 2014)

This paper will give an overview of how processes, especially in purchasing areas and network structures of supply chain, will change and develop because of additive manufacturing making its way to an important manufacturing technology. Based on that, recommended actions can be derived for companies, e.g. regarding know-how and competencies for procurement staff necessary for additive manufacturing, that is, amongst others, process knowledge and optimization, technical knowledge about the new products which need to be sourced.

2 Methodology

A literature review is a key method to overcome and manage the broad diversity of knowledge in management research. The main reason for conducting a literature review is to collect and assess already existing literature in order to specify a research question. With respect to the research question, the existing base of knowledge is about to be developed further. (Tranfield et al., 2003)

In addition to the advantages of literature review papers, such as giving a well-structured and up-to-date overview of a specific topic, it adds value by revealing knowledge gaps to the researcher. (Van Wee and Banister, 2016)

Newer technologies such as additive manufacturing that have not been adopted by a lot of companies yet, need a lot of guidance through its management. The difficulty is that there are only a few, if any, experienced employees or management staff because of the circumstances and challenges arising with such evolving technologies. Decision making can be really tough without any or only a little knowledge in this area. Literature reviews can provide the company with a broad base of information and knowledge. From this standpoint, it is easier for management and employees to handle decision making around additive manufacturing and develop its own experience and know-how.

The methodology for developing evidence-informed management knowledge provides three steps that have to be passed through for a systematic literature review. (Tranfield, et al., 2003) These steps are deployed in this paper to provide a desirable methodological approach: planning, conducting and evaluate the review.

2.1 Planning the review

The first step contains the systematic planning of the review. In this phase the guiding research question was developed, which is phrased as follows:

How does the implementation of additive manufacturing as a production technology influence future purchasing processes and the needed qualification of employees working in those processes?

The research question was developed upon the fact that an earlier literature review on the influence of additive manufacturing on company processes, in general, showed that those examinations mostly focused on production processes, value processes or supply chain processes. Due to the fact that purchasing processes get more and more important for companies, because of a globalized market and a reduction of manufacturing depths, also the impact of additive manufacturing on those processes has to be evaluated.

The database, which was used for the review research, was ”google scholar”. In a second stage, the searching process was also conducted on the database of ”Scopus”, but in this case it did not provide further relevant papers, and so no additional paper could be added to the detailed review.

In this database, the keywords ”additive manufacturing”, ”3D-Printing”, ”procurement”, and ”supply chain management” were combined and in the following the most corresponding papers were selected.

The following combinations of keywords were entered, the number of results for every combination is specified behind:

”additive manufacturing” AND procurement (2.610 results), ”3D-printing” AND procurement (2.390 results), ”additive manufacturing” AND ”supply chain management” (1.630 results), ”3D-printing” AND ”supply chain management” (2.370 results)

Because of the two very similar keywords ”additive manufacturing” and ”3D-Printing” a lot of papers appeared in both searches and made the review process less elaborately.

Statistically, most of the publications on this set of issues were published in the years 2016 and 2017 and were classified as an Engineering or Business, Management and Accounting topic.

2.2 Conducting the review

From the first collection of papers, the relevant section was selected to execute the literature review.

For this, a selection of papers and studies was developed, based on a predetermined research strategy. The criteria for the selection was the conceptual link of the papers to both of the topics ”Additive manufacturing” AND ”Procurement”. Only those papers that had a connection to both of these fields and treated the impacts in those fields were chosen for the literature review. This very restrictive search criterion has the advantage of avoiding issues that only mention the procurement process in additive manufacturing as an adjunct.

Beside this criteria, only papers which appeared in the period from 2006 to 2018, were collected in order to develop a current picture of the research field. The search yielded the 11 papers listed in table 1 and represent the final database for our analysis. A second search on the database Scopus was not able to identify additional papers concerning additive manufacturing and procurement.

The selection of papers is summarized in the following table.

Table 1: Selected Papers

Author	Title	Year	Key words
Baldinger M.	Supply Chain Management für Additive Manufacturing: Konzepte, Werkzeuge und Prozesse für die Zusammenarbeit mit Dienstleistern zur Reduktion der Risiken beim Einstieg in Additive Manufacturing	2016	Additive manufacturing cost, cost estimates, make-or-buy, service providers
Bogers M., Hadar R. Bilbergb A.	Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing	2015	3D printing, Additive manufacturing, Business models, Digital fabrication, Glocalized production, Rapid manufacturing, Rapid prototyping, Supply chains
Conner B.-P., Manogharan G.-P., Martof A.-N., Rodomsky L.-M., Rodomsky C.-M., Jordan D.-C., Limperos J.-W.	Making sense of 3-D printing: Creating a map of additive manufacturing products and services	2014	Additive manufacturing; 3D printing; Product development; Complexity; Customization; Volume; Complexity factor; STL; Surface area; Features; Part geometry; Product mapping; Strategy
Huang S.-H., Liu P., Mokasdar A., Hou L.	Additive manufacturing and its societal impact: a literature review	2012	Additive manufacturing. Environmental impact. Energy consumption. Supply chain. Health and wellbeing

Jiang R., Kleer R., Piller F.T.	Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing in 2030	2017	Additive manufacturing, 3D printing, Delphi, Forecasting, Scenario development
Liu P., Huang S.-H., Mokasdar A., Zhou H., Hou L.	The impact of additive manufacturing in the aircraft spare parts supply chain: supply chain operation reference (scor) model based analysis	2014	additive manufacturing; supply chain operations reference (SCOR) model; aircraft spare parts; safety inventory
Pellengahr K., Schulte K.-T., Richard J., Berg M.	Pilot Study Procurement 4.0 The Digitalisation of Procurement	2016	Procurement 4.0, Digitalization
Stucker B.	Additive Manufacturing Technologies: and Business Implications	2011	Additive manufacturing, Business Implications
Zhang Q., Vonderembse M.-A., Cao M.	Achieving flexible manufacturing competence: The role of advanced manufacturing technology and operations improvement practices	2006	Flexible manufacturing systems, Advanced manufacturing technologies, Operations management, Competences
Weller, C.; Kleer, R.; Piller, T.	Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited	2015	3D printing, Additive manufacturing, Market structure, Flexible manufacturing, Economic modelling
Campbell, T.; Williams, C.; Ivanova, O.; Garret, B.	Could 3D Printing Change the World? Technologies, Potential, and Implications of Additive Manufacturing	2011	3D-Printing, Platform, Additive manufacturing, Potentials

For the actual review the following impact areas, which were developed in the planning process, were evaluated, Influence of additive manufacturing on the purchasing portfolio, Influence of additive manufacturing on procurement organization, Impact of additive manufacturing on procurement processes, Influence of additive manufacturing on buyer-supplier relationships and the Influence of additive manufacturing on competence requirements in procurement.

3 Findings

For a first brief dissemination of this review a diagram was developed, which illustrates the main findings of the literature review on a numerical basis. The number of references of the impact in context with the changes of additive manufacturing on the different areas of procurement were counted and applied to create a descriptive diagram. This diagram shows in which of the above mentioned categories the selected authors of the papers see the broadest number of changes, or rather which ones are most important for the future procurement processes and in this connection also for future supply chains. It also shows which category is yet not mentioned that often but can also be an important impact in the future.

The diagram points out that the changing in procurement organization caused by additive manufacturing is most mentioned in the selected papers. The need of new qualification for especially procurement employees is not yet mentioned in many papers

In the following section the most striking findings about the influence of additive manufacturing on procurement are summarized based on the information from the papers listed in (Table 1: Selected papers). The results are divided into the mentioned categories purchasing portfolio, organization, processes, buyer supplier relationships and competence requirements.

3.1 Influence of additive manufacturing on the purchasing portfolio

With the installation of additive manufacturing in a company, new products and services are included in the purchasing portfolio that are 3D printers, raw materials, construction data, additional devices and equipment for post processing, or even additive manufacturing services, like design or production services. (Pellengahr at al., 2016)

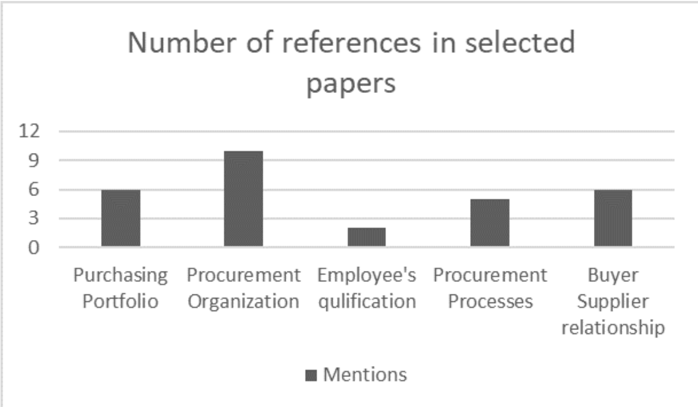

Figure 1: Number of references in papers

As the technological development progresses, innovative products must be sourced to stay competitive by keeping up with higher customer demands and changes in demand and price structures. (Pellengahr et al., 2016) To face the increasingly shorter product lifecycle Weller et al. point out that additive manufacturing is the appropriate manufacturing technology to produce initial prototypes. (Weller et al., 2005) That means the purchasing portfolio of industrial companies does not longer contain the prior number of tools or molds for conventional prototype production. This procurement of tools or molds is replaced by the purchasing of various raw material for the 3D-printers.
The increase of the integration of added manufacturing over different supply chains also influences the market prices that are volatile due to the current trends. It must be taken into account whether to make or buy additive manufacturing and which specific parts would be needed along the supply chain of additive manufactured goods. (Baldinger, 2016)
Conner discusses the nature of additive manufactured parts and necessary inputs like geometric complexity, customization, volumes, and implications for the interaction of product development, procurement and manufacturing further. (Conner, 2014)

3.2 Influence of additive manufacturing on the procurement organization

According to Bogers, due to a high customer focus and individualization, supply chains become more distributed on a decentralized basis. Production activities shift from manufacturer closer to customer. (Bogers, 2015)
In contrast, Liu describes two approaches for the organizational anchoring of additive manufacturing capacity: The capacity can either be centralized to replace inventories or distributed close to the customers. (Liu, 2014)
Additive manufacturing enables direct production of objects and enables the consumers to design own products. As an emerging market online databases offer product designs for additive manufacturing purposes (Jiang, 2017). Customer-centric focus on business models gives indications for operations along the supply chain. Flexibility and responsiveness need to be ensured by procurement organizations. (Bogers, 2015)
Also the integration of additive manufacturing platforms plays a significant role for the procurement organization. The option to use a network of companies as a supplier by using digital purchasing platforms can be one of the solutions for a not existing know-how of the production technology additive manufacturing. (Campbell et al., 2011)
Procurement along with other involved company functions faces the challenge that regulatory frameworks for additive manufacturing are still premature. That includes design and liability regulations, taking into consideration an outsourced additive manufacturing including digital platforms as service providers for data storage and print. (Gress and Kalafsky, 2015)

3.3 Influence of additive manufacturing on the procurement processes

Additive manufacturing influences supply chains and several enterprise processes. Additive manufacturing methods are used to reduce small batches. It has the potential to eliminate stocking activities for certain items and enable on-demand purchasing and production instead. Rapid prototyping becomes part of the strategic sourcing process. Supply logistics processes change as on-shoring is standard for additive manufacturing, different materials have to be procured and the procurement of spare part products decreases. (Stucker, 2011)
Simplified additive manufacturing increases efficiency and responsiveness in supply chains. (Huang, 2012) One advantage that takes effect in that case is that

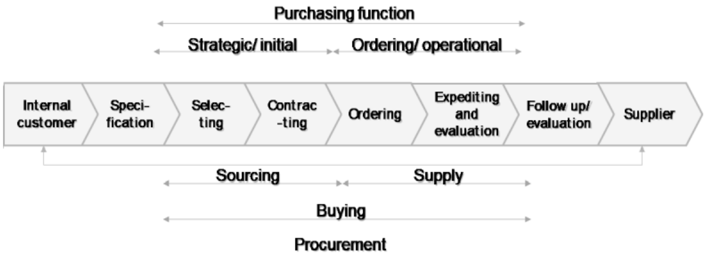

Figure 2: Effects on the PSM process phases. (Adapted from: Van Weele, 2014)

additive manufacturing enables the production of functionally integrated products. That means downstream production processes of several products can be eliminated using additive manufacturing. For example the assembly steps of different product parts can be reduced regarding the fact that with additive manufacturing these different parts can be integrated in just one component. For the procurement that means that the “scale-scope dilemma” of higher procurement costs links to a higher complexity of products can be solved by an supplier using additive manufacturing as one of his production technologies. (Weller et al., 2005; Campbell et al., 2011.)
Also the inclusion of the costumer into the product design process will play a big role for the changes in procurement processes. Additive manufacturing enables them to become a co-designer of their individual product. For procurement the sourcing of different modular parts for the individualization of products will decrease. (Weller et al., 2005)
With the procurement process structure by van Weele at hand, it becomes visible that all the following process steps are affected by changes through additive manufacturing:
In the process area of sourcing, the processes specification and selecting are most affected by additive manufacturing. The selecting process as a strategic procurement process contains the selection of a suitable supplier. Integrating additive manufacturing into the supply chain changes the supplier portfolio for this process. Now one service provider for additive manufacturing can take over the role of several modular materials suppliers.
In the process area of supply the ordering process can be simplified. Through functional integration, the complexity of products, which are produced additively,

can be reduced. That means that the supply risk along the supply chain decreases, as these products can be produced in a decentral manner at the point of use and by the lower number of suppliers involved in one product engineering process.

3.4 Influence of additive manufacturing on buyer supplier relationships

As additive manufacturing opportunities increase, procurement is more and more obliged to look at the costs and risks for make-or-buy-decisions and the choice of suppliers. (Baldinger, 2016)
Different and new suppliers are needed triggered by changes in purchasing portfolios. On the other hand, established suppliers might become obsolete. Procurement and manufacturing will be challenged to identify which items currently purchased from a third party can be developed internally. Companies can make use of offered additive manufacturing services or, with enough demand, buy their own printers. As material requirements continue to evolve, procurement continuously faces new challenges in identifying and developing strategically relevant suppliers and network partners. (Connor, 2014)
In the case of the special field of spare part supply, additive manufacturing can replace the buyer supplier process. With additive manufacturing it is now possible to produce spare parts for products or machines on demand at the point of use. In this case the supplier has to share the design file of the part only and the production takes place at the factory site. (Campbell et al., 2011)

3.5 Influence of additive manufacturing on competence requirements in procurement

PSM can stress its strategic role by gaining additional knowledge and networking as an equal partner within and outside the company. Besides technical expertise, which ensures that the correct new types of products can be bought, the networking as well as innovation scouting and sourcing role of the modern purchasers is fostered by further implementation of additive manufacturing. (Pellengahr et al., 2016)
Internal capacity for additive manufacturing projects is built up. This increases the knowledge about the technology and its potential applications for the focal firm. For successful implementation, personnel along the whole supply chain and network of which procurement is one of the essential functions connecting the involved companies need to be qualified accordingly.

Expertise is required for the procurement of the right products and technologies. Therefore, PSM needs to network with other departments, with suitable suppliers and stakeholders which calls for interdisciplinary know-how and interpersonal skills. In addition, entrepreneurial approaches and innovation abilities of the workforce are fostered. Buyers must have reliable product knowledge about their new digital procurement portfolio, e.g. about quality and pricing. As knowledge about current supply chain fundamentals and manufacturing techniques alters, procurement can benefit by remaining flexible and innovative in the face of 3D printing and other technologies. (Pellengahr et al., 2016)
Beyond explicitly PSM related new skills, technical infrastructure all over the networks needs to enhance regarding speed, security, availability of service and real-time efficiency. Curricula in practice as well academia should focus on increasing ICT skills in general. How these tasks can be embedded in the company depends on existing structures, process and know-how and will turn out clearer in the future. Procurement is one of the functions investigating intelligence solutions. Technological progress and related skills development can be pushed and controlled top down from management and strategic relevance. (Zhang, 2006)

4 Conclusion

One of the additional findings during the literature review is that the topic of additive manufacturing in connection with procurement processes or procurement organization was not often the main topic of the related papers. Most of them focused on technological or production issues. The changes in the area of procurement were only mentioned as a marginal note in the majority of the papers. Still, the systematic literature review has shown that a lot of advantages based on the production technology additive manufacturing can only be exploited by incorporating the specific features of additive manufacturing very early in the product lifecycle, right at the point of designing products in the supply chains and purchasing.
In addition to that, some of the main challenges procurement faces can be affected by progressing utilization of additive manufacturing in a positive way.
Certain risks can be minimized, e.g. by increasing own production of parts instead of relying on suppliers and by decentralization of production to locations close to the customer. Being a technology leader enhancing innovation potential can have positive influence on the company's reputation. The environmental impact decreases through the reduction of waste, transportation and inventory, and additive manufacturing can contribute to sustainability challenges and goals. It is

Figure 3: Challenges of procurement (Adapted from: Crawshaw, 2017)

important to demonstrate a partnership approach and develop a close network with the suppliers of new technology and data as well as with external and internal customers. These details are very important to exploit all advantages of additive manufacturing along the supply chain. Mentioned advantages have to be implemented already at the supplier stage to functionally integrate product parts at an early stage, so that the reduction of product complexity and a reduction of temporary storage can be spread as a monetary benefit alongside the complete supply chain. Centers of excellence can help establish the required know-how of new technologies and spread it throughout the organization as a support function. Procurement needs greater connections with stakeholders in the future to stay competitive, which is especially important for additive manufacturing net-works.

To point out the further research demands, based on the previous literature review, it can be summarized that past research concerning additive manufacturing and procurement is not broadly positioned in the research landscape. Most of the research focuses on additive manufacturing as a new technological production method and on the new products that can be realized with it. The changes in procurement as an early step in companies' processes have not been developed so far.

Additional to this finding, the competences of procurement employees as important decision-makers who affect the whole supply chain (e.g. if a part should be bought or produced additively) are not yet explored scientifically in a strategic way. Nevertheless, it is obvious that especially at this point in the supply chain process a decision concerning additive manufactured parts is indispensable. That indicates that especially interdisciplinary research teams containing the disciplines of engineering and educational science should work together for the development of new education programs containing additive manufacturing topics.

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Part II

Innovation and Technology Management

Efficiency Analysis for Digitalised Working Systems of Truck Drivers

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The current research discussion postulates a digital transformation, characterized by new and in its extent unknown development and application potentials. At this stage scientists and practitioners know little about how these changes will transform specific work tasks. And the question is still even more opaque, whether there are real efficiency gains to be won by digitalization steps. Therefore, this paper develops an efficiency analysis to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers. Data Envelopment Analysis (DEA) is used in order to quantify truck driver performance in the logistics processes of a German food retailer. As inputs we use loading time and cost. Outputs are load factor of units, invoice charged to shops and value of damage. The findings indicate that a change in the level of digitalization entails a loss of efficiency in the first instance which can partly be compensated later. By using correlation analysis we prove a low statistical linear relationship of age and efficiency plus a strong statistical linear correlation of employer size and efficiency as well as period of employment and efficiency, always regarding the changing levels of digitalization in the working system of professional truck drivers. We derived the importance of employee retention programs for HR management along with a positive working environment provided for truck drivers to reduce fluctuation effects. Furthermore, we advise to design software for truck drivers as commonplace as possible and in the style of widespread smart phone software user interfaces.

Keywords: Digitalisation; Data Envelopment Analysis; Efficiency analysis; Truck driver

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1 Introduction

According to the results of a cross-sectoral survey of more than 500 German companies by the digital association Bitkom, 84% of companies with logistics processes rely on digital technologies (Bitkom, 2017, online). Referring to this digital transformation, the current research discussion postulates almost unanimously a development boost that is characterized by a new and in its extent unknown development with non-foreseeable application potentials (Avent, 2014, p. 2). The trend is referred by different views as "Second Machine Age" (Brynjolfsson and McAfee, 2014, p. 7), "Third Industrial Revolution" (Rifkin, 2011, p. 2; Markillie, 2012, p. 1), "Distributed Capitalism" (Zuboff, 2010, p. 1) or "Industry 4.0" (Kagermann, et al., 2011, p. 1). The social and economic consequences can be described as disruptive and affect logistics as a science discipline, activity and industry (Avent, 2014, p. 2; Koch, et al., 2014, p. 4; Wee, et al., 2015, p. 7). Yet scientists and practitioners know little about what exactly is behind these buzz words and how the emerging changes of working systems will transform work tasks or working relationships - and especially the question of efficiency improvements is without widespread empirical answers yet.

Therefore, this paper aims to develop and apply an efficiency analysis to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers. We aspire to answer the following research questions: What are the components of an efficiency analysis aimed to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers? (RQ1) Which level of efficiency exists before the change in the level of digitization, how does it develop during and after the changeover? (RQ2) What effect has age, size of the employer and period of employment - hence work experience - on the level of efficiency? (RQ3).

After this introduction (section 1) we present a short literature review on impacts of digitalization on the human workforce in logistics and identify existing research gaps (section 2). In section 3, the efficiency analysis for digitalised working systems of truck drivers is elaborated by explaining basics of Data Envelopment Analysis, selecting applicable inputs and outputs for the efficiency analysis and explaining the setup and data collection. Based on the findings of the case study which are presented in section 4, section 5 of the paper discusses these results and derives implications for logistics management. The paper concludes with a summary and outlook in section 6.

2 Digitalization and human workforce in logistics

The logistics sector plays a key role in implementing Industry 4.0 solutions (BVL, 2017, p. 5), which raises the questions of consequences for employees and employers. From a sociological point of view, the human workforce can be theoretically structured in job clusters with mainly skilled and unskilled work tasks. The first group can be described as jobs that do not require profound vocational training, work that is carried out after short training on the job or a brief induction phase. On the other hand, qualified skilled workers play an important role: Typical occupational profiles include e.g. specialists in warehouse logistics, dispatchers, skilled workers in harbors and professional truck drivers (Eisenmann and Ittermann, 2017, p. 4). When investigating the human workforce, recent scientific literature also differentiates between blue-collar and white-collar workers.

The first describes a class of workers with primary physical working activities and is inspired by the blue working clothes that employees in the production sector use to wear. Their counterparts are white-collar workers who perform in professional, managerial, or administrative work whereby the expression is derived from the idea of a typical manager wearing white shirts. In this paper we examine qualified skilled workers in the working class of blue-collar workers.

2.1 Findings of literature review and resulting research gap

To identify an existing research gap, the development boost mentioned in section 1 was analyzed by a systematic bibliometric analysis based on Elsevier's abstract and citation database Scopus. Therefore, we concentrated on publications dealing with the impact of digitalization between 2008 and 2018 within the document types of textbooks, conference papers and journal articles. Furthermore, publications related to the sections of social sciences or business/management/accounting were investigated. We used TITLE-ABS-KEY ("impact" AND "digitalization") AND PUBYEAR > 2008 AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "BUSI")) as search term. To illustrate the 154 resulting publications we applied VOSviewer, a software tool for constructing and visualizing bibliometric networks (van Eck and Waltman, 2010, p. 523). The bigger a circle, the more frequently the keyword appears in the publication set from Scopus. The keywords are assigned to a cluster, based on a computer algorithm. Each cluster has its own color related to the year of publication.

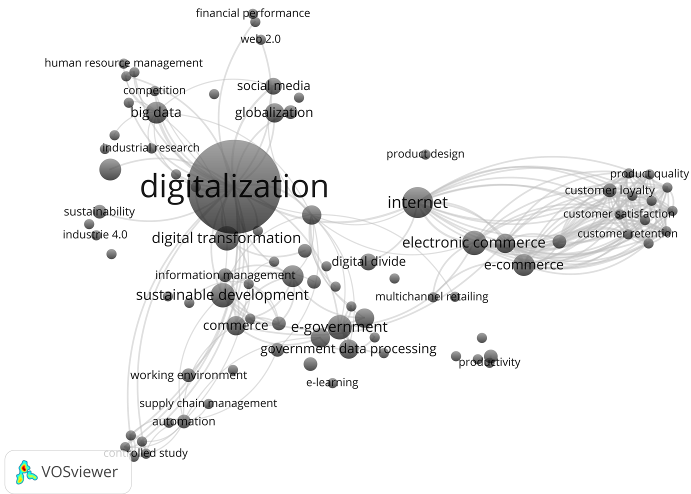

Figure 1: Keywords map of investigated publications

The results show that the current research discussion concentrates on the investigation of digitalization in the industrial sector (keyword e.g. industry 4.0, manufacture) and moreover on the impact on human workforce and existing working systems (keyword e.g. human, working environment, education). Therefore, the blue-collar workers in the logistics sector are hardly addressed. The research approaches of the publications are either conceptual frameworks (Dombrowski, et al., 2014; Hirsch-Kreinsen, 2015; Huchler, 2016; Eisenmann and Ittermann, 2017; Klumpp, 2018; Hirsch-Kreinsen, et al., 2018) or empirical studies based on qualitative research methods (Stowasser and Jeske, 2015; Windelband and Dworschak, 2015; Bauer and Schlund, 2015; Ahrens, 2016; Will-Zocholl, 2016; Wróbel-Lachowska, et al., 2018). Consequently, we identified a research gap for investigating the impacts of digitalization in logistics based on a quantitative methodology.

2.2 Impacts of digitalization on human workforce

Scientific contributions investigating the changes in organizations are often related to change management. It addresses the preparation, realization and analysis for developments or far-reaching changes aiming to improve the current situation of a company and the efficiency of company's activities (Vahs and Weiand, 2010, p. 7). There are several theoretical-conceptual approaches to describe organizational changes on a macro-level, e.g. Kotter's 8-Step Process for Leading Change (1995) or micro-level, e.g. Lewin's 3-Step Model (1947, 1963). Lewin was one of the first researchers who investigated the procedure and effects of changes, especially the reactions of groups that have to face planned changes. According to him, the process of change can be divided in 3 phases called "unfreezing", "moving" and "refreezing". Furthermore, the model states individual levels of efficiency depending on the current change phase (Lewin, 1947, p. 34). The following figure illustrates this development.

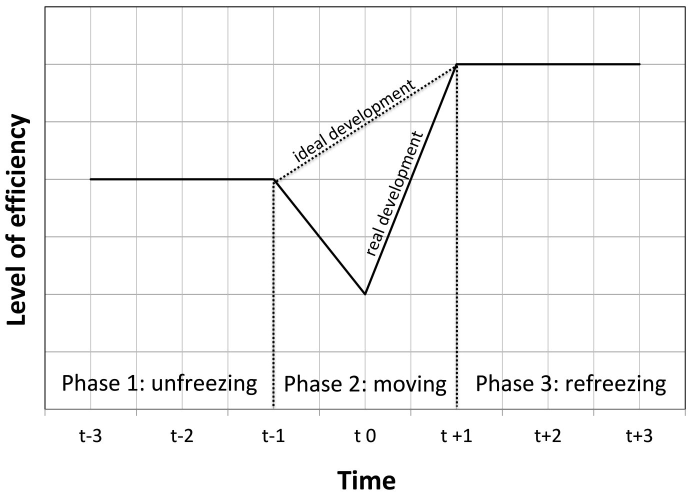

Figure 2: Theory of level of efficiency in change processes, following Lewin, 1963, p. 2017 in Mohr, 1997, p. 73.

In order to explain where the change takes place exactly, the model of a working system created by Hardenacke et al. is used (Hardenacke, et al., 1985). The focus of the model is the work task which is derived by a superior mission of the organization. To accomplish the working task, the human resource impinges on the work object by using work equipment (Luczak, 1997, p. 13). An interaction between humans and the work equipment is necessary and requires a certain level of qualification for successful interaction. Besides the inputs into the working system (e.g. energy, material and information) and the output factors (e.g. work results), there are exogenous factors influencing the working system and subsystems like the physical and social environment (Schultetus, 2006, p. 15). The truck drivers examined in this paper have to face changes in digital innovations related to track and trace systems. The work equipment is a mobile device used to display work tasks for the truck driver e.g. to load a certain amount of containers for a grocery store and deliver it within a given time window. In order to fulfill the task, the truck driver has to scan all relevant 1D barcodes which are attached to the containers, load them into his truck and record differences between the data provided by the mobile device and the determined condition of transported goods.

3 Efficiency analysis for digitalised working systems of truck drivers

There is a wide variety of definitions for the term efficiency in scientific literature. Forsund and Hjalmarsson already described in 1974: "Efficiency is a word easy to use, but very difficult to give a precise operational meaning (Forsund and Hjalmarsson, 1974, p. 152)." Current research approaches postulate almost unanimously that there is no uniformly widespread definition for the concept of efficiency in business literature (Tzika, et al., 2017, p. 530). Efficiency in this research is understood as the relationship between the results achieved (outputs) and the resources used (inputs) for this purpose (DIN EN ISO 9000, 2000, p. 22). To measure efficiency quantitatively, performance measurement differs between key figures, parametric (e.g. Ordinary Least Squares, Stochastic Frontier Analysis) and non-parametric efficiency analysis (e.g. (Stochastic) Data Envelopment Analysis). The main difference is that non-parametric methods do not require a functional relationship between input and output factors whereas parametric methods do (Burger, 2008, p. 48).

3.1 Data Envelopment Analysis

The data envelopment analysis (DEA) method is a non-parametric optimization method of mathematical programming for measuring the relative efficiency of decision making units (DMUs) that have multiple inputs and outputs. A basic model was introduced by Charnes et al. (Charnes, et al., 1978, pp. 429–444) and is based on Pareto's definition of economic efficiency (Pareto, 1897), Koopmans activity analysis concept (Koopmans, 1951) together with the publications of Debreu and Farrell dealing with radial efficiency measurement (Farrell, 1957; Debreu, 1951). The increasing use in scientific research is related to the extensive scope of application where DMUs can be organizations or organizational units such as banks (Chen, et al., 2018; Huang, et al., 2018), universities (Lee and Worthington, 2016; Yang, et al., 2018), airlines (Omrani and Soltanzadeh, 2016; Chen, et al., 2017), employees (Khodamoradi, et al., 2016; Dugelova and Strenitzerova, 2015; Azadeh and Mousavi, 2014; Du, 2013; Zbranek, 2013; Shirouyehzad, et al., 2012) or nations (Malhotra and Malhotra, 2009). Further advantages beyond multiple inputs and outputs included are the facts that DEA is solely based on empirical data without the need of a priori existing production function and the fact that there is no need to weight factors, as this is done endogenously by the mathematics optimization model. The production process or throughput is seen as a black box. The basic mathematical notation is as follows (Wilken, 2007, p. 35):

$$\text{eff DMU}_0 = \frac{virtual\ ouputs\ of\ DMU_0}{virtual\ inputs\ of\ DMU_0} = \frac{\sum_{j=1}^{s} u_{0.j} y_{0.j}}{\sum_{i=1}^{m} v_{0.i} x_{0.i}} \tag{1}$$

eff	Abbreviation for efficiency
DMU_0	DMU with index 0 as exemplary decision unit
s:	Number of outputs to each DMU
m:	Number of inputs to each DMU
$u_{0.j}$:	The weight assigned to the output
$v_{0.i}$:	The weight assigned to the input
$y_{0.j}$:	Amount of the j output produced by DMU 0
$x_{0.i}$:	Amount of the i input consumed by DMU 0

The basic idea is to calculate an efficiency frontier that is used as a best practice input-output-combination for the underlying production scenario. DMUs that are on the efficiency frontier are considered as 100% efficient, whereas the relative inefficiency of a DMU can be determined by measuring the distance between individual DMU performance and the efficiency frontier. As the equation above requires n calculations for all n DMUs, the optimization problem is solved by a linear programming formulation (Charnes, et al., 1978, pp. 435–437). The optimization method can furthermore be based on constant returns on scale (CRS) in the CCR-model (Charnes, et al., 1978) or variable returns on scale (VRS) in the BCC-model (Banker, et al., 1984) and in each case with an input or output orientation.

3.2 Selection of applicable inputs and outputs for DEA

In this paper we analyze the efficiency of truck drivers working in the sector of distribution logistics for a large German food retailing company. Their transportation unit is responsible for delivering food and non-food items from the central logistics center to all grocery shops of the relevant delivery area complete and on time as well as for returning recyclable materials plus empty load carriers from the grocery shops back to the logistics center. To get a clear idea of the underlying scenario, the description is divided in financial flows and physical material flows related to the retailers supply chain.

From a financial point of view, the sales unit of the retailing company is charged by the logistics unit with individual service costs based on cost rates determined at the beginning of a financial year. It can be seen as a revenue stream for the logistics unit. To deliver all orders, the food retailing company uses solely carriers of different sizes whereby the tours are planned by the dispatchers of the retailing company. The carriers receive a payment for the physical distribution which is based on transported units. On the other hand the carriers have to pay for goods damaged in the delivery process.

Focusing the daily business of professional truck drivers and the physical material flows, the work process can be divided in the following steps: (1) Register at the responsible dispatcher in the logistics center, (2) Receive data for delivery tour through mobile device, (3) Load the truck by scanning barcodes on load carriers through mobile device, (4) Receive freight documents from dispatcher, (5) Drive to n grocery shops, (6) Unload cargo at n grocery shops, (7) Return recyclable

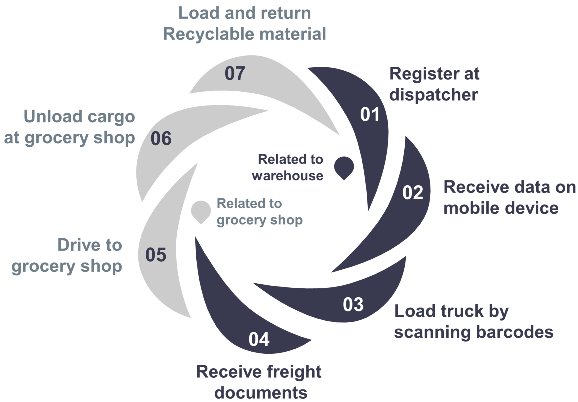

Figure 3: Illustration of work tasks of professional truck driver

material and empty load carriers back to logistics center. Hence, the question arises where truck drivers get in touch with a change in the level of digitalization and where they feel a change in their daily business. The following Figure 3 illustrates the work tasks of a professional truck driver in the given scenario.

Therefore, we choose to investigate the loading process (2) and (3). Analyzing the whole chain is unsuitable due to the fact that too many confounding factors e.g. waiting time at logistics center or grocery shops, traffic jams and vehicle breakdowns can distort the factor time as an important element in an efficiency analysis. The sub-processes (1), (4) and (5) are unsuitable because a change in the level of digitalization does not affect them. Furthermore, (6) and (7) are suitable for the scenario but require less interaction with the mobile device than (2) and (3).

For the DEA we use the loading time needed to load the truck and occurring transportation costs as inputs. The second factor is quantified by the payment to carriers for transported units. Choosing the whole payment is unsuitable as this does not take into account that only a sub-process, the process of loading the truck, is analyzed. Therefore, we use a percentage of the whole payment based on the ratio of needed loading time and total time of a tour, whereby latter is the planned total time of a tour based on the calculation of the route planning software to avoid confounding factors like traffic jams or waiting time.

$$Relevant\,transportation\,costs = \frac{Actual\,loading\,time}{Planned\,total\,time\,of\,tour} \times Total\,payment \tag{2}$$

As outputs we use 3 factors. The first one is the invoice of the transportation unit of the retailing company to the sales unit for all rendered logistics services where we do not use the whole amount but the equal percentage as for the input transportation costs. It can be seen as a revenue for the logistics sector which is often used as an output factor for performance evaluation of logistics firms based on a DEA model (Hong and Xu, 2015; Momeni, et al., 2015; Tang, et al., 2015; Ye, 2015). The second output factor is the monetary value of all goods that are damaged or destroyed while loading the truck. In this case we do not use the sales prices of goods that can be found in the grocery shops but the purchase price of the food retailing company which presents the product value at the time of damage. As high output values increase the efficiency of DMUs we use the reciprocal calculated by the following formula.

$$Damage\,value\,of\,DMU = Max.observed\,damage - damage\,caused\,by\,DMU \tag{3}$$

The third output factor is related to the transport units that are loaded into the truck. We could simply use the amount of units and argue that when loading a roller container (square measure 72cm x 81,5cm and max. load 500kg) or a bigger pallet (square measure: 120cm x 80cm and max. load 1500kg) one barcode scan is required and therefore, the effort is equal. But with regard to the driver loading his truck, the different weights of the transport units cause a fundamental difference in the effort of handling. We take this unequal effort into account by rating loading equipment based on their geometrical square measure. Therefore,

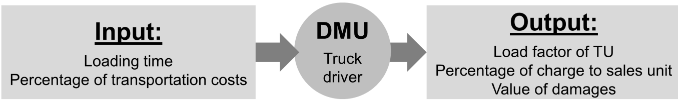

Figure 4: Components of the efficiency analysis

1.0 transport unit (TU) shall correspond to the dimensions of a roller container and all others are converted based on this standard, e.g. 1.64 TU for a pallet $[(120cmx80cm)/(72cmx81,5cm)]$. With the justification of every single input and output factors we can answer RQ1 "What are the components of an efficiency analysis aimed to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers? (RQ1)" and summarize the results of the elaboration in the following Figure 4.

3.3 Setup and data collection

To analyze the efficiency levels for digitalised working systems of professional truck drivers, the daily loading activities for 30 of them were examined during 4.5 weeks by evaluating 1,344 delivery tours. The digital change in the underlying scenario was the replacement of mobile devices based on windows mobile software with complex operation using a keyboard, by new mobile devices based on Android software with a user friendly full touch display. Another major modification was the integration of more and new processes into the existing workflow that is handled by the mobile device and have not been included before, e.g. special application for high value products like cigarettes, elimination and digitalization of accompanying documents along with a clear menu navigation.

To be able to prove that the developments in efficiency levels are not based on external factors, the results of a n $= 15$ group with n $= 15$ of professional truck drivers with digitalization (DG) are contrasted with a n $= 15$ control group (CG, n $= 15$) of professional truck drivers without any changes in the level of digitalization. The change was done at the beginning of calendar week 16 (t_0). To get an own empirical curve progression based on Lewin's 3-Step Model we analyzed the 3 phases "unfreezing" ($t-4$,$t-3$,$t-2$,$t-1$), "moving" (t 0) and "refreezing" ($t+1$,$t+2$,$t+3$,$t+4$). The sociodemographic structure of the digitalized group and the control group has been chosen identically in order to guarantee a maximum level of construct validity. The following figure shows the sociodemographic structure.

Furthermore, we analyzed the period of employment of relevant professional truck drivers. As the retailing company only uses carriers, information about the period of employment of truck drivers is not relevant, when investigating the impact of digitalization. Therefore, we enquired the truck drivers about their time of occupation at the transport unit of the food retailing company. Figure 5 shows the results for the digitalization group and the control group.

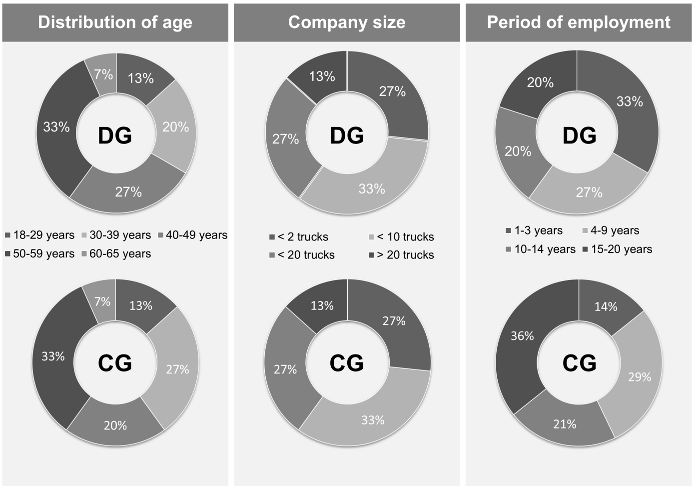

Figure 5: Sociodemographic structure of digitalized and control group

4 Findings of the case study

In the case study we use an input oriented model as the company aims to minimize loading time of professional truck drivers and cost for transportation. The

Table 1: Statistical measures for results of CCR-model

Period	Digitalized group D			Control Group C			Diff. of mean values
	Min	Mean	Max	Min	Mean	Max	
$t-4$	0.80	0.93	1.00	0.64	0.94	1.00	+0.01
$t-3$	0.78	0.93	1.00	0.68	0.94	1.00	+0.01
$t-2$	0.79	0.94	1.00	0.86	0.94	1.00	±0.00
$t-1$	0.72	0.92	1.00	0.85	0.93	1.00	+0.01
$t\,0$	0.63	0.80	1.00	0.61	0.86	1.00	+0.06
$t+1$	0.74	0.89	1.00	0.76	0.91	1.00	+0.02
$t+2$	0.77	0.93	1.00	0.76	0.92	1.00	-0.01
$t+3$	0.67	0.89	1.00	0.66	0.91	1.00	+0.02
$t+4$	0.78	0.92	1.00	0.69	0.88	1.00	-0.04

investigation was done during 4.5 weeks what we divided into 9 periods with 3 days (MO-WE and TH-SA) each. We chose $t-4$,$t-3$,$t-2$,$t-1$ as periods before the change, t 0 as the time frame of the change and $t+1$,$t+2$,$t+3$,$t+4$ as periods after the change. All truck drivers of the digitalized group received their new mobile devices at the beginning of t 0 and before starting their daily work. The following table shows relevant statistical measures for the results of the DEA CCR model calculation.

We chose a CCR-model with constant returns on scale which is most commonly used as a basic model in scientific literature. This can be explained by the underlying assumption regarding the optimal operational size (Cantner, et al., 2007, p. 11). A DMU under evaluation that operates with CRS performs with a most productive scale size (MPSS). Therefore CRS assume that all DMUs exhibit an optimal operational size. The concept of MPSS has been defined by Banker, et al. where DMUs do not naturally operate at MPSS but would achieve it by scaling its operations up and down via VRS (Banker, 1984, p. 39). Hence BCC-model is only applied when it is specifically required to check for increasing or decreasing returns to scale. As we assume that the MPSS, in the case of professional truck drivers performance defined as the individual performance capability, is equal for each DMU the CCR-model is applied. The following Figure 6 illustrates the curve progression of DEA efficiency measures for $t-4$ to $t+4$.

The graphs in Figure 6 show that the efficiency of the digitalized group decreases significantly in t 0 where the change in digital technology took place. The data

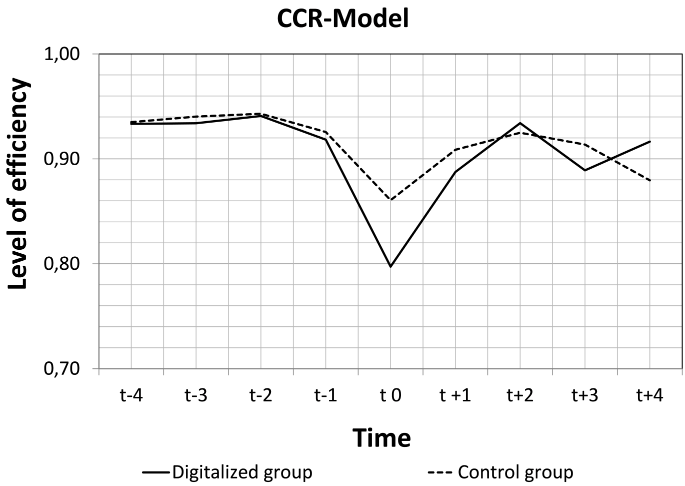

Figure 6: Curve progression of DEA efficiency measures for $t-4$ to $t+4$

cannot be interpreted solely by the total efficiency values, but by the difference between the mean values of the 2 groups. Before the digitalization process the curves were closely related with a deviation of max. 1% but in t 0 the differences in efficiency values are 6% in the BCC-model. This is enough evidence to answer RQ2 ”Which level of efficiency exists before the change in the level of digitization, how does it develop during and after the changeover?”: Before the change there is an efficiency level of an average of 93% (CCR-model) and during the change in the level of digitalization we monitored a significant loss of efficiency that increased to the former level in $t+2$. After the changing level of digitalization the level of efficiency averages 91% and is therefore higher than during the change but lower than before. We assume that the effect of an increasing level of efficiency through digitalization will occur in long-term investigations which outline further research needs.

To be able to answer RQ3 ”What effect has age, size of the employer and period of employment on the level of efficiency?” we use a correlation analysis to investigate the statistical relationship between the level of efficiency and sociodemographic attributes. We chose the efficiency values of t 0 (CCR-model) for the group with digitalization as it is the period where the change in the level of digitalization takes place. A high efficiency in this period proves that the driver is affected by the change but still efficient in the work he does.

The correlations coefficient r for the relationship of ”age in years” (x) and ”level efficiency” (y) is $r = 0.1496$. Therefore, there is a low statistical linear relationship between these 2 factors. The following figure shows the correlation graphs for the relationship of ”total trucks of company” for the carrier's size (x) and ”level of efficiency” (y) as well as the relationship of ”period of employment” at the food retailing company and not as a truck driver (x) and ”level of efficiency” (y).

Due to the correlation coefficients there is a strong positive linear statistical relationship between a company's size and the level of efficiency during a digital change. Furthermore, we can determine a strong positive linear statistical relationship between the period of employment in a certain occupation and the level of efficiency during a digital change. These findings answer RQ3.

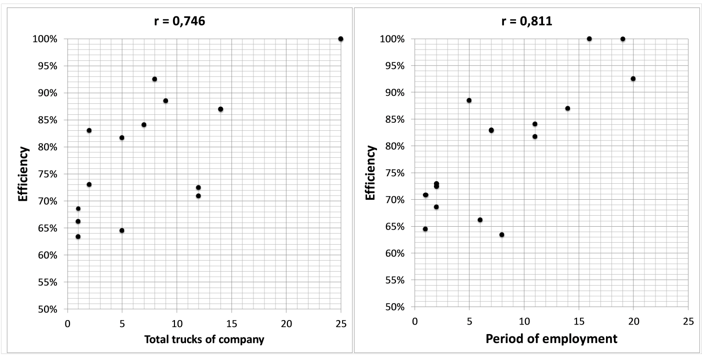

Figure 7: Correlation graphs for company size and period of employment

5 Discussion and implications for management

The curve progression of the analysis indicates a loss of efficiency during the first days of the change which has been explained in the previous chapter. In addition, the investigation shows that the initial level is not constantly reached in the periods after. Due to the limited periods included into the analysis we cannot answer the question if the increasing level of digitalization can increase the level of efficiency for this case.

The results of the correlation analysis indicate that age is less relevant when discussing the changing levels of digitalization for professional truck drivers. One reason for this is that mobile devices like mobile phones became a part of our every day's life, independent of our age or social status. More than 10 years ago the use of internet and mobile devices was interpreted as a border that had to be crossed and where users had to intentionally go to. This can be understood by reenacting the motto of the internet conference re:publica in 2007 called "living in the internet". Digital devices and the internet are no parallel worlds to go into any more, it rather became a medium that permanently and unconsciously expands the reality we are living in. All of the professional truck drivers investigated in this case possess a private smart phone and are therefore used to the full touch display introduced with the mobile devices. A recommendation for IT business units and software engineers is to design virtual dialogues on mobile devices as commonplace as possible. For HR management our analysis gives indications that the age of employers will less be a problem in regards to changing levels of digitalization. The results of the correlation analysis investigating the size of the company can be traced back to the fact that bigger carriers use supervisors to coordinate truck drivers and their service at the logistics unit of the food retailing company. A direct contact for questions has a positive impact on the efficiency level when changing the levels of digitalization. This can be a hint for logistics process management to invest in experts helping all truck drivers by placing them on the area of outgoing goods in the logistics center to weaken the negative effects on efficiency levels. The last correlation analysis with the period of employment at the food retailing company indicated that being proficient in the company's processes can be essential for a successful analog-to-digital conversion. An employment of more than 5 years and the knowledge gained in this time seems to be a valuable asset. This means that HR management of carriers should concentrate on developing and promoting employee retention programs to lower fluctuation effects of professional truck drivers. For the contracting authority, in our case the food retailing company, it also means to provide a positive working environment with short waiting times, clear objectives and permanent support.

6 Conclusion and outlook

The aim of this paper was to develop and apply an efficiency analysis to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers. RQ1 "What are the components of an efficiency analysis aimed to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers?" was answered by the development of a DEA analysis using loading time and percentage of transportation costs as input factors plus load factor of TU, percentage of charge to sales unit and value of damage (reciprocal) as output factors. We applied the analysis in order to evaluate the truck driver's (DMU) performance in the logistics sector of a food retailing company. On the basis of this case study we answered RQ2 "Which level of efficiency exists before the change in the level of digitization, how does it develop during and after the changeover?" by deriving the curve progression of relative efficiency during 4.5 divided in 9 periods with 3 days each. Before the change there was an efficiency level of an average of 95% (BCC-model) and during the change in the level of digitalization we monitored a significant loss of efficiency that increased to the former level in $t + 2$. Finally RQ3 "What effect has age, size of the employer and period of employment on the level of efficiency?" was answered by correlation analysis comparing the level of efficiency during the change in the level of digitalization (t 0) with the age of the truck drivers, the size of their employers and their period of employment at the German food retailer. We showed a low statistical linear relationship of age and efficiency plus a strong statistical linear relationship of employer size and efficiency as well as period of employment and efficiency, always regarding the changing levels of digitalization in the working system of professional truck drivers.

The contributions and implications presented in this article were taken from a quantitative (DEA analysis) and explanative (related to Lewin's 3-Stage Model of Change) approach, which is why the results have limitations and an enlargement of the scope would enable new insights in the future: We did not include further qualitative input and output factors like the satisfaction or motivation of truck drivers. Moreover, we examined a change in the level of digitalization without any training methods applied to prepare the professional truck drivers.

Therefore, research is necessary and interesting along the lines of the following possible research questions: (i) How can qualitative soft factors like employee's satisfaction and motivation be integrated in an efficiency analysis for professional truck drivers? Current research approaches regarding human resource management include soft factors into DEA for efficiency measurement of employees (Shirouyehzad, et al., 2012; Zbranek, 2013; Du, 2013; Azadeh and Mousavi, 2014; Dugelova and Strenitzerova, 2015; Khodamoradi, et al., 2016). Furthermore, (ii) How and to which extend can training methods like seminar based training or self-studies with digital mock ups reduce negative effects in the level of efficiency when changing the level of digitalization for professional truck drivers? These questions would constitute interesting research pathways following the first quantitative results presented here.

Altogether, the presented analysis and management implications have shown the importance and value of a quantitative-empirical approach regarding the digital transition in specified logistics processes and human work contexts. This will be a long-term research and business practice question for the future of logistics.

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Alternative Development Paths for Supply Chains in 2030

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Many different megatrends such as digitalization, are posing specific challenges and opportunities for supply chains creating the urgent need to adapt and rethink the way they are organized. This paper aims to define development paths (DPs), which constitute projections into the future. The DPs are based on the analysis of megatrends, which might have an impact on the design of supply chains until the year 2030. The results are 51 possible DPs, which are derived from the identified megatrends and clustered under 22 descriptors, which are in turn assigned to the PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) dimensions. These DPs consider the underlying criteria reasonability and conceivability. They describe how the future might look like in 2030 and can be used to address developments, challenges and opportunities that may arise in supply chains. Thus, this paper creates the starting basis for further research that deals with the creation of holistic industrial scenarios affecting future supply chains.

Keywords: Supply Chain; Megatrends; Development Paths; Scenarios

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1 Introduction

The biggest trader and exporter is the political and economic European Union (EU) of 28 member states. It is expected that in the next 10-15 years 90% of the global economic growth will come from outside the EU (ALICE, 2014). Therefore, on one hand, the EU companies have to be able to adapt and gain a competitive advantage by accessing these new markets. On the other hand, companies must configure accordingly their supply chains to respond efficiently to incoming challenges, such as customization and scarcity of resources. Digitalization accompanied by acceleration of technological developments affect different industries, such as process, discrete manufacturing and logistics industry that are significant sectors for the EU's economy.

The process industries are industries where the production processes are either continuous, or the batches of materials are indistinguishable (Institute of Industrial and Systems Engineers, 2018). The product is created by using a formula to refine the raw materials leaving no way to break down the final product into its basic components (Cole and O'Donnell, 2017).

Different divisions of the process industry sector such as chemicals, minerals non-ferrous metals, are united under SPIRE - Sustainable Process Industry through Resource and Energy Efficiency (Tello and Weerdmeester, 2012). These divisions comprise more than 450,000 companies, employ 6.8 million people and have a yearly sales volume of more than EUR 1.6 billion. The common feature between these types of companies is the high dependence on resources (e.g. energy). The process industry is important for Europe since it covers 20% of the overall European industry in terms of employment and sales volume (Tello and Weerdmeester, 2012).

The discrete manufacturing sector has 29.7 million employees in over 2 million companies generating a turnover of EUR6.98 billion and a value added nearly to EUR 1.63 billion; the sector represents 17% of the EU GDP (EFFRA, 2013). Companies in this sector produce distinct items that can be easily counted and the products are measurable in distinct units.

The top five branches for value added and employment in the discrete manufacturing sector are machinery and equipment, food products, metal products, motor vehicles and electric equipment (EFFRA, 2013).

As reported by Eurostat and the alliance for European Logistics, the logistics sector constitutes the single biggest industry in Europe: it creates 7 million employees and the revenue per year is more than EUR 900 billion, representing around 7% of total European GDP (Savills Investment Management, 2016).

In order to address these challenges and benefit from the opportunities provided by megatrends, companies use mechanisms such as collaboration and reconfiguration of supply chains. Berger (2015) identified the top ten trends impacting the supply chain: (i) rising customer requirements regarding reliability, (ii) rising customer requirements regarding flexibility, (iii) increasing demand volatility, (iv) rising customer requirements regarding lead times, (v) rising customer requirements regarding cost, (vi) increasing uncertainty, (vii) increasing complexity, (viii) increasing globalization, (ix) increasing heterogeneous customer requirements, and (x) increasing speed of change. Cost and reliability are revealed as the most important targets in supply chains (Berger, 2015). In the future, lead time and flexibility will also have a high importance. More recently, Kersten et al. (2017) analyzed the trends and opportunities in supply chain management that lead to digital transformation opportunities from a twofold perspective: endogenous and exogenous. Endogenous trends include: digitalization of business processes, business analytics, transparency in the supply chain, automation, networking/ collaboration, and decentralization. Exogenous trends comprise: cost pressure, demand fluctuations, government regulations/ compliance, individualization, staff shortages, risks/ interruptions, complexity, sustainability, and changed consumer behavior.

The analysis of challenges and opportunities in the supply chain has generally been addressed in the literature by focusing on one or several dimensions. For example, Zhong, et al. (2016) focus on Big Data technology and identify current challenges, opportunities and future perspectives from six aspects: data collection, data transmission, data storage, processing, decision-making, and applications. Similarly, Bechtsis, et al. (2017) study the impact of Automated Guided Vehicles for a sustainable supply chain. Barbosa-Póvoa, da Silva and Carvalho (2018) include three dimensions (economic, environmental and social) in their analysis to identify opportunities and challenges from an operational perspective. However, few studies have considered other dimensions (e.g. legal, political).

Challenges increment the complexity of supply chains in three main aspects: operational, logical and administrative (Yami, 2018). According to Yami (2018), a study carried out in 2006 performed a ranking of complexity drivers in the supply chain leading to the following result: product/ services, customers, direct materials, ship-to locations, manufacturing locations, suppliers, and distribution centers. The actions focused on the control of the complexity of the supply chain that will have a positive impact in the competitiveness of the firm.

In this regard, handling change is an integral part of managing supply chains. However, the speed of change is so fast that it is difficult to identify where to focus the company's management resources. Under this uncertain environment a framework for the identification of future scenarios in the supply chain has been developed. The framework comprises a PESTLE analysis to identify megatrends that interact to create the challenges and opportunities future supply chains might face. This paper uses the process, discrete manufacturing and logistics industries as input in order to be able to analyze megatrends from different points of view. The results of this paper are final DPs that consider these three industries like a single system. This approach provides the opportunity to create generic DPs, which are required to build industrial scenarios.

This paper is divided into five sections. Section 2 includes a literature review related to scenario development in the field of supply chain management (SCM). Section 3 describes the methodology developed for the definition of DPs. The defined DPs are summarized in Section 4 and elaborated in detail for the technological dimension in Section 5. Section 6 entails the conclusion and an outlook on further research.

2 Literature Review

Today, supply chains face several challenges and opportunities, such as globalization and emerging technologies that change and shape the future of industries. Thus, it is crucial for companies to develop robust strategies and prepare for the future (Singh, 2004; Melnyk, et al., 2009). To this end, scenario planning is the most appropriate approach for a long-term planning to support decision making in uncertain situations (Schoemaker, 1993).

Scenario planning has been utilized by several studies in the field of SCM (e.g. Mazzarino, 2012; PwC, 2009; von der Gracht and Darkow, 2010). As for the planning horizon, most of the papers in the field of SCM focus on a range of 8–10 years (e.g. von der Gracht and Darkow, 2013) and a few take into account a planning horizon of more than 10 years (Jiang, Kleer and Piller, 2017). Regarding the context of the scenarios, the focus of those papers is mainly on the logistics industry (e.g. DHL, 2012; von der Gracht and Darkow, 2016). There are a few papers that develop scenarios for the discrete manufacturing industry (e.g. Arora and Putcha, 2013; Jiang, Kleer and Piller, 2017) and process industry (e.g. Willigens and von der Gracht, 2013). To the best of our knowledge, there is not any study on industry scenarios that support decision-making in all of these three industries so that companies could take a holistic perspective into consideration. This requires a more thorough approach to manage long-term planning in the process, discrete manufacturing and logistics industry. Our research closes this research gap by developing alternative DPs that consider all the three aforementioned industries.

Scenario publications mainly use the Delphi technique to develop and present only the final scenarios (e.g. von der Gracht and Darkow, 2010; Jiang, Kleer and Piller, 2017). In the contrary, our study follows the Gausemeier and Plass (2014) approach, which is described in the methodology section. This paper also presents potential future DPs that enable companies to recognize different developments based on megatrends. From the DPs final scenarios, which reflect the overall system relations between the chosen dimensions, can be developed in further research.

The central idea of developing alternative paths for long-term planning is to lead decision makers to specific directions within the PESTLE dimensions and provide support in uncertain times (Powell, 1992). However, most of the studies give emphasis mainly on the environmental dimension (e.g. Arora and Putcha, 2013; von der Gracht and Darkow, 2013; von der Gracht and Darkow, 2016; PwC, 2009). Only a few studies (e.g. DHL, 2012; Mazzarino, 2012) have addressed all of them. Our focus lies within all of the PESTLE dimensions. Based on the gaps discussed above, this study tries to answer the following research questions:

1. What development paths might emerge from megatrends in the industrial sector by 2030?
2. How will the technological dimension particularly shape the DPs for the industrial sector by 2030?

3 Methodology

This paper follows the scenario technique developed by Gausemeier (Gausemeier, et al, 1998; Gausemeier and Plass, 2014) in order to create projections, which constitute developments into the future, specifically until the year 2030.

The Gausemeier approach has five stages: (i) preparation, (ii) scenario field analysis, (iii) scenario prognosis, (iv) scenario development, (v) scenario transfer. This paper presents the third stage, in which a range of possible futures (typically 2-4) is defined for each descriptor (i.e. megatrends such as globalization). These projections represent alternative and dissimilar developments of the descriptor.

Thus, this study shows all the potential future developments, which enable companies to evaluate different paths for different megatrends, instead of presenting the final scenarios that result from different combinations of a variety of DPs within the underlying dimensions. This basis allows building final consistent scenarios in further research.

These DPs are derived from the analysis of identified megatrends in previous research (Kalaitzi, et al., 2018), which in turn have been organized according to the PESTLE dimensions. Some megatrends have been rephrased if necessary in order to derive the descriptors. The decision to rephrase a certain megatrend is subject to its tendency. If the megatrend has a positive or negative inclination, it is rephrased to represent a neutral position; e.g. the megatrend “protectionism” has been renamed to the descriptor “trade policy”. A descriptor can have a positive, negative and neutral DP. However, deviating settings are also feasible. Consequently, the number of DPs per descriptor is not fixed and varies by descriptor. Each descriptor is characterized by diverging DPs that express possible future states of the descriptor and describe circumstances companies and societies might face.

The analysis of the megatrends considered statistics, forecasts and descriptions of the respective megatrends found in literature (Kalaitzi, et al., 2018). Hence, quantitative and qualitative data is combined in order to derive the DPs. Additionally, several iterative workshops with three to 17 experts from different departments, sectors and with different backgrounds were conducted in order evaluate the DPs derived from literature as well as elaborate on further possible DPs. This approach provides a comprehensive picture throughout all PESTLE dimensions as well as the three industries under consideration.

Each DP is assigned to one of the PESTLE dimensions. Nevertheless, certain DPs also can have impacts on other dimensions since it is rarely that developments affect only one of the PESTLE dimensions. This is due to the comprehensive nature of the study and a holistic analysis of opportunities and challenges of megatrends.

The main criteria for the creation of DPs are its reasonability and conceivability (Gausemeier and Plass, 2014). Hence, we propose that every DP needs to fulfil certain quality criteria, namely: (i) plausibility - a DP needs to be plausible to the complete scenario team, (ii) dissimilarity - all DPs have to be distinct to each other, (iii) completeness - a set of projections within a descriptor has to provide a comprehensive set of possible developments, (iv) relevance - each DP requires a check regarding its future relevance, and (v) information content - each DP needs to add further value to the set of DPs within a descriptor. A DP can be futuristic but needs to rely on valid arguments or requires justification by statistical developments.

Suitable DPs must be distinct, so that the consistency check, needed in subsequent research for the scenario building, does not lead to many different evaluations and, hence, to inconsistent scenarios. Rather reasonable combinations of DPs are necessary for the creation of consistent scenarios.

Section 4 presents the results of this research by listing the descriptors with a definition and the assigned DPs organized by the six PESTLE dimensions.

4 Overview of the Development Paths

Table 1 contains the descriptors per PESTLE dimension along with a definition for each descriptor, and provides an overview of the identified DPs per descriptor.

Table 1: Summary of development paths in the PESTLE dimensions

Dimension	Descriptor	Definition	Development Path
Political	Political Setting	Political setting describes the political activity in a society, the satisfaction level of the population and general risks that might affect a country (Campos and Gassebner, 2009).	Constant development in Europe Government collapse in Europe
	Trade Policies	”Trade policies are policies aimed at influencing the international commercial relations and the flow of goods and services across borders” (Jarman, 2017) affecting the availability, and therefore price and use goods and services.	Political concord in Europe Protectionism Free trade
	Confederation	”That form of association between states in which the general government is dependent upon the regional governments has often been described as a confederation” (Bennett, 1964).	Contented union Unstable confederations Fragmentation

Economic	Global Trade Shift	Global Trade Shift describes the changes in location of economic activities between industrialized countries and emerging economies (Dicken, 2015; UNCTAD, 2012).	The pendulum shifts Steady titans US & Europe
	Global Corporate Structures	Global Corporate Structures "define and clarify responsibilities for operational, control, and reporting processes" (Baret, et al., 2013, p.2) on a global governance level.	Think global, act local Rise of born-global firms
	Digital Economy	Digital Economy describes the changing environment in which digitalization is becoming more and more integrated into the business environment enabling new business concepts (Brynjolfsson and Kahin, 2000).	Traditional economy persists Digital potential Digital impediment
	Financial Innovations	Financial innovation is "something new that reduces costs, reduces risks, or provides an improved product/service/instrument that better satisfies participants' demands" (Frame and White, 2002, p.3) within a financial system.	Bank and Fintech collaboration A world without banks Big five are the banks of the future

Social	Demographic Change	Demographic change describes the changes and tendencies of the population regarding age, gender, birth and death rate and migration. It also comprises longer and healthier life expectancy (Cambridge Dictionary, 2017).	Ageing population and acceleration of disparities Awareness of inequalities and wealth redistribution
	Urban Living	”The process of the economic development which leads to a significant concentration of human resources, economic activities, and resource consumption in cities (modern environment or refurbished buildings, studios and lofts” (Madlener and Sunak, 2011).	Smart regions Smart cities
	Consumption Patterns	Consumption patterns describe the buying behavior and the handling of the purchased goods or services (Fletcher and Emmanuel-Stephen, 2016).	Much and cheap Consumption awareness DIY society Individualized consumption

Customer Orientation	"Customer orientation refers to the importance an employee places on meeting customers' needs and expectations" (Nguyen, et al., 2014, p.1097).	Individualism – focus on variety Collectivism – focus on the crowd
Knowledge-based economy	Knowledge-based economy describes "trends in advanced economies towards greater dependence on knowledge, information and high skill levels, and the increasing need for ready access to all of these by the business and public sectors" (Organisation for Economic Cooperation and Development, 2007, pp.434).	Investments equalize the labor market Rapid changes cause unemployment
Digital Transformation	Digital transformation describes the changes related to the application of technologies and their integration into all aspects of human life and society, e.g. to improve performance of enterprises or convenience of social life or to change the way business is done (Probst, et al., 2017, p.10).	Rapid advancement of digitization and digitalization Obstacles restraining digital transformation Digital stagnation

	Autonomous Systems	Autonomous systems describe objects or devices that can act and make situation-dependent decisions independently without interference by humans or other outside forces and have the ability for self-governance in the performance of control functions (European Group on Ethics in Science and New Technologies, 2018; Antsaklis, et al., 1991, p.5).	Dynamic development of autonomous technologies Innate reluctance to accept autonomous technologies
Technological	Alternative energy generation, storage and usage	Alternative energy generation, storage and usage illustrates how energy can be obtained and stored in sustainable ways. Moreover, it describes the usage of alternative energy for industrial, transportation and mobility purposes (Kleiner, et al., 2017; Hydrogen Council, 2017, p.10).	Established electrification technologies and green systems Ongoing electrification and alternative energy endeavors
	Decentralized connection of information and physical devices	Decentralized connection of information and physical devices describes how companies cope with the masses of data and take advantage of the smart decentralized linkage (Dickson, 2016).	Dominance of global players Start-ups and SMEs take up business

	Disruptive Production Technologies	Disruptive technologies describe developments that bring revolutionary changes to social life and to the way companies understand and do business. In the context of production technologies, the concept of Industry 4.0 reflects this emerging pattern, encompassing the integration of different technologies into an autonomous production system that can regulate itself based on knowledge and sensors (Lasi, et al., 2014; Hofmann and Rüsch, 2017).	Continuous exploitation of disruptive technologies Coexistence of conventional and disruptive technologies
Legal	Consumer Protection Laws	Consumer protection law is defined as "all legal principles and rules governing relationships and problems between various parties or each other in relation to goods and / or services in the aspects of life" (Azis, 2018, p.56).	Promotion of laws and full product transparency Legislation is lagging behind dynamic market development
	Intellectual Property Laws	Intellectual property (IP) laws deal with the laws that apply for "creations of the mind: inventions; literary and artistic works; and symbols, names and images used in commerce" (World Intellectual Property Organization, 2018, p.2).	Full security for inventors and data providers Low confidentiality for data and market participants

	Social and Environmental Regulations	Social and Environmental regulations describe regulations that urge companies and societies to act and use environmental functions in an environmentally friendly and ethical way (Organisation for Economic Cooperation and Development, 2007, pp.253, 725; Shift2Rail, 2017).	Comprehensive regulatory framework Heterogeneous regulations
Environmental	Climate Change	It is a "a change in global or regional climate patterns, started from the mid to late 20th century onwards and attributed to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels" (Oxford's dictionary, 2017).	Our planet is recovering Our planet on the brink
	Environmental Resource Management	It describes the management of human interaction with the environment and aims to assure that the state of an environmental resource affected by humans is maintained for future generations, and for ecosystem integrity through considering ethical, economic, and scientific (ecological) variables (Pahl-Wostl, 2007).	Countering resource depletion Rise in depletion of natural resources

Due to numerous DPs in each of the six PESTLE dimension, it is not feasible to illustrate all DPs in detail in this paper. Hence, the focus in Section 5 is on the technological dimension. More specifically, ”Autonomous Systems” are chosen as example since these technologies are expected to progress on a high pace with vast impacts on all industries and the related supply chains.

5 Development Paths for Autonomous Systems in the Technological Dimension

The two DPs under the descriptor ”Autonomous Systems” are exemplarily outlined for the technological dimension.

Autonomous systems describe objects or devices that can act and make situation-dependent decisions independently without interference by humans or other outside forces (European Group on Ethics in Science and New Technologies, 2018). These technologies have an immense impact on ways of working, particularly how people will collaborate with other people, machines and virtual formats in entirely new ways (Wisskirchen, et al., 2017).

Based on the previous research (Kalaitzi, et al., 2018), autonomous systems encompass the trends robots, drones, automated vehicles/ automated guided vehicles and cyber-physical systems. The DPs take up on these trends and are described in the following Subsections 5.1 and 5.2.

This section focuses on the DPs. DPs describe how the future in 2030 might look like. Since this study is part of a comprehensive scenario generation approach, it is subject to further research to analyze which DPs are feasible in the context of a holistic scenario. The scenarios are composed of combinations of several DPs from various descriptors and different PESTLE dimensions. Hence, at this stage of research it is yet not possible to derive which implications arise, how companies need to prepare for the future, how supply chains will change concerning their configuration or how the developments will affect specific industries (e.g. process, discrete manufacturing or logistics).

5.1 Dynamic Development of Autonomous Technologies

This DP describes that companies are taking advantage of digital technologies to find new markets, business models and revenue streams and that human workforce can benefit from this development.

Technology advancements, especially with regard to robots, drones and autonomous vehicles are progressing at a rapid pace. Cyber-physical systems play a key role for autonomous systems in the industrial environment. They constitute enablers for efficient communication and control by transferring and exchanging data over the internet in real time. An increased exploitation of these technologies leads to a highly automated and autonomous environment which permits to improve the productivity rate (for example robots can perform 24/7) reducing quality problems, errors and down times (Wisskirchen, et al., 2017). Coupled with the ability to share and act upon the associated data and derived insights, new service and production related business opportunities arise for global players as well as start-ups. New business models emerge both within and across organizations, removing traditional silos as well as simplifying trust and contractual agreements. Automation (both physical and virtual) replaces an increasing range of human tasks (Bingley, et al., 2016).

Implications on supply chains

The described technological advancements allow the administration of supply chains to be simplified and to operate with less cost and better customer satisfaction. In particular, the first step in the advancement of autonomous systems is at the process level in order to automate non-value added activities. In this regard, rapid changes could lead to high rates of unemployment. In this case, companies need to define approaches for reallocation of staff along the supply chain and consider the possibility to improve their capabilities since these technologies require advanced IT skills. By tracking the whole supply chain, transparency between the supply chain actors can be increased, which improves the capability to react efficiently and quick to external influences. If new business models are implemented to handle the increasing complexity of autonomous systems, the supply chain can achieve high performance in terms of agility, reliability and transparency.

5.2 Innate Reluctance to Accept Autonomous Technologies

This DP states that the use of advanced technologies is reshaping the work landscape intensifying competition on the labor market and causing worker displacements.

The technological development enables a high degree of automation and autonomiztion. Suppliers provide modular and standardized components so that technology solutions become affordable, but still often lack profitability (Gausemeier and Plass, 2014). Since an autonomous technology requires suites of expensive sensors, the average cost of this technology is high and this could slow down the application of this technology. A particular technological roadmap to reduce those costs is yet to be established (Omohundro, 2014; Anderson, 2016). Although autonomous technologies often lack profitability (Gausemeier and Plass, 2014) or regulations prevent the full exploitation of their potentials, automated and partly autonomous factories are progressively becoming the standard in Europe. The result is a shift from assistance of human activities to a more machine-centered environment. This development radically reshapes the work landscape and creates new business models (Bingley et al., 2016). Users struggle with operating the highly complex machines (Gausemeier and Plass, 2014). Hence, employees fear for their jobs, get frustrated and demotivated and eventually adopt a negative attitude towards emerging advanced technologies.

Implications on supply chains

High costs, privacy and cyber security issues, low IT penetration into processes as well as a lag of technology standards make the adoption of new technologies slower and restrain digital transformation. Supply chains need to revise processes and move from traditional supply chains towards a connected, smart, and highly efficient supply chain ecosystem in order to achieve comprehensive agility and transparency.

6 Conclusion and Outlook

This paper identifies 51 DPs that might emerge from megatrends in the industrial sector by 2030. DPs constitute projections of each megatrend into the future.

They are grouped under 22 so-called descriptors and assigned to the PESTLE dimensions. Each DP creates different conditions that will have an impact on supply chains and their configuration.

In order to address our first research question, we have extended previous scientific publications and grey literature by taking a holistic approach and considering three different industries (i.e. process, discrete manufacturing, and logistics) as well as six PESTLE dimensions. We assessed megatrends and their associated challenges and opportunities in order to define DPs for the future. The systematic collection of information regarding megatrends and their analysis permits a complete and well-structured illustration of a set of DPs.

To answer our second research question, we exemplarily elaborated on two DPs for autonomous system by providing a comprehensive description of the two divergent DPs. Furthermore, possible implications of these DPs on supply chains and companies are described.

The construction of DPs is part of a comprehensive scenario technique. Future research will show the impacts of each DP on each specific industry and the related supply chains. Then, by using the Gausemeier and Plass (2014) methodology, it will be necessary to create the most plausible and diversified industrial scenarios. These scenarios help to define the best strategies to engage the different challenges of the future.

Our research is limited in the way that process, discrete manufacturing and logistics industries are considered as an input only. The resulting DPs are not classified by industries. Thus, this study follows a holistic approach and can be used to create scenarios for different industries in future research and to derive specific DPs for the aforementioned industries. Additionally, the DPs were validated with a small group of experts. More experts could provide other insights. Some DPs are concentrated in a European context since the focus was on existing European roadmaps. Practically, this study enables supply chain professionals to understand possible DPs and serves as basis to develop future scenarios in subsequent work.

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About the Future Role of Software in the Product

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Product development is shifting towards realizing an extended scope of product functions in software. This leads to new challenges in terms of a methodological integration and synchronization of different development disciplines. This paper provides insights on how to systematically manage the harmonization of traditional development disciplines with agile software development based on an integrated data model. To achieve this, the traditional product data model is extended to a seamless system data model that covers – based on a common function structure – the product itself but also services induced by digitalization and infrastructure backends.

Keywords: Product Data Model METUS; Software Development; Agile and SCRUM; Harmonization Digitalization

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1 Software as a Function Owner in Digitalized Products

"Bending sheet metal is not our value creation's core anymore", this is – slightly exaggerated – how manufacturing companies put a major change into a nutshell, that has become essential in product development. The functions of technical products are to an increasing extent determined by Software and digital connectivity, "bent sheet metal" does not ensure market success anymore.

Today, software is an indispensable ingredient of technical products. An example is embedded software like in an automobile's control unit or as a control system of a machine or plant. Nevertheless, traditional development processes based on a two-stage freezing of requirements often lack the consideration of software and do not recognize it as an essential element of the development process according to its role in the completed product.

Mechanics and electronics may feature different development methods, but their common ground and their origin descend from a physical world. Where these disciplines think based on product structures, software development choses a structure based on data models. In addition, software development as a discipline has come up with its own methodology: Agile approaches such as SCRUM (Schwaber & Suther-land 2017) are entirely different from traditional product development processes.

Up to now, a common solution has been to encapsulate the discipline of software development right into the traditional product development process. By this, software development could retain its own approaches and data models. An integration with other development disciplines' statuses has been conducted based on completed releases, milestones and snapshots. Against the background of major differences regarding methodology and data models of other development disciplines, such an approach seemed to be sufficient. Today on the contrary, such a methodological segregation fails to be a promising way to go (Eigner et al. 2018).

Why is this the case? Software as an ingredient of technical products in the previous sense contains a system related machine control. It might be embedded in a control unit's firmware with the aim to interpret signals from a machine's or plant's sensors and pilots corresponding actuators based on algorithms.

In an easy example, the software of a car's engine control unit uses the values from sensors at the crankshaft, throttle valve and intake air temperature to calculate

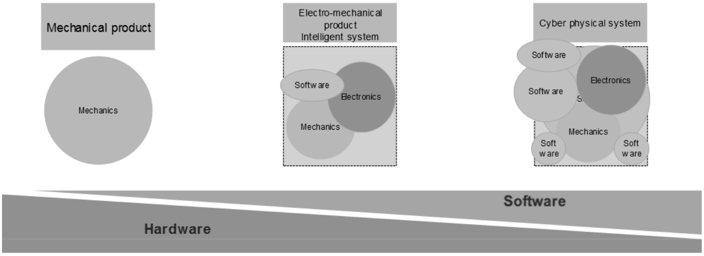

Figure 1: In future products, the software's significance will be enhanced (Source: own representation)

an optimal timing and duration for the fuel injection and subsequently provides the resulting values to the corresponding actors.

This previous sense of software that is despite all complexity well manageable has already been outdated (Figure 1): To this day, software has been modified from an integrated system element to a self-contained function owner. Mainly mechanically determined products have been altered into today's mechatronic products. In the future, due to a higher share of software in products as well as of digital connectivity, this will result in "cyberphysical systems" (Eigner et al. 2016).

2 Software's Promise: More Value from Less Effort

A product's competitive edges can be realized in software to an increasing degree, without changing the hardware in the ideal case. An example from the automotive industry would be an entertainment module that comes with an identical hardware (screen, control unit, operating controls) to minimize the number of physical variants. Particular functions, e.g. a hands-free-speakerphone, can be activated by software. To achieve this, the software covers the maximum functionality. By this, variants can be derived by locking and unlocking individual functions. In this context, software offers the attractive promise of an increased customer value without bearing the costs of a higher physical variance (Khaitan & McCalley 2015).

The opportunities of software as a function owner in a product are numerous and attractive:

1. Variance in software can be realized in a more flexible and more cost-effective way compared to hardware.
2. Additional prospects for differentiation can be derived by additional product functions and services provided by software.
3. Existing products can be updated with more recent software to run new functions. This enhances customer satisfaction and extends the hardware's competitiveness in the life cycle.
4. Elongated operating times regarding hardware, that can be updated with software, reduce the TCO and therefore might be a competitive advantage.

However, these opportunities face several risks:

1. Traditional competitive edges regarding products more and more lose their significance.
2. The high innovation frequency in agile software development can only be transferred to other engineering disciplines with several limitations.
3. Customers have a limited willingness to pay for software due to their experience regarding apps that are free of charge or at least cheap.

Software is not only an essential ingredient of a product – be it as a machine control or as a hands-free-speakerphone's software – but also to an increasing degree a "virtual" system element. This refers to software that an end user will experience as a part of the product functionality, but it is not part of the particular product. To provide an example, an app on the end user's own device like a smartphone will serve as a control for his digitally connected coffee machine.

From this point of view, products increasingly lose their physical boundaries, become more and more digitally connected elements of cyberphysical systems (Eigner et al. 2016). Thereby, new value propositions and business models can be identified and subsequently implemented. But before implemented, both the product development process and also product structures have to be adapted to the new requirements.

For this, the following three areas inhibit new challenges:

1. Methodological integration: The development methods and displaying of requirements in software engineering differ considerably from those in the development disciplines for mechanics and electronics.
2. Integration of "virtual" product components: Components that are a product's ingredient from a functional perspective, but are not in the physical product structure's scope (e.g. a smartphone app for machine control) are not considered in conventional development processes (Conti et al. 2012).
3. Synchronizing the diverse product and innovation cycles among different development disciplines: Agile principles in software development often contain iterations that are not sufficiently synchronized with development cycles of the corresponding hardware.

The following section provides insights on how to systematically manage these three areas, in order to utilize a digital product's advantages to a full extent.

3 Requirements: Traditional, Agile or Both?

Product functionality and innovation are increasingly shifted from mechanics to software. In several areas, mechanical designs have achieved high degrees of maturity. Consequently, disruptive innovations become rather unlikely or require disproportionally high development efforts. Therefore, software can serve as an adequate leverage for new and innovative functionalities.

In the utmost case, the hardware's role is downgraded to a software‘s operating environment. This has the consequence that requirements to hardware are determined by the dedicated software functionalities. If software becomes a functional driver, it will provide the basis for hardware development. Accordingly, hardware in terms of an operating environment for a software has to be designed with the aim to be able to "carry" an ex ante defined number of software cycles with more and more comprehensive functionality.

This requires enhancing the harmonization of different development disciplines based on a common functional level. This means after initially determining a common function structure, the development team has to decide not only how, but also in which discipline a function shall be realized. In addition, realizing functions in software also calls for a comprehensive management of requirements that incorporates all disciplines.

Agile software development allows for a realization of a product's market-ready versions in short iteration loops that feature additional functions that are successively implemented in further releases. Compared to this, traditional development disciplines have a higher effort to realize a new product release because an incremental approach comparable to software engineering is not feasible (Vogel & Lasch 2016). The reason for this is the extent to which changes in product's hardware impact the operations – e.g. starting with molding design and subsequently logistics and production.

Agile and traditional methods for requirements management and engineering will thus need to coexist even though a convergence can already be noticed. Against this background, the argument can be derived that traditional and agile requirements processes need to be further harmonized and interrelated to display an overall view on the product system. A seamless product data model plays an important role not only in the course of the entire product development process, but also regarding a common understanding in different development disciplines.

This requires a methodological approach that consolidates a market and product view on the one hand as well as the phases of product definition, design and implementation on the other hand into a common data model that subsequently allows for flexible and numerous visualizations. The METUS methodology and the corresponding software have proven to be appropriate for this (METUS 2018).

4 From Product Architecture to System Architecture

Traditional product architecture models start an entire product's description of with requirements and functions, followed by the product structure consisting of individual function owners that can be both, mechanical and electronical components and modules (Göpfert & Tretow 2013). Without adaptions, such an architecture may not be able to incorporate the external or "virtual" scopes of a product into its structure.

Following the goal of a purposeful enhancement of a product's customer value driven by software functionality (or shifting the realization of functions from hardware (HW) to software (SW)), the traditional product architecture model does not suffice anymore. The model has to be enlarged in order to also manage

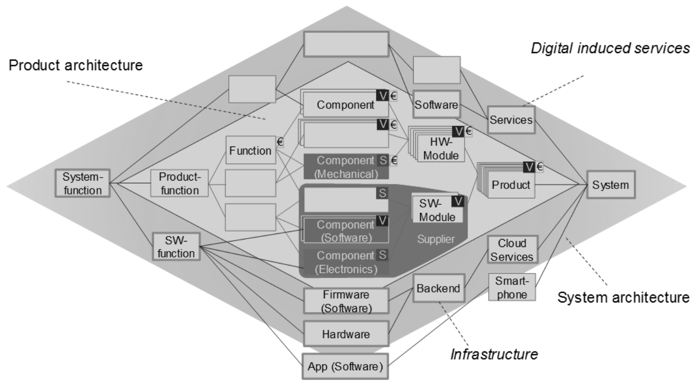

Figure 2: Internal variance is shifted from hardware to software (Source: own representation)

new components and services as an ingredient of the extended architecture. This requires raising the product architecture to a system architecture (figure 2). If this raise is successful, the product's system architecture also covers new "digital" scopes that feature similar characteristics in the function structure like mechanically or electrically realized functions. In addition, this step may also contain changes of the infrastructure, e.g. the provision of a backend or a cloud for value-added services that are required by digitalization (Crawley et al. 2015).

5 Synchronizing Tact Rates of Several Development Disciplines

In a similar way, like software will become a major driver of new product functionalities, the pulsing of software development will increasingly determine the pulsing of the entire development process.

In an age of mainly mechanical products, the product lifecycles corresponded to the innovation cycles (figure 3). Modularizing product architectures has enabled a decoupling of these two different cycles (Skirde 2015; Bahtijarevic et al. 2014; Lau et al. 2011; Mikkola 2006). Technology and innovation leaps can be realized only in particular modules that replace outdated modules in the original product. The increase of mechatronic products has come with diverging the pulsing of product lifecycle and innovation cycles: New software releases, for example the already explained automobile engine's control unit, are deployed without changing the operating environment provided by the hardware.

To realize an extended scope of product functionalities with software functions, the hardware design has to be adequately dimensioned in advance: it has to be able to operate a software's future releases right from the start. For this, product management has to define up to which future software releases the hardware is supposed to remain unmodified. The ability for updates, known by every end user of a smartphone or tablet computer, will become a feature of nearly every technical product.

The conceptual design of updateable products requires a function roadmap containing software updates planned by the product management. This roadmap has to be transparent for all involved parties and agreed as an ingredient of the entire system architecture represented by a product embedded into this architecture. If this succeeds, new perspectives can be raised: particular scopes of the product variance can be shifted from hardware to software. In total, an extension of the performance spectrum towards a comprehensive product-service-system is likely (figure 4).

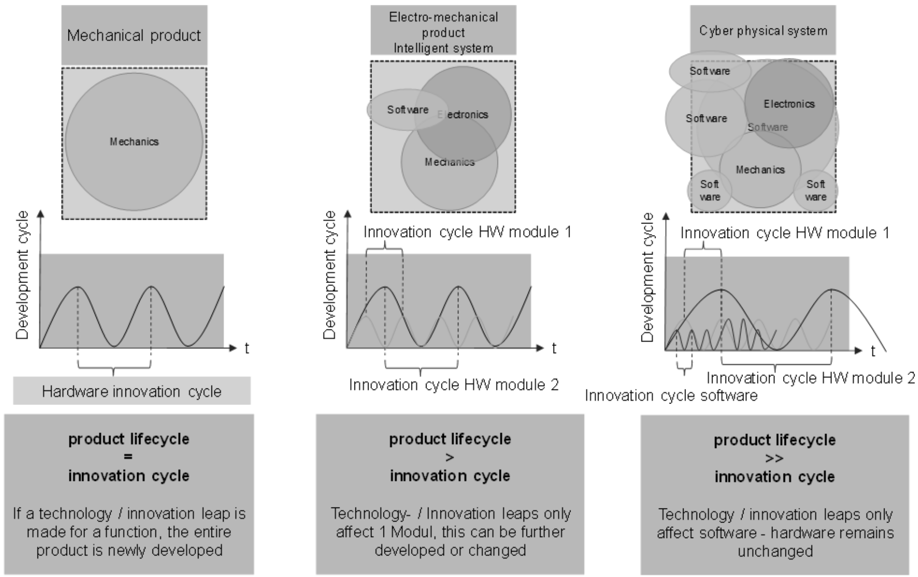

Figure 3: Software's changed significance has an impact on future product development and the entire product lifecycle management (Source: own representation)

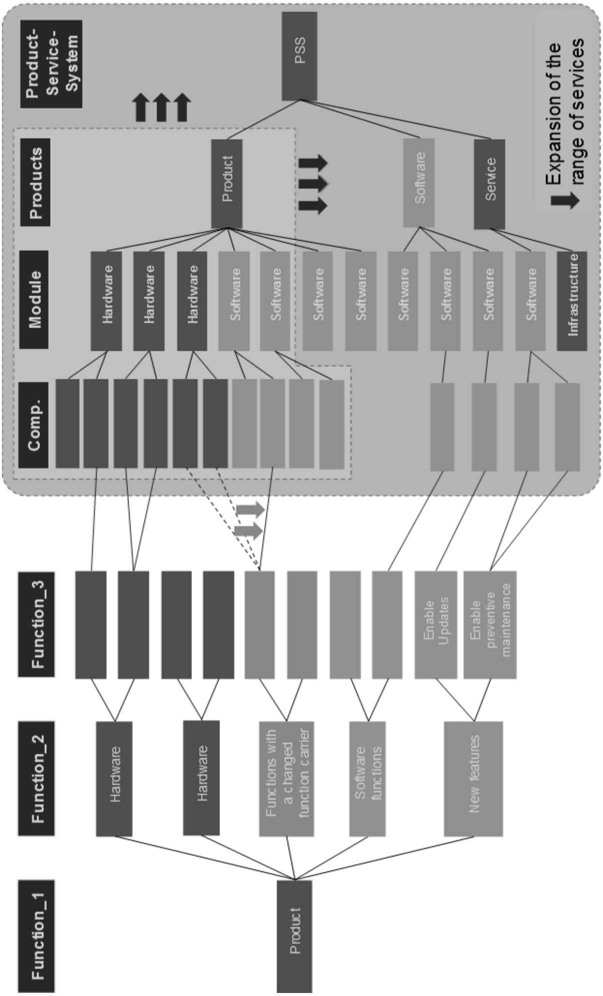

Figure 4: A particular scope of internal variance can be shifted from hardware to software (Source: own representation)

6 Pricing for Software-Based Product Functions

The increasing usage of software as a function owner determines that a higher share of the product requirements has to be fulfilled by software. Consequently, the share of the product's value proposition that has to be covered by software is increased accordingly. From this change, the question can be raised how to achieve an appropriate pricing for software as a function owner.

Today, software development is often accounted into the company‘s indirect costs. In comparison to the production of physical products, software comes with high non-recurring costs (NRC), but causes only very little recurring costs (RC). In terms of transparency, assigning the costs of individual software development to the corresponding scope of the function structure seems to be more beneficial from an economical perspective than accounting these into the indirect costs (Skirde et al. 2016). An analogous argumentation can be derived for assigning software development costs to requirements as well as the value proposition.

The major success factor that can be derived from a function-based pricing is again the overall view on the product, which is the basis that allows for a cost-oriented analysis of functions:

By connecting the value proposition with requirements (traditional and agile), function structure and finally the product structure with its mechanical, electronical and now also digital scopes, comprehensive data continuity from the market to the product view can be established.

If this procedure in the sense of a function analysis is then conducted the other way around – from the software scope in the direction of the function structure, the software's contribution towards fulfilling a requirement and realizing the value proposition can directly be derived.

The chance to increase a product's customer value by enhancing the software ingredients and thus to realize a greater extent of variance in software on a low level of costs, simultaneously shortening innovation cycles, seems to be exceedingly attractive.

Completely exploiting the chances outlined in this paper will probably only succeed for those companies, that already today turn their attention to a seamless product development process that interconnects a market and a product perspective on a reliable methodological basement.

7 Summary and Conclusion

Product development is shifting towards realizing an extended scope of product functions in software, challenging the past development paradigms. In this paper, the new challenges in terms of a methodological integration and synchronization of different development disciplines have been pointed out. To conclude, our recommendation to companies is to systematically manage the harmonization of traditional and software related development disciplines based on an integrated product data model. A common functional structure representing the entire product can support this harmonization. In addition, it allows for deriving data for the pricing of software related functions and product features. An extension of the product data model can enable a company to consider new services induced by digitalization as well as accordingly required infrastructure scopes in their value proposition.

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Environmental Innovation of Transportation Sector in OECD Countries

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Climate change is a global concern and transport sector contributes to it significantly. This study aims to identify the factors which contribute to the development of environmental innovation in transport sector and to examine their effects. The analysis is carried out via a panel regression model with a dataset for 23 OECD countries for the period between 1997-2012. Environmental patent data in transportation is used as a proxy for the innovation capacity. The independent variables consist of value added, environmental stringency, CO2 emissions and GDP growth. Empirical exercises suggest that innovation in transport has a positive relationship with CO2 emissions and a negative relationship with environmental stringency. The negative impact of environmental regulation on innovation in transport sector is an important insight. This can be associated with excessive adjustment costs of regulation with respect to benefits of improved efficiency by innovation. Furthermore, innovation may be realized in response to rising fuel prices rather than in response to environmental mitigation policies. The positive effect of CO2 emissions may imply that as the CO2 emission caused by transport sector rises, innovation capacity increases through the search for more energy-efficient vehicles. This study contributes to the literature by analyzing the utilization of technology for environment specifically in the field of transport. The analysis can be conducted in a more comprehensive manner including manufacturing sector. The results might provide some important insights for policy makers as well as executives in transportation sector.

Keywords: environmental innovation; environmental stringency; technology ; transport

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1 Introduction

Concerns on climate change have caused the adoption of United Nations Framework Convention on Climate Change (UNFCC) in 1992 to avoid damage caused by human activity on the climate system (UNFCC, 1992). With Paris Agreement, countries have become dependent on long term climate change goals of keeping the rise in global temperature under 2 ^{0}C above pre-industrial levels and further restricting global warming under 1.5 ^{0}C above pre-industrial levels to the end of the century (United Nations, 2016).

Transport sector plays an important role in the economies as it serves as an enabler for international trade by transportation of goods and as a global connector by passenger transportation. In terms of climate change, transport is one of the most important sectors as a source of greenhouse gas emissions. In a report by IEA (2009, p.3), it is stated that 25% of energy-related CO2 emissions are produced by transport sector which holds crucial importance in climate change mitigation. Moreover, technological transition is designated as a requirement for sustainability in companion with policies adopted to utilize these technologies in the report. In this context, transport sector experience diligent attention to achieve such goals due to its fuel dependency and CO2 emission reduction potential (Rogelj et al. 2015). Technological development and related applications is regarded as an area to mitigate climate change on a large scale (Sims et.al.,2014, p.613). The prominence of transport sector for stringent climate change mitigation is also stressed by Zhang et al. (2018), indicating that technological transformation in the sector offers the most remarkable capacity to lower CO2 emissions.

Climate change mitigation in transportation is an area which attract great attention by policymakers, international organizations, governments and researchers. Jolley (2004) asserts that transportation demand rises at a faster pace than income growth in developing countries. Moreover, it is pointed out that technology holds significant potential to compensate the mismatch between exponential increase in transportation demand and relatively fixed environmental capacity in the long run.

This study aims to detect the determinants of climate change mitigation technology development in transport sector and to scrutinize their impacts. The rest of the paper proceeds as follows. In part 2, literature on the relationship between innovation and environmental regulation is discussed and then studies investigating the role of transport sector in climate change mitigation are reported. In part 3, the determinants of innovation in transport sector to mitigate climate change are identified in line with the existing studies and empirical analysis is conducted. Afterwards, the results are discussed in section 4. The last part includes concluding remarks on the contribution of the study and recommendations for upcoming research.

2 Literature Review

Research on the determinants of environmental innovation in specific to transport sector lacks in the literature to the best of our knowledge. So, the literature review starts with presentation of empirical studies which explore the relationship between environmental regulation and technology development. Subsequently, studies on climate change mitigation in the transport sector are outlined.

The role of technology in environmental protection is underlined by Porter and Van Der Linde (1995). They argue that environmentalism and industrial competitiveness are not necessarily opposites, asserting that it can enhance competitiveness with higher productivity. Jaffe and Palmer (1997) find that environmental compliance costs have a positive effect on R&D expenditures, however they find no significant evidence for the relationship between environmental costs and patents for a panel of US manufacturing industries by using Pollution Abatement Control Expenditures (PACE) data as a proxy for stringency of environmental policy. Lanjouw and Mody (1996) show the correlation between environmental regulation and innovation by analyzing patent data and PACE data for the US, Germany and Japan for the period between 1972-1986. They employ all R&D and patent data without eliminating groups which are irrelevant to environment. In order to deduct better insights, they suggest to study chosen industries in focus with disaggregated data. Moreover, Brunnermeier and Cohen (2003) utilize panel data for 146 US manufacturing industries for the span between 1983-1992 to identify determinants of environmental innovation. They report that PACE is positively associated with environmental innovation. Popp (2006) analyzes air pollution control patent data for US, Japan and Germany between 1970-2000. Analysis reveals that environmental regulation has a direct impact on domestic emission control innovation. From a different perspective, Jaffe et al. (2003) draw attention to link between technological development and environmental policy within the context of environmental economics.

Another line of research gathers on connection between transport, urbanization and climate change mitigation. Economic growth and transport are intertwined and mobilization of products in large distances along with decentralization because of rapid urbanization has increased transport demand further (Kejun, 2010). Dulal et al. (2011) advocate high-density settlement and high-density employment to mitigate climate change. Emission reduction alternatives are examined via scenario analysis in terms of cost and scope for urban transportation in developing countries (Wright and Fulton, 2005). A set of measures with an emphasis on modal shift is proposed as the possible minimum cost policy after comparing fuel technology and policies for modal shift.

Technological innovation is not the solution to reduce emissions from transport merely, but behavioral change to promote modal shift to more environmentally friendly modes and policies to control demand for mobility are other areas to tackle as discussed in IEA (2015) and EEA (2012). In terms of policy development, Colvile et al. (2001) suggest that as technology and transport system gradually become capable of stable decrease of emissions from road transport, policies on air quality will become more rigid. This argument implies a long run cointegration between technology and climate change mitigation. In the same manner, Howey et al. (2010) assess climate change mitigation stringent goals of UK and conclude that dramatic changes which dictate innovative technologies coupled with long run coherent policies are required for UK in fulfilling the CO_2 reduction commitment. Likewise, an important mitigation tool for climate change caused by transport sector is stated as advances in vehicle technology in Shaheen and Lipman (2007). These improvements consist of increased utilization of electric vehicles and utilization of alternative energy sources accompanied with the necessary technology to use them. By the same token, Chapman (2007) asserts that improvements in transport technology is essential to address climate change issue in the long run. On the other hand, it is also claimed that policy to promote behavioral change holds critical role in the short run to benefit from the technological developments in a solid way. Jolley (2004) supports this view by stating that emissions caused by transportation can be reduced with a sustainable transportation strategy integrated with developments in transport technologies. Van Der Zwaan et al. (2013) conduct a scenario analysis for the period until 2100 to examine technology diffusions to fulfill a predetermined climate change policy. It is predicated that the dominating vehicle technology along with alternatives can be identified by R&D practices of private sector. As implied by this finding, transformation pathway can be designated by innovation. In a recent empirical work by Beltrán-Esteve and Picazo-Tadeo (2015), environmental performance in the transport sector is studied for 38 countries between 1995-2009. The results show that environmental performance improvement is primarily driven by eco-innovations.

3 Data and Methodology

In the scope of this study, factors which determine environmentally related innovation in transport sector are identified to analyze their relationship with innovative output across time and countries. The analysis is conducted with a panel data covering the period between 1997-2012 with annual frequency for 23 OECD countries. The countries are Australia, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States. Innovative capacity of transport sector in relation to environment has been measured by patents as a dependent variable following Costantini et al. (2017) and Dechezleprêtre et al. (2013). Besides, to capture differences across countries, patent data based on inventor's residence is considered. The number of granted patents at the European Patent Office (EPO) for climate change mitigation technologies related to transportation are retrieved from OECD (2018a).

Explanatory variables set consists of a diverse group of parameters. Firstly, following Jaffe and Palmer (2007), value added is taken as an explanatory variable. In order to take the size of the sector into account, data for share of value added by the transport sector is obtained from OECD (2018b). Environmental regulation is also considered as a determinant in environmental innovation in transport. For this variable, Environmental Policy Stringency Index is taken from OECD (2018c). The index measures the degree of penalty for actions causing pollution or environmental damage within a range between 0 and 6, the former implying zero stringency and the latter referring to highest level. Bearing in mind that transport is one of the primary contributors to emissions as discussed earlier, CO2 emissions from transport sector in relation to GDP data acquired from OECD (2018d) is also included as an independent variable. From a macroeconomic point of view, the integration of transport sector and economic growth suggests the inclusion of a variable about demand. Thus, GDP growth series are taken from OECD (2018e) as it is referred to as one of the determinants of transport demand in Zhang et al. (2018). Descriptive statistics for the panel dataset is presented in Table 1.

Table 1: Descriptive Statistics of Variables

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Patents	368	50	102	0	499
Value Added	368	5	1	3	9
Environmental Stringency	368	2	1	0	4
CO2 Emissions	368	85	42	24	250
GDP Growth	368	2	3	-9	11

The modeling procedure is to be discussed after a brief description of panel data and explanation on panel regression. To begin with, panel data can be defined as observations for the same subjects (firms, countries etc.) at multiple points in time. Panel data is a rich source to analyze as it has two dimensions: cross-sectional units and time. It enables to explain heterogeneity across subjects and dynamic effects that are not obvious in cross sections (Greene, 2010).

In panel estimation, two methods can be utilized: fixed effect and random effect. The fixed effect model controls for unobserved data or omitted variables due to unavailability of data. On the other hand, random effect model assumes all relevant variables are included.

By the structure of our dataset for 23 countries and 16 time periods, a panel regression model of the following form is to be estimated;

$$PAT_{it} = \beta_0 + \beta_1 VALUE_{it} + \beta_2 STR_{it} + \beta_3 CO2 + \beta_4 GROWTH_{it} + u_{it} \tag{1}$$

where

$$u_{it} = \mu_i + \upsilon_{it}$$

In (1), PAT is patents, β_0 is intercept term, VALUE is value added, STR is environmental stringency index, GROWTH stands for GDP growth and CO2 refers to CO2 emissions. In these kind of models, year dummies can be used to control for year specific effects in the data. In that case, the model to be estimated is as follows;

$$PAT_{it} = \beta_0 + \beta_1 VALUE_{it} + \beta_2 STR_{it} + \beta_3 CO2 + \beta_4 GROWTH_{it} + \beta_5 YD_{it} + u_{it} \quad (2)$$

where

$$u_{it} = \mu_i + v_{it}$$

In (2), YD stands for year dummies. In these models, μ_i are assumed to absorb individual specific effects (Baltagi, 2008, p.14). These two model types will be compared based on Akaike Information Criterion (AIC). AIC developed by Akaike (1973) is a technique to compare different model specifications. In statistical modeling, two common considerations about the predictive capacity are over-fitting and under-fitting. An over-fitted model includes unnecessary variables which inflate the variation. An under-fitted model lacks relevant information by omitting related variables, in which case the model fails to capture the true relationship. AIC is based on the view that a model should seize the real relationship between variables without including irrelevant parameters. AIC is calculated by the following equation for each model i:

$AIC_i = -2MLL_i + 2k_i$ where MLL stands for the maximum log likelihood value and k is the number of estimated parameters.

4 Empirical Findings

Panel modeling is not a straightforward process as the properties of cross-sectional data impose some restrictions. So, we adopt a stepwise approach. Initially, the evaluation of random effect or fixed effect model specification is carried out by Hausman test (Greene, 2010, p.420). This analysis has led to fixed effect modeling. Afterwards, assessment of model specification (1) and (2) reveals that year dummy variables improve AIC in the estimation. The estimation results are presented in Table 2. According to the results, all variables except for value added are significant determinants of innovation capacity building in transport sector. Besides coefficient of determination also known as R2 of 19.28 % indicate that the model can explain almost 20% of the deviation in innovation of transport sector. Moreover, the F-statistic of 4.1 with p-value of 0.00 reveals that the model is significant.

Diagnostic tests for the base model including cross-sectional dependence test developed by Pesaran (2004), modified Wald test for groupwise heteroscedasticity in (Greene, 2010) and Wooldridge autocorrelation test (Wooldridge, 2002) are shown in Table 3. All explanatory variables along with time dummies are included for preliminary analysis with only exception for autocorrelation test as test specification does not allow for time dummies. According to diagnostic test statistics, there is cross-sectional dependence, heteroscedasticity and autocorrelation problems in the model. In this case, main assumptions of Ordinary Least Squares (OLS) estimators are violated and model is not reliable.

Table 2: Base Model Estimation Results

Variables	Coefficient	P-value	Year Dummies	Coefficient	P-value
VALUE	3.28	0.30	1998	4.20	0.54
STR	-8.68**	0.02	1999	11.23*	0.10
CO2	0.19**	0.04	2000	13.40*	0.05
GROWTH	0.78**	0.02	2001	15.74**	0.02
INTERCEPT	0.94	0.96	2002	19.82**	0.01
			2003	30.13***	0.00
			2004	32.79***	0.00
			2005	41.54***	0.00
			2006	49.63***	0.00
			2007	55.41***	0.00
			2008	49.79***	0.00
			2009	54.80***	0.00
			2010	54.30***	0.00
			2011	53.08***	0.00
			2012	37.91***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

Table 3: Diagnostic Tests for the Base Model

Test	Statistics	P-value
Wooldridge Test	50.98***	0.00
Modified Wald Test	5,,375.97***	0.00
Pesaran’s CD Test	13.80***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

In order to handle the aforementioned problems, Driscoll and Kraay regression is employed as it gives heteroscedasticity consistent standard errors and provides robustness to general forms of cross-sectional and temporal dependence (Hoechle, 2007). The results of estimations are displayed in Table 4.

Table 4: Regression Results with Driscoll-Kraay Standard Errors

Model 1			Model 2		
Variables	Coef.	P-value	Variables	Coef.	P-value
VALUE	3.28	0.31	VALUE	-	-
STR	-8.68 *	0.05	STR	-8.94 **	0.03
CO2	0.19 *	0.06	CO2	0.22 *	0.06
GROWTH	0.78	0.45	GROWTH	-	-
INTERCEPT	0.94	0.97	INTERCEPT	19.16	0.16
YD			YD		
1998	0.62 ***	0.00	1998	3.83 ***	0.00
1999	0.63 ***	0.00	1999	11.22 ***	0.00
2000	1.39 ***	0.00	2000	13.42 ***	0.00
2001	1.60 ***	0.00	2001	14.46 ***	0.00
2002	1.99 ***	0.00	2002	18.20 ***	0.00
2003	3.18 ***	0.00	2003	28.92 ***	0.00
2004	3.73 ***	0.00	2004	32.94 ***	0.00
2005	5.24 ***	0.00	2005	41.38 ***	0.00
2006	6.10 ***	0.00	2006	49.98 ***	0.00
2007	5.95 ***	0.00	2007	55.98 ***	0.00
2008	7.81 ***	0.00	2008	48.10 ***	0.00
2009	10.99 ***	0.00	2009	49.24 ***	0.00
2010	8.21 ***	0.00	2010	53.72 ***	0.00
2011	9.05 ***	0.00	2011	51.69 ***	0.00
2012	9.41 ***	0.00	2012	35.33 ***	0.00
R2	19%		R2	19%	
F-test (19,15)	23.92 ***	0.00	F-test (17,15)	23.46 ***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

In Table 4, Model 1 is estimated with all independent variables along with time dummies and Model 2 is estimated by eliminating insignificant variables to obtain a parsimonious model. The F-test results of both models indicate overall significance of the variables in explaining innovation in transport. As shown in Table 4, all the year dummies are significant. This result is reasonable as the technology development along with environmental regulations entail a long period of time. Besides, there is a lag between a technological change and its adaptation. Environmental stringency is a significant factor and has a negative effect on environmental innovation in transportation. This inverse relationship can be explained by an implied and indirect negative impact of environmental policies on firms in reference to the lack of consensus on the directional impact of environmental regulation as stated by Leiter et al. (2011). Companies operating in transport sector may anticipate that cost of adjustment to environmental regulations outweighs the efficiency gains of technology development. Moreover, as innovation process does not give results in short term, firms may be in expectation of looser environmental regulation in the future thereby they don't undertake capital and organizational responsibility by investing in research and development. In addition, innovation might be driven by efforts to remedy dependence of transport sector on petroleum, likely in response to volatility in energy prices which is another implication for focus of transport companies on costs. The positive sign of CO2 emissions might indicate that search for energy-efficient vehicles results in increased technology development when emissions of the sector rise. This plausible insight might indicate that transport sector embraces environmental mitigation after it is realized that the damage is continuous.

5 Conclusion

The role of technology development draws close attention to mitigate environmental damage. As an important source of air pollution (Colvile et al., 2001), innovation of transportation sector is important to control climate change. The objective of this study is to identify the determinants of such innovative capacity and analyze their effects. To do this, a panel regression for environmental patents in transport sector is performed on input variables of environmental stringency, CO2 emissions by transportation, GDP growth and share of value added by the sector for the period between 1997-2012 for 23 OECD countries. The empirical findings suggest that environmental stringency and sectoral CO2 emissions are significant factors determining innovative capacity in transportation. The stringency of environmental regulation has negative correlation with innovation in transportation. This might be due to costs being firms' primary focus rather than environmental mitigation and energy prices acting as a primary catalyst in technology development for transportation. The positive effect of CO2 emissions on innovation suggest that efforts for higher energy efficiency in transport sector end up with innovation as CO2 emissions rise. This study is limited to the analysis of transport sector only, however manufacturing sector can be also considered due to the interaction between one another. Besides the availability of data limits the time span in the analysis, thus time horizon can be extended by utilizing different parameters to proxy environmental stringency.

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Design of an Added Plan with Social Responsibility

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For decades and worldwide, steel has been one of the most important commodity in the development of the industry due to its multiple uses. At present, the offer of steel in Colombia is too low compared to the sector's demand. This has caused market speculation and a low added value regarding all products made with steel. In such a competitive market, the organizations involved have been developing strategies to improve their incomes, some of these are developed in the operations area, where the planning is the most important part regarding the cost reduction, minimize the rate of rotation of the personal in the operations area and increment in the effectivity of the supplies chain. Having this need and tendency created, the investigation group designed an added planning model, based on the case of an enterprise that transforms steel in cloves. Using this model in the enterprise will guarantee decrease the shortage in posterior periods and as consequence lower the costs and wastes caused by shortfalls, the costs of keeping an inventory and costs due to high lead time to market. Furthermore, the model will minimize the rate of rotation of the personal in the operations area, this will result encouraging social responsibility which contribute to the organization's productivity.

Keywords: Steel transformation; Added planning; Optimization; Social responsibility

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1 Introduction

Since the start of the 50's, steel in Colombia has become a resource quite relevant regarding development of the industry and the country's infrastructure. 500.000 tons of steel are expected to be the demand in the projects of infrastructure, such as the routes 4G (El Espectador, 2017). Nowadays, according to Camacero (Cámara Colombiana del Acero), Colombia produces 1.2 million tons of steel and consumes 3.6 million tons, this shows a shortfall in the primary supply chain of the sector. Therefore, the producers and marketers must import around 2.4 million tons per year, so the demand can be satisfied (Portafolio, 2017).

Production of this sector represents 7% of the national industrial GDP and even though it creates more than 40.000 jobs, it still shows problems in reducing the production and logistics costs. This is a consequence of the lack of knowledge regarding the practices in the supply chain and exterior facts, such as the increment of imports in lower prices (Dinero, 2017).

Keeping in mind the late technological and industrial tendencies in the world, China has shown to be the asiatic country with the highest production of steel, with around 800 tons per year, provides about 50% of the global demand (El nuevo siglo, 2016). Their companies are owned by the state, so they are highly subsidized and are not governed by market rules (Alacero, 2017). For this reason, their prices are lower than the market, which is known as dumping (El español, 2016).

This has generated an oversupply of this product and a drop in international prices (Portafolio, 2017). Not to mention the technical stoppages and closures of steel plants that the overproduction of this asiatic giant has generated (Alacero, 2017).

Consequently, the Chinese government has hardworking to close those companies that produce low quality steel made of scrap. Same, with the objective to reduce its production capacity by more than 50 million tons, increment their prices and minimize environmental impacts (Infoacero, 2018). In addition, these decisions are part of the government's goal of changing its economic model, with less dependence of the industry and more focalized on new technologies (Angencia EFE, 2018).

Regarding this inconvenient, the sector must know that it will continue to fight with the price against this rival, since the asiatic country will continue to produce steel at very competitive prices. For this reason, the national companies of sector should implement best practices throughout the supply chain, specifically in the primary chain and the planning of its production, to guarantee the supply of this product at a competitive cost.

Given the fact that this product is a commodity, the enterprises involved with this supply chains have had to deal with the prices, and therefore the organizations are concerned and have worked slowly in reducing the operational costs with the purpose of improving their opportunities and therefore their oncomes.

Even though detecting the wasting and overspends along the process is relevant (Nave, 2002), this practice does not reduce the costs significantly in comparison to an adequate planning in its supply chain. As Chopra (2008) says, an adequate plan will guarantee the focalization of the resources along the chain so that an emerging market can be handled, even more if there are high lead time to market, uncontrolled product portfolios, over-stock, low service quality, lost sales, and unsatisfied customers.

However, the arrival of enterprises such as Gerdau, Votorantim and Techint has improved the sectors know how and its technology level. This, marked by the demand of competitiveness, requires that the customer service and the attention to the market demand an expansion in the investments of the information systems and adequate planning in the supply chain (Munar, 2008).

By identifying this need in the sector, the research group has built a model of added planning, through the application of linear programming, for an enterprise located in Bogotá (Colombia) that works in the transformation of steel in construction products, such as rod, mesh, cloves, picks, and other products. The model's aim is to lower the costs of the planning in the supply chain, the costs are the inversions made with the expectations of getting benefits in the future, but also in the present. How we try to impact in the enterprise is to generate benefits along the whole chain so that we can accomplish a balance between the demand and the offer of cloves.

To meet this end, a model has been developed so that the effectivity and the productivity of the resources is improved. A model like this is a representation of reality using linear mathematic expressions, in which we can know with certainty the parameters and by giving it a solution, the model proposes which should be the decisions to make in one or more time periods (Bohórquez Quiroga , Sarmiento Lepesqueur, & Jaimes Suárez, 2013).

2 Added Planning Models

There are many methods of added planning which can be divided in three groups according to Boiteux, these are: comparative alternatives, use of decision rules and based in models of linear programming (Boiteux, 2007). The linear programming models are the most used nowadays.

There are some authors that have developed applications, in this sector, there is Cañas (2013), who planned the production of an industry that belong at the metallurgical industry so that he could maximize utilities by introducing multiphase, multi period, multiproduct models of linear programming and by the development of a constructive heuristic based on the principles of the restrictions theory. Chavez (2014), designed a model of linear programing with the purpose of resolving a problem of added planning in production for Huachipato metallurgical company, considering the restrictions concerning inventory, demand, and capacity. Zurito (2010), made a model of linear programming to minimize the lacks in the inventory and therefore the associated costs. Gholamian & Tavakkoli & Nezam (2015), developed an entire mixed model of linear programming with a multi objective approach, to minimize the total production cost, improve the service quality, minimize fluctuations in the rates of change of the work force and maximize sales.

3 Case Study

3.1 Company and Process Background

The enterprise to be analyzed is part of the labor union Camacero (Cámara colombiana del acero), which was created in 2014 with the objective of gathering more than 40 national enterprises dedicated to the production, transformation, and commercializing of steel. This with the purpose of generating solutions in the value chain (El Espectador, 2014). Nowadays, the labor union counts with more than 400 producers registered.

In Latin-American, Colombia is stablished as the fourth steel producer after Brazil, México, and Argentina (Alacero, 2017). Nevertheless, Colombia must work to increase its production and improve its competitiveness.

According to the ANDI (Asociación nacional de empresarios de Colombia) between 2007 and 2016 the sector grew 13% (Andi, 2018), despite the hard situation that it has been facing.

Given this need and considering the shortage of raw material, the strong competence with foreign enterprises, a model of added planning is proposed so that it determines the ideal production, capacity inventory, stock-out and out-sourcing levels required to satisfy the cloves demand, the product that was chosen to this case of study (Sunil Chopra, 2008). Nevertheless, if the organizations in addition to making a correct planning would add practices of social responsibility, they would assure not only the decrease of costs, but also will assure an improve in their competitiveness.

It is also necessary to identify the stage in which the workers are about the learning curve, this means to know if they are beginners, medium or advanced. If enterprises reduce the rotation of their advanced personnel, they could assure not only quality but also the flux in production. We know this because the workers with more experience have a more efficient handling of the resources and guarantee the improvement of the production.

3.2 The Process

The fabrication process of the 3”x 24 -kilogram galvanized clove has 5 steps. The raw material for this product is 5-milligram SAE 1023[1] steel which comes in approximately 2-metric ton rolls. The supplying of this material is made with forklifts, leaving 2 rolls per round in two reelings. These feed two drawing machines, the koch 1 and koch 2. These machines are automatic, the operator handling is needed during the time of charge and discharge. The drawing is the plastic conformation of a material through tensile continuous stresses, through rows, it is possible it’s thinning (Boca, 2017). In this case, a diameter of 5.5-milligram was thinned to a diameter of 3.8-milligram. This wire is deposited in coils of up to 900-kilogram., which are transported by the forklift to the area of hot galvanizing. On each route, the vehicle can carry up to four coils. In the hot galvanizing line, usually 2 lines are programmed for this type of product.

[1] It is a quality of low carbon steel that can be used in cold. It has high tenacity and low mechanical resistance.

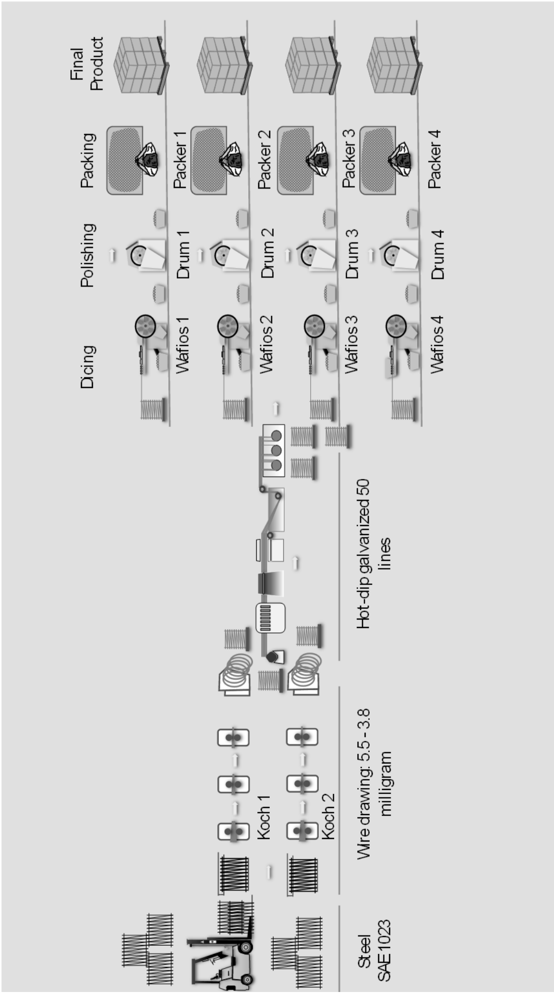

Figure 1: Galvanized 3”x 24-kilogram clove process

The entire line has 50 threads, but only two lines are programmed for this type of clove; these coils are unrolled at a slow pace, going through a process of hot galvanizing, which is a surface treatment in a zinc vat at high temperatures that allows the wire to be protected from corrosion, so that later, the galvanized wire is winded at the end of the line, also, with up to 900-kilogram (Berto, 2017). This material is taken by the forklift to the cloves ship, where 4 wafios equipment are programmed. These machines turn the wire into cloves, temporarily storing them in baskets of up to 300-kilogram. Using a bridge crane, in the same ship, the baskets are taken to the polishing area, where 4 drums that turn with sawdust, clean, and polish the clove. These polished cloves are deposited again in the same baskets and loaded by the bridge crane to the packing section. Generally, 4 packers are scheduled for the packing of this material. Each packer manually weighs about 600-grams with a tolerance of 10-grams. In each pack, and each one of these, the packer deposits the clove in a cardboard box of 24-kilogram. As they finish each carton they stack it in a stowage, until completing 54 cartons. The operator that is completing the stacking, packs the stowage with stretch film[2].

[2]Vinipel, translucid plastic film with a high resistence.

Table 1: Statistics of the process of the 3”x 24-kilogram galvanized clove. May 2017.

Operation	Equipment	Production speed (ton/hour)	Efficiency (%)	Real production (ton/hour)
Drawing	Koch 1	2.1	65	1.4
	Koch 2	2.5	57	1.4
Galvanizing	2 lines	3.5	63	2.2
Dicing	Wafios 1	1.7	72	1.2
	Wafios 2	1.3	67	0.9
	Wafios 3	1.5	70	1
	Wafios 4	1.2	55	0.7
Polishing	drum 1	0.7	85	0.6
	drum 2	0.8	92	0.7
	drum 3	0.7	80	0.6
	drum 4	0.6	89	0.5
Packing	packer 1	0.024	78	0.008
	packer 2	0.024	82	0.008
	packer 3	0.024	72	0.007
	packer 4	0.024	86	0.009

4 Methodology

4.1 Data Gathering

The product that was chosen to carry out this research was the galvanized 3”x 24-kilogram clove, which was selected through an ABC analysis, which is a tool used to classify products into, high, medium and low turnover categories, also known as pareto’s 80:20 law, which indicates that 80% of the money from the sales of a company is generated by 20% of the existing products in its portfolio, so that this product has an A classification (Bravo, 1996).

4.2 Model Formulation

In order to develop the added planning model, the planning horizon of six months and the demand to be supplied are identified. Based on Table 2, the demand of the 3”x 24-kilogram clove is shown based on a historical data given by the organization. Furthermore, Table 3 shows the costs associated with the aggregated plan.

In order to calculate the kilograms per standard hour produced by each of the drawing, galvanizing, dicing and polishing machines, the speed of production and efficiency for each machine are considered.

Then, to calculate the kilograms per standard hour produced by each of the drawing, galvanizing, dicing and polishing machines, the speed of production and efficiency for each machine are considered.

Table 2: 3” x 24- kilogram cloves demand

Months	Demand unit (kilogram)
June	16500
July	13800
August	13100
September	18450
October	18465
November	22350

Table 3: Costs associated with the added plan. May 2017.

Item	Price	Unit
Material	11	€ /kilogram
Inventory maintenance cost	1.4	€ /kilogram/month
Stock-out cost	1.8	€ /kilogram/month
Hiring cost	225	€ /worker
Dismissal cost	315	€ /worker
Packing MOD cost	8.3	€ /hour
Extra hours cost	14.3	€ /hour
Drawing cost	19.5	€ /hour
Galvanizing cost	75	€ /hour
Dicing cost	33	€ /hour
Polish cost	12.6	€ /hour
Outsourcing cost	60	€ /kilogram

Drawing operation: It has two drawing equipment, the koch1 and the koch 2.

$$Drawing\,machine = \left(2100\frac{kilogram}{hour} * 65\%\right) + \left(2500\frac{kilogram}{hour} * 57\%\right) = 2790\frac{kilogram}{hour} \tag{1}$$

Galvanizing operation: It has one machine

$$Galvanizing\,machine = \left(3500\frac{kilogram}{hour} * 63\%\right) = 2205\frac{kilogram}{hour} \tag{2}$$

Dicing operation: It has four machines (Wafios).

$$Dicing\,machine = \left(1700\frac{kilogram}{hour} * 72\%\right) + \left(1300\frac{kilogram}{hour} * 67\%\right) + \left(1500\frac{kilogram}{hour} * 70\%\right) + \left(1200\frac{kilogram}{hour} * 55\%\right) = 3805\frac{kilogram}{hour} \quad (3)$$

Polish operation: It has four machines

$$Polish\,operation = \left(700\frac{kilogram}{hour} * 85\%\right) + \left(800\frac{kilogram}{hour} * 92\%\right) + \left(700\frac{kilogram}{hour} * 80\%\right) + \left(600\frac{kilogram}{hour} * 89\%\right) = 2425\frac{kilogram}{hour} \quad (4)$$

Based on the kilogram per standard hour of each machine, the cost per hour is calculated. Table 4 shows the costs associated with the drawing, galvanizing, dicing and polishing operations. The kilogram per hour produced by the packing operation depends on the efficiency of each worker, because this operation, unlike the drawing, galvanizing, dicing and polishing operations, uses labor for its operation. The efficiency of each packer is determined by the seniority. The classification is shown in Table 5.

In order to calculate the labor of packing, the following assumptions are considered: 1 shift has 7.5 hours a day and 1 month has 25 days.

Beginner packer labor per hour

$$Beginner = \frac{\left(54\frac{boxes}{turn} * \frac{24}{1}\frac{kilogram}{box} * \frac{1}{7.5}\frac{turn}{hours} * 55\%\right)}{4} = 24\frac{kilogram}{hour} \quad (5)$$

Table 4: $ per-kilogram costs. Source: the authors

Operation cost	Price	Unit
Drawing cost	0.01	€ /kilogram
Galvanizing cost	0.03	€ /kilogram
Dicing cost	0.01	€ /kilogram
Polish cost	0.01	€ /kilogram

Table 5: Personal classification in the Packing operation

Type	Efficiency	Seniority
Beginner	55%	Less than 3 months
Medium	65%	Between 3 and 4
Advanced	85%	More than 4 months

Medium packer labor per hour

$$Medium = \frac{\left(54\frac{boxes}{turn} * \frac{24}{1}\frac{kilogram}{box} * \frac{1}{7.5}\frac{turn}{hours} * 65\%\right)}{4} = 28\frac{kilogram}{hour} \quad (6)$$

Advanced packer labor per hour

$$Advanced = \frac{\left(54\frac{boxes}{turn} * \frac{24}{1}\frac{kilogram}{box} * \frac{1}{7.5}\frac{turn}{hours} * 85\%\right)}{4} = 37\frac{kilogram}{hour} \quad (7)$$

Furthermore, based on the amount of days we can have an inventory of the product in the process of drawing, dicing, and polishing. The used inventory policies are shown in Table 6.

The first step to build a model of added planning is to identify the decision that the enterprise can make (Sunil Chopra, 2008).

Table 6: Inventory policy

Drawing (Kilogram)	Galvanizing (Kilogram)	Dicing (Kilogram)	Polish (Kilogram)	Final Product Inventory (Kilogram)	Stockout (Kilogram)
10 days	4 days	6 days	8 days	15 days	Policy
5500	2200	3300	4400	8250	250
4600	1840	2760	3680	6900	250
4367	1747	2620	3493	6550	250
6150	2460	3690	4920	9225	250
6155	2462	3693	4924	9233	250
6548	2619	3929	5239	9823	250
6856	2742	4114	5485	10284	250

4.2.1 Decision Variables

Be t= 1, ... ,6 the horizon time to analyze, Where 1=June, 2= July, ..., 6 = November.

The next step in the construction of the model is establishing the objective functions.

Table 7: Decisions can be taken

Variable	Description
B_t	Number of employee's beginner for packing at the beginning of month t.
Md_t	Number of employee's medium for packing at the beginning of month t.
A_t	Number of employee's advanced for packing at the beginning of month t.
D_t	Number of employees dismissed for packing at the beginning of month t.
C_t	Number of employees hired for packing at the beginning of month t.
F_t	Amount of kilogram produced in drawing in month t.
P_t	Amount of kilogram produced in dicing in month t.
G_t	Amount of kilogram produced in galvanizing in month t.
U_t	Amount of kilogram produced in polishing in month t.
M_t	Amount of kilogram of finished product in packing in month t.
EB_t	Number of extra hours of beginner hired for packing at the beginning of month t.
EMd_t	Number of extra hours of medium hired for packing at the beginning of month t.
EA_t	Number of extra hours of advanced hired for packing at the beginning of month t.
IF_t	Inventory of drawing at the end of month t.
IG_t	Inventory of galvanizing at the end of month t.
IP_t	Inventory of dicing at the end of month t.
IU_t	Inventory of polishing at the end of month t.
IM_t	Inventory of finish product at the end of month t.
S_t	Number of pending units in month t.
SC_t	Number of subcontracted units in month t.

4.3 Objective function:

Minimize the total cost of the organization during the time of the planning, in this case its 6 months.

$$\text{Min Z} = \sum_{t=1}^{6} 225 * C_t + \sum_{t=1}^{6} 315 * D_t + \sum_{t=1}^{6} 1532 * B_t + \sum_{t=1}^{6} 1532 * M_t + \sum_{t=1}^{6} 1532 * A_t + \sum_{t=1}^{6} 14.3 * (EB_t + EM_t + EA_t) + \sum_{t=1}^{6} 0.01 * F_t + \sum_{t=1}^{6} 0.03 * G_t + \sum_{t=1}^{6} 0.01 * P_t + \sum_{t=1}^{6} 0.01 * U_t + \sum_{t=1}^{6} 1.4 * IM_t + \sum_{t=1}^{6} 1.8 * S_t + \sum_{t=1}^{6} 60 * SC_t + \sum_{t=1}^{6} 11 * F_t \quad (8)$$

4.4 Subject a:

The size of the work force: the size of the work force, which is the total of the hired workers in the month t, considering the actual workers (beginner, medium and advanced), but not the dismissed ones.

$$B_t + Md_t + A_t = B_{t-1} + Md_{t-1} + A_{t-1} + C_t - D_t \quad (9)$$

Extra hour: a worker (beginner, medium and advanced) can work until 10 extra hours in the month t (Gerencie, 2017).

$$EB_t \leq 10 * B_t \quad (10)$$

$$EMd_t \leq 10 * Md_t \quad (11)$$

$$EA_t \leq 10 * A_t \tag{12}$$

Packing capacity: the amount of kilogram cloves produced should not be above the available capacity of the packer (beginner, medium and advanced).

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{24-kilogram}{hour}\right) * B_t + \left(\frac{24-kilogram}{hour}\right) * EB_t \geq M_t \tag{13}$$

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{28-kilogram}{hour}\right) * Md_t + \left(\frac{28-kilogram}{hour}\right) * EMd_t \geq M_t \tag{14}$$

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{37-kilogram}{hour}\right) * A_t + \left(\frac{37-kilogram}{hour}\right) * EA_t \geq M_t \tag{15}$$

Machine capacity: the production capacity of the machines must be greater than the production required in the drawing, galvanizing, dicing and polishing operations.

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{2790-kilogram}{hour}\right) \geq F_t \tag{16}$$

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{2205-kilogram}{hour}\right) \geq G_t \tag{17}$$

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{3805-kilogram}{hour}\right) \geq P_t \tag{18}$$

$$\left(1\,turn * \frac{7.5\,hours}{1\,turn} * \frac{25\,days}{1\,month} * \frac{2425 - kilogram}{hour}\right) \geq U_t \tag{19}$$

Inventory: the inventory in each operation must be equal to the inventory in the immediately previous period, plus the production carried out in that period, minus the production required in the next season, minus the inventory that should remain in the operation; to guarantee the flow of production.

$$IM_t = IM_{t-1} + M_t + SC_t - S_{t+1} + S_t - demand(t) \tag{20}$$

$$IF_t = IF_{t-1} + F_t - G_t \tag{21}$$

$$IG_t = IG_{t-1} + G_t - P_t \tag{22}$$

$$IP_t = IP_{t-1} + P_t - U_t \tag{23}$$

$$IU_t = IU_{t-1} + U_t - M_t \tag{24}$$

Constrain positive: ensure that the variables take positive values.

$$\begin{aligned} B_t, Md_t, A_t, C_t, D_t, EB_t, EMd_t, EA_t, F_t, G_t, \\ P_t, U_t, M_t, IF_t, IG_t, IP_t, IU_t, IM_t, S_t, SC_t \geq 0 \end{aligned} \tag{25}$$

On the other hand, it must be guaranteed that the out-sourced units do not exceed 250 units and that the inventory policies established are equal to the inventory of each operation in each month.

5 Results

The total cost with the proposed model is 1.51 M €. The Tables 8, 9, 10, 11, 12, and13 shown the results. This Table shows the production that is required in each operation, drawing, galvanizing, dicing, polishing and final product to satisfy the demand of claves.

These tables show the inventory that each operation should have according to the corresponding inventory policies. As can be observed, the only month with shortage in units is November.

Table 8: Production during the planning horizon (2017)

Month	Production drawing (kilogram)	Production galvanizing (kilogram)	Production dicing (kilogram)	Production polishing (kilogram)	Final product (kilogram)
June	38600	32000	33100	29800	25400
July	10290	11370	11190	11730	12450
August	12190	12470	12423	12563	12750
September	25405	23265	23622	22552	21125
October	18485	18479	18480	18477	18473
November	20929	20457	20536	20300	19985

Table 9: Inventory WIP (2017)

Month	Drawing inventory (kilogram)	Galvanizing inventory (kilogram)	Dicing inventory (kilogram)	Polishing inventory (kilogram)	Final product inventory (kilogram)
June	5500	2200	3300	4400	8250
July	4600	1840	2760	3680	6900
August	4367	1747	2620	3493	6550
September	6150	2460	3690	4920	9225
October	6155	2462	3693	4924	9233
November	6548	2619	3929	5239	9823

Table 10: Policies of Stock-out and Outsourcing

Month	Stock-out (kilogram)
November	250

Table 11: Work force required for each period

Month	Worker Force
June	15
July	8
August	8
September	12
October	11
November	12

The number of workers after the month of August is regular. The distribution according to the time horizon is shown in Table 12.

Table 12: Distribution of work force

Month	Hiring cost	Dismissal cost	Beginner	Medium	Advanced
December					4
June	11		6	5	4
July		7	3	3	2
August			3	3	2
September	4		5	4	3
October		1	4	4	3
November	1		5	4	3

Table 13 shows distribution of costs according to the type and time period such as the total costs of hiring, dismissal and extra hours.

Table 13: Total costs

Month	June	July	August	September	October	November
Hiring cost	2475			900		225
Dismissal cost		2205			315	
Beginner	9281	4641	4641	7734	6187	7734
Medium	7734	4641	4641	6187	6187	6187
Advanced	6187	3094	3094	4641	4641	4641
Extra hours cost				215	391	
Drawing cost	270	72	85	178	129	146
Galvanizing cost	1088	387	424	791	629	696
Dicing cost	287	97	108	205	160	178
Polish cost	155	61	65	117	96	105
Inventory cost	11137	9315	8842	12453	12464	13260
Stock-out cost						450
Outsourcing cost						
Material cost	405300	108045	127995	266753	194087	219755

The kilograms of the final product that the organization should produce to satisfy the demand are 110183 kilograms with the raw material unit cost estimated as 11 €, which gives a total cost of 1.2 M€ and a total cost of planning of 1.5 M€. The cost of buying raw material represents 77 % of this cost. This shows a shortage in the supply chain of this sector.

6 Improvements

Aggregate planning plays a fundamental role in the supply chain, because it allows any organization to determine the quantity of production, inventory, outsourced units, minimum of inventory shortage and capacity that it must have in a given period, to satisfy the demand. In turn, it will guarantee the reduction of costs and improve the level of service.

On the other hand, performing an aggregate planning model, considering the level of learning of workers, i.e., if the worker is beginner, medium or advanced, allows the organization to classify workers according to their efficiency in each period. In this way, a fair wage could be guaranteed for them.

Whit the proposed model, the organization may:

— Determine the optimal level of inventory that this should have, to ensure a good level of service and incur a low cost to maintain inventory.

— Identify the cost in which the organization incurs to keep the three kinds of workers. (beginners, medium and advanced)

— Verify if it complies whit the established inventory policies of the organization.

— Include social responsibility issues to ensure a fair wage for their employees which will depends on their efficiency.

— Reduce the inventory shortage and their associated costs.

— Minimize the operations personnel turnover.

— Manage the variability of delivery time and demand.

7 Relevance in the Sector

The combination of aggregate planning with social responsibility is essential if organizations seek to increase their productivity and consequently their competitiveness. Each one fulfills a fundamental role, in the first case it seeks to make the best decisions at the aggregate level, and in the second case, to ensure a focus on the organization's human capital, so that a fair payment is made.

One of the decisions that any organization should take when planning is to decide how many workers to hire and how many to dismiss, if the organization considers the efficiency of its workers and plans based on this, it will be able to reduce the rotation of the Operations personnel, because their workforce will be enough to supply all the demand. Consequently, their workforce would be motivated, and the organization would not have to incur costs for fired.

On the other hand, being steel is one of the scarcest raw materials at the national level and with greater use, its cost of acquisition is high compared to international prices, for this reason the organizations immersed in the sector must contend at price level.

8 Conclusions

The aggregate planning being more than a mathematical model, is a tactic tool that enables the determination of the inventory, production, stock-out levels as well as the workers that the organization needs to satisfy the demand in the corresponding period of time. In addition, it guarantees the optimization of cost, time and resources.

The planning guarantees an organization a high level of service, reduced costs and controls the variability of demand. However, the planning should consider the social responsibility in order to ensure fair wages and level of workforce in all working periods.

Finally, the organization should considers its operations within the whole supply chain. This includes the added value from the side of raw material to the final product in order to decrease the lead time to market along with the associated costs and waste caused by shortages and inventory.

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Part III

Supply Chain Analytics

Multi-Method Decision Support Framework for Supply Network Design

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In a business context characterized by increased competition due to digital transformation and technological breakthroughs, massive penetration of online purchasing, greater customers' expectations and switch of manufacturing paradigms, the role of logistics has become today more critical to firms than ever before. One critical initiative that logistics providers can undertake in order to gain a truly competitive edge is to optimally seize and utilize key resources such as storage and transportation assets. This paper is an effort in that direction and proposes a decision support framework to design a cost effective supply network in the last leg of deliveries. A case study based approach about a postal service provider in Southeast Asia is presented to showcase the applicability of the proposed framework. By leveraging on the integration of data analytics, network optimization and simulation, this work highlights the advantages of adopting a holistic approach to decision making for the used case. Results show that number of storage facilities, and their locations, affect speed and cost-effectiveness of last mile distribution. For the case at hand, 18% of savings in transportation and warehousing cost with no impact on service level can be achieved by reducing the number of facilities in the network from 9 to 4. By reading the present paper, decision makers will gain insights on how to address challenges related with supply network design, transportation costs reduction and optimization of overstretched transportation routes.

Keywords: Network Design; Network Optimization; Last Mile Logistics; Transportation Optimization

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1 Introduction

Over the past few years, the attention given by academics and practitioners to supply chain management and logistics issues is increased tremendously (Yazdani et al., 2017). Logistics encompasses several business activities, which mostly relate with planning, organization, and control of the material flow (direct and reverse) from raw material at manufacturers to final points of consumption (Jonsson & Mattsson, 2005). With the surge in online purchasing, the role of logistics has become today more critical than ever before, with the sector registering a spike in the level of competition accompanied by a severe increase in usage of Third Party Logistics Service Providers (LSP). Between 2010 and 2016, the LSP industry has registered a steady yearly growth in revenue, reaching the global amount of 802.2 billion U.S. dollars in 2016 (+64% compared to 2010) (Statista, 2018 a). Worldwide, the market size for LSP in Asia Pacific is the largest. In 2016, the regional market was seized at approximately 305 billion U.S. dollars 2016 (38% of total), followed by North America (25% of total), and Europe (21% of total) (Statista, 2018 b). Constant regional economic growth and rapid surge of middle-class, demographic profile of consumers and businesses, advantageous trading conditions, and recent crystallization of the ASEAN Economic Community (AEC) make in fact Asia Pacific region particularly appealing to global freight forwarders and related firms (Spire Research and Consulting, 2016). Moreover, elements such as low cost for outsourcing, supply chain inefficiencies, and increased demand for LSPs, creates even more favorable conditions for the further increase in the presence of logistics players in near future (Spire Research and Consulting, 2016). Additionally, the gradual liberalization of regional logistics services is slowly increasing competitiveness and foreign participation, thereby introducing more logistics players into the market (Logistics, Insights Asia, 2016). With competition shifting from firm-to-firm to supply chain against supply chain (Christopher & Towil, 2001) there is clear need for LSP to rethink about supply chain and logistics management strategies so as to reduce operational costs and increase competitiveness (Tartavulea & Radu, 2013).

Thus, for a local LSP that wants to operate profitably in such a competitive context, there is a burning need of more streamlined logistical processes so as to gain concurrent cost effectiveness and superior service level. One such important initiative that LSP can undertake in order to gain competitiveness is to optimally allocate and utilize their logistics assets such as storage and transportation. Particularly, practical experience and academic research suggest that number of storage facilities, and their locations, greatly affect both speed and cost-effectiveness of logistics operations (Zhang & Xu, 2014). Therefore, a seamless and effective navigation of storage assets through an optimum design of supply network (SN) would be highly beneficial for an LSP that aims at gaining a truly competitive edge in both offline and online marketplaces, particularly in the final leg of deliveries. Last mile logistics is considered in fact the least efficient, costly, and most polluting sections of the entire logistics chain [(Gevaers, et al., 2014), (Wang, et al., 2016)]. Therefore, by taking these "last mile problems" into consideration, the present work is motivated by the real need to develop location decision models for interested LSPs that aim to streamline their logistics processes through an optimum design of their last mile distribution network and by the potential gain that such models can bring into practice. By focusing on the last mile distribution network of the National postal service provider (PSP), one of the major LSP in Indonesia, we will demonstrate how the proposed models can lead to significant gains in terms of costs, with no impact on service levels, using a real-life case in the Asia-Pacific region. The scope of work is on the PSP' supply network structure which, in the context of one of the most populated urban areas in Indonesia, comprises of 1 large Distribution Centre (DC), 9 intermediate DCs, and several demand points. This paper will assist researchers and practitioners in understanding how the following research questions are to be addressed

RQ1: How to determine the suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia), and what is the suitable number of DCs for the particular case at hand?

RQ2: How to decide on the locations for the intermediate DCs of an optimized supply network, and what is the optimum network configuration for the particular case at hand?

The remainder of the paper is structured in the following sections. Section 2 presents a review of relevant literature. Section 3 describes the real world application by presenting the logistics landscape of Indonesia, and by setting the background of the case study. Section 4 describes the methodological approach. Section 5 discusses the model implementation for the selected case and results to date. Finally, section 6, highlights managerial implications, limitations, and next steps to reinforce findings to date.

2 Literature Review

Decisions on logistics system design are typically about number of storage facilities, their locations, allocation of products to facilities and to market (Korpela & Tuominen, 1996). Logistics system design studies have been largely applied to commercial sector, and a fair number of research papers are available in the domain of network design. Some research groups looked at strategic and tactical decisions such as flows of commodities across supply networks [(Keskin & Uster, 2007), (Qin & Ji, 2010)], or transportation policies (Tancrez, et al., 2012). Some others focused upon operational issues (Chow, et al., 2012) such as service level improvement (Rodziah, 2017). Substantial contributions have been made in addressing cross-level decisions such as inventory control (Ho & Emrouznejad, 2009), transportation flows (Lee, et al., 2008), location decisions [(Sun, 2002), (Balcik & Beamon, 2008)] or warehouse capacity planning (Francas & Minner, 2009). In literature, network design problems are typically tackled using either mathematical modeling/optimization, Multi-Criteria Decision Making (MCDM), and simulation models. Seldom, two methods of the above are integrated.

2.1 Supply network optimization

Network optimization refers to a series of methods which, by defining objective functions and constraints, are capable of determining the optimal supply chain network design with the lowest total cost structure [(Beamon, 1998), (Supply Chain Acuity, Management Consulting, 2013)]. A recent work by Kovács, G. et al. (2017) highlighted the need of establishing efficient supply chain operations to withstand the increasing global competition, and suggested to focus on minimum total cost and lead time, and improved customer service level, as objectives of the supply chain optimization. Benyoucef, Xie and Tanonkou (2013) considered a two period SC design model addressing facility location/supplier selection problem. The authors used a Monte Carlo approach in combination with Lagrangian relaxation, so as to minimize fixed DCs location costs, inventory and safety stock costs at the DCs as well as ordering costs and transportation costs across the network. Zokaee, S. et al. (2017) proposed the use of robust optimization to determine the strategic locations and tactical allocation for a four-tier supply chain. Their model was then extended to incorporate uncertainty in key input parameters such as demand, supply capacity and major cost data including transportation and shortage cost parameters. Ghaffari-Nasab, N. et al. (2015) proposed the use of mixed integer nonlinear programming model and linearization using a step-by-step approach to decide on the number, location and operation of hub facilities so as to minimize the total logistics costs for the network for a LSP. Authors compared the performances of two alternative distribution strategies namely hub-and-spoke and direct shipment, with the first showing significant advantages in terms of cost.

2.2 Multi-Criteria Decision Making (MCDM)

MCDM is concerned with structuring and solving decision problems on the basis of multiple decision criteria. A common application of MCDM is to tackle those decision problems for which a unique optimal solution does not exist and it is necessary to use decision maker's qualitative inputs to differentiate between solutions [(Majumder, 2015), (Roh, et al., 2015)] such as facility location problem as per Timperio, et al. (2017). Ho & Emrouznejad (2009), explored the use of a combined approach analytic hierarchy process (AHP) and goal programming (GP) to design a logistics distribution network in consideration of qualitative inputs from domain experts (e.g. on delivery and service level elements), with limited resource availability. Galvez, D. et al. (2015) integrated Mixed Integer Linear Programming (MILP) optimization and Analytical Hierarchical Process (AHP) for the implementation of a logistics network in the domain of sustainable energy production processes.

2.3 Supply chain simulation

Is used for supply network design decisions or design of supply chain policies. The main advantage of simulation is that it allows to assess supply chain behavior in a virtual environment, hence reducing the risk of making costly mistake in implementation (Thierry, et al., 2008). Munasinghe, I. U. et al. (2017) proposed a simulation-based approach to assess the impact of the facility location and product differentiation on supply chain network design. Six different scenarios were tested, with the goal of minimizing total distribution network cost. Salem R. W. & Haouari M. (2017) proposed the use of a simulation-optimization based approach to address a three-echelon stochastic supply chain network design problem. Outcomes of their work included selection of suppliers, determination of warehouses locations and sizing, as well as the material flow, with the objective of minimizing total expected cost.

2.4 Research Gaps and Contribution of the Current Research

Despite the comprehensive literature available in the domain of network design, to our knowledge, most research groups have handled the facility location problem by selecting a single method, and only in few cases two methods were integrated (mostly optimization and simulation). Although previous works provide fair solutions to this category of problems, it is also evident the lack of an adequate holistic support (strategic, tactical, and operational) to decision making. Thus, it appears that none of the research groups have considered an integration of methodologies, and this paper fills this gap. By reading the present paper, decision makers will be able to gain comprehensive answers to the following questions:

How to determine the suitable number of DCs for a cost-effective and time responsive last mile urban delivery?

How to decide on the locations of DCs for a cost-effective and time responsive last mile urban delivery?

As such, the work presented in this manuscript will apply data analytics, network optimization, and dynamic simulation to demonstrate the theoretical and practical relevance of the proposed solution approach. In particular, the study seeks to bring the following contributions:

- Generate deeper insights (static and dynamic) in the domain of network design by uncovering strategic, tactical and operational elements;
- Determine the optimal network configuration for the case study at hand;
- Bridge theoretical knowledge with practice in the nice of network design;

3 Indonesia Logistics Landscape

Located in the South East Asia region, Indonesia is the 14th largest nation by size in the world which covers 1,811,569 square kilometers of land and 5,800,000 square kilometers of water. The country spans three time zones and counts over 260 million people spread over more than seventeen thousand islands.

According to the World Bank's Logistics Performance Index of 2016, Indonesia ranks as 63rd on a global scale in regards to key logistics elements such as customs procedures, infrastructure, international shipments, logistics competence, tracking & tracing, and timeliness (The World Bank, 2016). This translates in logistics costs accounting for the 26% of national GDP (US$ 861 billion), worse than its neighboring countries like Singapore (8%) and Malaysia (14%). Poor logistics performance affect a) Country's economic competitiveness and b) In-country disparities in terms of accessibility and pricing of primary commodities (Indonesia-Investments, 2013). In such a challenging context, having in place an optimized supply network would be highly beneficial for increasing profits and optimizing overstretched routes

3.1 The Case at Hand

This case study focuses on the distribution network of the PSP in Indonesia that operates a countrywide network serving various type of businesses and consumers. However, the focus of this work is on the PSP' supply network dedicated to serve a highly populated urban area in Indonesia comprising of 1 large Distribution Centre (DC), 9 intermediate DCs, and several demand points (Figure 1). After a series of field visits, interactions with operations team, and basic data analytics, it has been identified that the existing network structure is leading to high operational and distribution costs, and therefore in need of a restructuring.

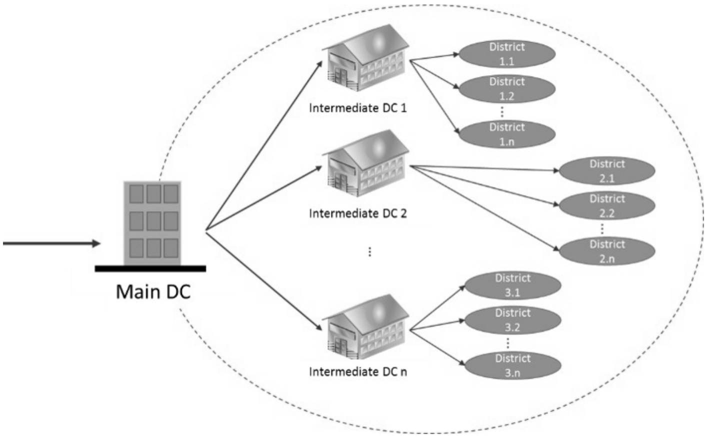

Figure 1: Schematic Representation of PSP's Supply Network (for Illustration Purpose only)

4 Solution Approach

To tackle the research problem of above, a solution approach integrating data analytics, network optimization and simulation has been conceived and tested. The proposed approach encompasses three Phases:

Phase 1. Identification of optimum number of DCs to be included in the supply network;

Phase 2. Structuring and Optimizing the Supply Network;

Phase 3. Stress-testing the supply network and measuring performances based on pre-identified parameters.

Figure 2 shows the proposed integrated decision support framework.

The proposed solution approach is used in this particular case to restructure an existing supply network. However, in those instances whereby a new network is to be established, the same framework can be also applied.

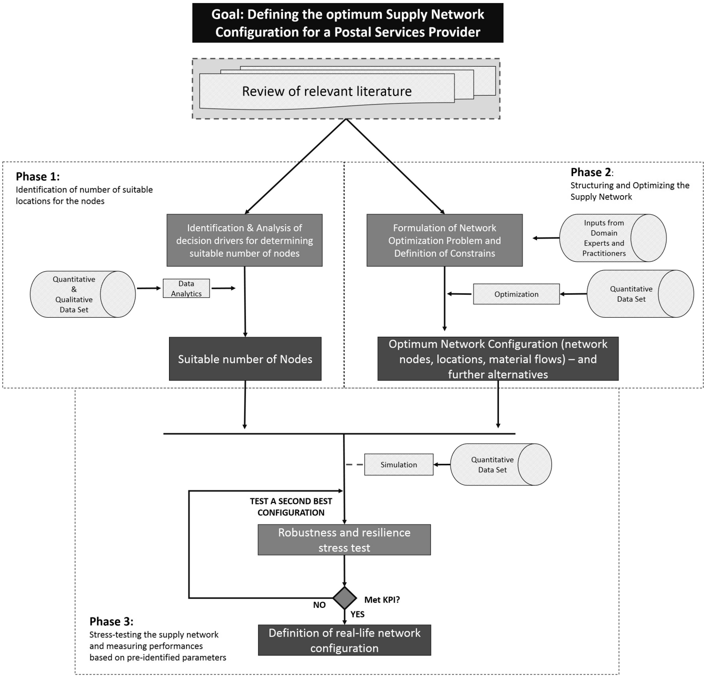

Figure 2: Proposed Integrated Decision Support Framework

In order to restructure an existing supply network the necessary steps include the development of the “AS-IS” Model, followed by the “TO-BE” (Ideal) model, and finally the “TO-BE” (real) in consideration of real-life constraints (Figure 3):

(1) “AS-IS” model. This model is required to understand the existing network configuration, operational requirements, and identify bottlenecks and areas for improvement. Performances of “AS-IS” network will be used to set the benchmark for any proposed changes.

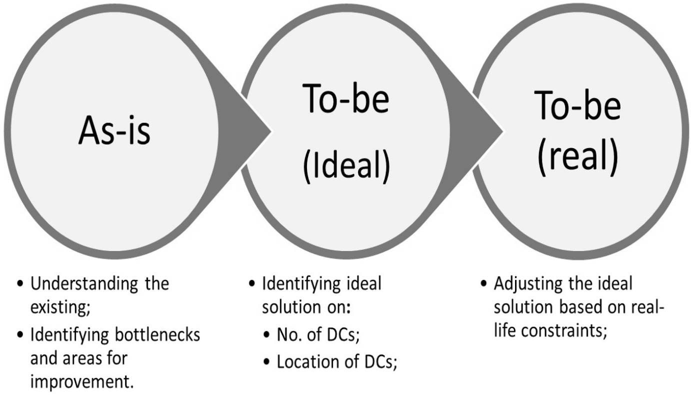

Figure 3: Stages to Supply Network Restructuring

(2) Ideal "TO-BE" model. This intermediate model is needed to identify the "unconstrained solution" (ideal) in terms of number of DCs and their locations;

(3) Real "TO-BE" model. This final model will lead to the identification of real-life solution, that is an adjustment of "TO-BE" ideal based on real-life constraints set by the PSP;

4.1 Phase 1: Identification of number of suitable locations for the nodes

Network design begins with the identification of number of suitable locations for the nodes. These decisions are traditionally based on total cost (warehousing, transportation, lost sales). Two different strategies, centralized and decentralized supply networks, can be adopted based on logistics requirements. Centralized warehousing is a system where a single (or few) DC is used to serve a particular area whereas a decentralized approach encompasses the use of several facilities

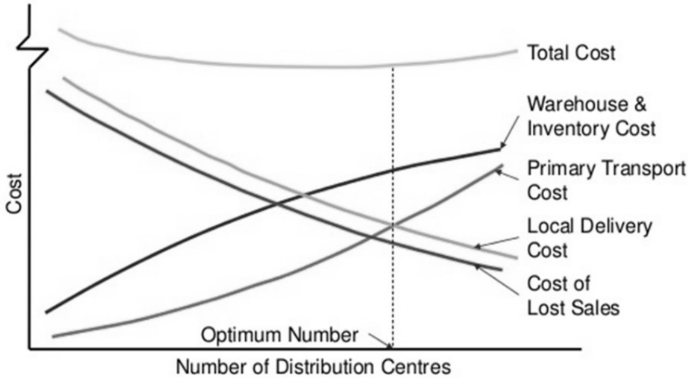

Figure 4: Determining the Optimum Number of DCs in a Conventional Supply Chain

spread out to cover a particular area (Kokemuller, 2014). At changes of number of network nodes (DCs), corresponds a trend of costs as shown in Figure 4.

Source: Barloworld Logistics Africa (PTY) LTD

1. Warehouse & Inventory Cost. Since fewer resources are needed to run one warehouse as opposed to several, lower number of DCs has a positive effect on costs related to warehousing activities. Additionally, variable costs of warehousing such as labor, warehouse management, equipment, and training of personnel can be also kept at minimum in case of centralized system.

2. Primary Transport Cost. The transportation cost of the first tier (e.g. from main DC to intermediate DCs) are lower in case of centralized supply network. Consolidation of shipments can be in fact be implemented, with a positive impact on costing structure.

3. Local Delivery Cost. The transportation cost of the second tier (e.g. from intermediate DCs to final consumers) are higher in case of highly cen-

tralized system. In case of decentralized network in fact, the distance in between intermediate DCs and customers is lower.

4. Cost of Lost Sales. A decentralized system helps in achieving shorter lead times and higher percentages of on-time delivery, resulting in higher service level, and thus lower cost of lost sales.

In the case study undertaken in this research, data analytics and green field analysis were used to determine the cost items. Green field analysis is a GIS/center of gravity based approach (Russel and Taylor, 2010), which seeks to determine the geographic coordinates for a potential new facility. Computations are based on minimum transportation cost (calculated as “distance” * “Product Amount”) (AnyLogistix, 2018) in consideration of aggregated demand for each customer and product, customer locations (direct distance between customers and DCs/Warehouses), and service distance (or number of facilities to locate) (AnyLogistix, 2018). To perform green field analysis, 2 years of operational information on historical demand (by location, amount, and time distribution), product flows, and costs were required. A template in MS Excel was shared with the company to facilitate data provision. The company provided the historical data referring to the biennium 2016 and 2017.

4.2 Phase 2: Structuring and Optimizing the Supply Network

Once Phase 1 is completed and the number of suitable locations for the network nodes is determined, Phase 2 will be used to identify the optimum network configuration in terms of both nodes (location of DCs) and arcs (connections in between DCs) using Network Optimization (NO). NO is an optimization technique which seeks to find the best configuration of a supply chain network structure as well as the flows based upon an objective function, which typically maximizes profits (Sample in Table 1),

Table 1: NO Cost Components

Component	Amount [$]
Revenue	XXX, XXX, XXX, XXX
Supply Cost	(XXX, XXX, XXX)
Production Cost	(XXX, XXX, XXX)
Transportation Cost	(XXX, XXX, XXX)
Inbound Processing Cost	(XXX, XXX, XXX)
Storage Cost	(XX, XXX, XXX)
Outbound Processing Cost	(XXX, XXX, XXX)
Fixed Cost	(XX, XXX, XXX)
Opening Cost	(XX, XXX, XXX)
Closing Cost	(XX, XXX, XXX)
Profit	XXX,XXX,XXX

The mathematical model can be formulated as such:

Let:

x_{ijk} = quantity of product k shipped from DC i to demand point j

y_i = indicator (binary, 1 = Yes and 0 = No) variable for the selection of DC i

δ_{ij} = indicator (binary, 1 = Yes and 0 = No) variable for the selection of shipping from DC i to demand point j

f_i = operating cost for each DC i

c_{ij} = unit cost of moving a unit weight, w_k of product k from DC i to demand point j

p_{ik} = unit cost of processing a unit weight of product k in DC i

m = total number of DC to consider

n = total number of demand points

d_j = demand from demand point j

M = maximum number of DC in the network

α = maximum number of DC to fulfil a demand point j

The formulation is as follows:

$$min\left[\begin{pmatrix} facility \\ operating\ cost \end{pmatrix} + \begin{pmatrix} transportation \\ cost \end{pmatrix} + \begin{pmatrix} facility \\ processing\ cost \end{pmatrix}\right]$$

$$min \sum_{i}^{m} f_i y_i + \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} c_{ij} x_{ijk} w_k + \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} p_{ik} x_{ijk} w_k \tag{1}$$

Subject to Maximum number of DC. As an additional planning consideration, the maximum number of DCs to include in the network can be limited due to constraints such as budget.

$$\sum_{i}^{m} y_i \leq M \tag{2}$$

Demand-supply balance. In the case of deliveries of items, the network must (hard constraint) be able to fully fulfil the demand.

$$\sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} x_{ijk} = \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} d_{jk} \delta_{ij} \tag{3}$$

Flow constraint. The connection of a demand point to a DC can only exist if and only if the DC is open.

$$\delta_{ij} \leq y_i \forall i, j \tag{4}$$

Fulfilment constraint. Demand fulfilment can be either from multiple sources (multiple DCs) or constrained to a single source (single DC).

$$\sum_{i}^{m} \delta_{ij} y_i \leq \alpha \forall j \tag{5}$$

In this case, the NO model was developed using AnyLogistix (ALX) software.

4.3 Phase 3: Stress-testing the supply network and measuring performances based on preidentified parameters

Once the ideal network configuration is defined (Phase 2), Phase 3 will stress-test the supply network based on performance measures (e.g. service level, profits). This final phase will assess network robustness and resilience, as well as measure operational performances. This Phase can be undertaken by using various computer simulation techniques such as discrete-event simulation in AnyLogistix (ALX) software.

5 Implementing the Solution Approach

The implementation of the integrated solution approach described above for the PSP case was initiated by collecting structural (existing network structure, transportation assets, product flows) and operational data (demand patterns, costs). An initial analysis of data led to the identification of bottlenecks, criticalities, as well as areas for improvements. A sample of district-level demand patterns is in Figure 5.

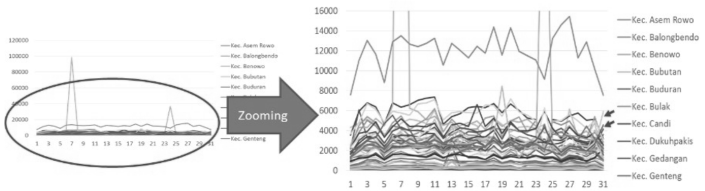

Figure 5: District-level Demand Patterns

5.1 Phase 1: Identification of number of suitable locations for the nodes

Given the unique nature of the business whereby the PSP in consideration operates in, the only cost item driving the decision about optimum number of facilities are transportation cost. In fact:

Warehouse and inventory cost are not relevant due to 1) PSP does not carry any inventory, and 2) Manpower is fixed, regardless the number of DCs; Cost of lost sales does not apply since there is no other competitor offering the same service; Transportation cost, which includes primary transport cost and local delivery cost, have been calculated using green field analysis in AnyLogistix (ALX) (sample in Figure 6). Transportation cost and marginal cost reduction with changed number of DCs is in Figure 7.

Results show that by increasing the number of intermediate DCs, the overall transportation costs to serve final customers would reduce.

5.2 Phase 2: Structuring and Optimizing the Supply Network

Once Phase 1 is completed, next step consists of optimizing the baseline network configuration. This phase will select the optimal network nodes out of the subset of suitable candidates from Phase 1, based on costs. The optimization problem of calibrating the baseline network configuration consists of finding the optimum number and location of the distribution centers as to effectively distribute goods, while satisfying multiple constraints.

In this work, Transportation Cost, Inbound Processing Cost, Outbound Processing Cost and Fixed Cost were considered for formulating the NO model. Other cost items listed in Table 1 were not considered due to a) Data unavailability (opening and closing costs) and b) Limited relevance based on the nature of the PSP business (Supply, production, storage).

Results show that the ideal “TO-BE” (ideal) network configuration should be inclusive of 4 intermediate DCs (Figure 8 and Figure 9), which will minimize overall supply chain cost, with no changes on service level as compared to ”AS-IS”.

In order to define the “TO-BE” (REAL) network configuration, the constraint on maximum distance travelled per delivery man (100 km) in a day was included. Results highlighted that ”TO-BE” Ideal and ”TO-BE” real overlap.

A comparative analysis of ”TO-BE” network versus ”AS-IS” network shows that while terms of service level the two network perform similarly, in terms of cost effectiveness the ”TO-BE” network surpasses the ”AS-IS” by nearly the 1% of total costs. Although a lower number of DC determines higher transportation cost (+7.74%), the saving coming from a lower fixed costs of facilities (-8.76%) is more substantial. On these two cost items in fact, an overall improvement of over 4% in costs can be appreciated. Although not yet assessed, further savings could be achieved via economies of scale e.g. through consolidation of manpower and/or transportation assets.

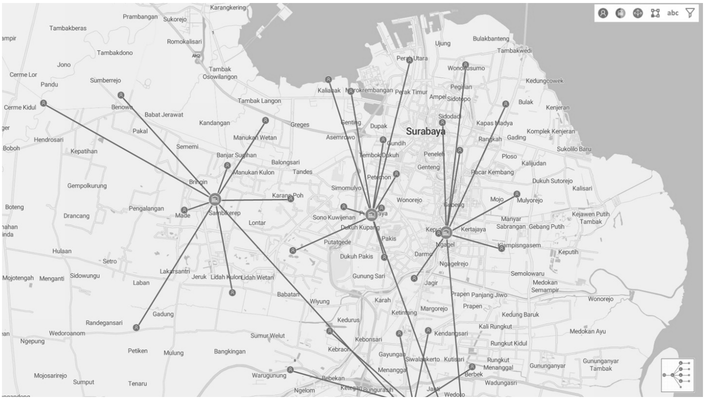

Figure 6: Illustration of Green Field Analysis

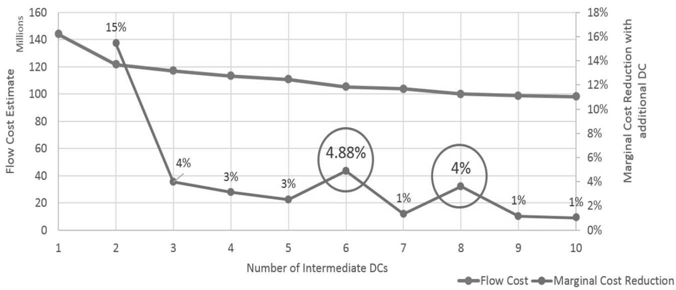

Figure 7: Transportation Cost and Marginal Cost Reduction with Changed Number of DCs

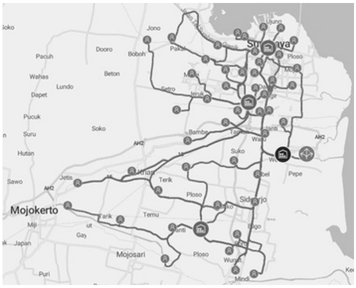

Figure 8: ”TO-BE” (Ideal) Solution

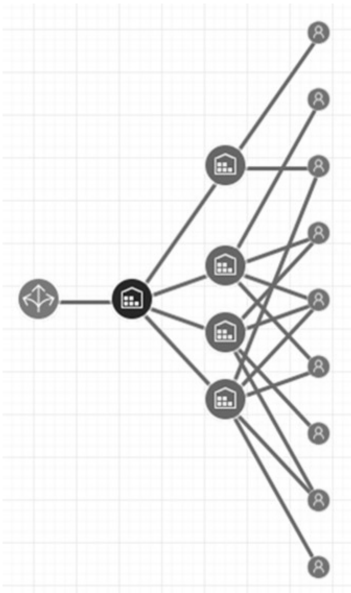

Figure 9: ”TO-BE” Ideal, Material Flow

6 Conclusions & Managerial Implications

This paper has proposed a decision support framework for network design and has demonstrated the applicability to real life case on a PSP operating in Indonesia. Starting from an initial identification of suitable locations for the network nodes, the proposed framework depicts procedures and tools to leverage on across the various phases of the problem's solution seeking. The full implementation of the proposed approach would lead to the definition of the optimum network configuration, assessment of its robustness and measurement of operational performances. However we applied the framework partially, as to define a preliminary solution to the problem at hand.

As anticipated in the introduction, this paper can assist researchers and practitioners in understanding how the following research questions are to be addressed, and key findings include:

RQ1: How to determine the suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia), and what is the suitable number of DCs for the particular case at hand?

The suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia) can be determined by combining data analytics with green field analysis, and network optimization. For the geography of reference (greater Surabaya), and with the provided datasets, the number of suitable intermediate DCs should be equal to 4.

RQ2: How to decide on the locations for the intermediate DCs of an optimized supply network, and what is the optimum network configuration for the particular case at hand?

Locations for the intermediate DCs of an optimized supply network can be selected using a network optimization approach. The optimum network configuration for PI in Greater Surabaya should include the four nodes as per Figure 8. The identified set of facilities guarantees enhanced cost effectiveness (-18% of transportation and warehousing cost) at comparable service level;

Managerial Implications. This study is able to support decision makers in a wide range decisions in the context of network design. GFA can help decision makers with the determination of transportation cost at increased number of DCs, as well as identification of potentially suitable locations. The NO can help logistics managers to make strategic decisions about DCs' locations.

Limitations. This work has few limitations. First, the dataset on demand is limited to the biennium 2016-2017. An extension of the dataset with inclusion of more data points would provide a more accurate solution to the problem at hand. Secondly, inclusion of cost items such as cost for opening or closing a DC and manpower allocation would help to fine tune the proposed solution.

Next steps. In order to reinforce the findings to date, a dynamic simulation model can be developed (Phase 3). This would allow to:

- Determine transportation (fleet size) and storage requirements;
- Perform what-if analysis with comparison of alternative network configurations;

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Business Model of Aircraft Fleet Planning using ANN

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The purpose of Aircraft Fleet Planning is to provide the number and type of aircraft for acquisition, its time of acquisition, and trade-in or phase out of fleet. Airlines select a particular type of aircraft from the manufacturer on the basis of optimum cost, considering a number of constraints. Because of existence of several conflicting criteria, the solution approach becomes an NP-hard problem. As such, a traditional linear programming approach cannot optimize the system in a reasonable time frame. This paper aims at developing a model for selecting aircraft using Artificial Neural Networks. Key inputs have been obtained from the major areas of aircraft design characteristics, aircraft physical performance, maintenance needs, operating economics, acquisition cost, operating cost and customer satisfaction. The input values are fuzzy in nature. However, several methods for combined use of fuzzy logic systems and neural networks have been suggested. Experience, which is conventionally used for selecting a particular type of aircraft, has been used for training of the proposed network. Single-layer ANN model provided a good solution with optimality in cost, without sacrificing time constraint and algorithmic complexity. The airline business will be immensely benefited from the solution procedure.

Keywords: Aircraft Fleet Planning; ANN; Fuzzy

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1 Introduction

Aircraft Fleet planning process determines type of aircraft the airline should buy and their numbers, in order to achieve organizational goals. Corporate planning deals with the need of the airlines, current resources, corporate objective, projected industry environment and marketing strategy. Specific requirement of the airlines is then identified through marketing research and analysis on the basis of the set company objectives.

Given a flight schedule, which is a set of flight segment with specified departure and arrival times and a set of aircraft, the fleet assignment problem is to determine which aircraft type should fly each flight segment (Clark et al., 1996). The objective is to maximize revenue minus operating cost. In the basic fleet assignment problem considered by Clark et al.(1996) a daily, domestic fleet assignment problem is modeled and solved with up to eleven fleets and 2500 flight legs.

Satisfied customers usually return back and buy more, they tell other people about their experiences. Customer Satisfaction is one of the most important processes in airline industry and is recognized as the key to the success of business competition. Like any other industry, airlines first measure the expectation of its passenger, analyzes the consumer behaviour, prepares a customer satisfaction program to provide a set of standard customer services, identifies the service gap and tries for continual improvement.

This research considered the issues of aircraft cost and customer satisfaction in selecting aircraft and developing models integrating these two separate issues – cost estimation and customer satisfaction. Solution methodologies of Fuzzy Logic and Artificial Neural Network have been adopted.

1.1 Aircraft Selection Process

Air transportation offers both passenger and freight services that are essential for economic growth and development. In a highly competitive environment, airline companies have to control their operating costs by managing their flights, aircraft, and crews effectively.

Fleet assignment involves the optimal allocation of a limited number of fleet types to flight legs in the schedule subject to various operational constraints (Jacobs and Johnson, 2008). Airlines typically manage their annual business cycle by subdividing the year into a sequence of scheduling periods that span about a month each (Ahmad, 2000).

Aircraft selection process is a dynamic function, coordinated by a number of group functions including corporate planning. The life cycle starts with the corporate objective of acquisition of new aircraft in the fleet. The planning life cycle is shown in Figure 1.

Data acquisition is the next step. Information related to any kind of lease or purchase of aircraft and making comparative statements, relevant information is required. Then evaluation of data is the logical sequence.

The next step is the purchase negotiation and finally acquisition of the aircraft. Many sections of the airlines will be involved when aircraft is going for its operation. Continuous updating/modifying the aircraft will be going on until the aircraft is disposed off.

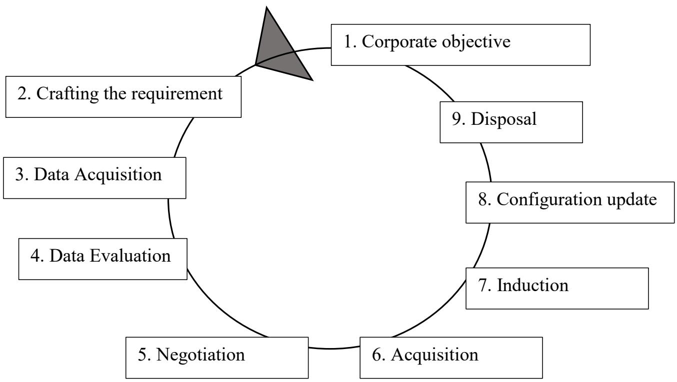

Figure 1: Fleet planning life cycle

1.2 Cost Consideration of Airline

In order to maximize anticipated profit, cost is a vital area for all business. Costing is also important for pricing of its product. The price of average revenue per passenger mile must be sufficient to cover average cost per passenger mile flown. Airline operating cost is categorized in two areas – direct operating cost or variable costs and indirect operating cost or fixed-overhead costs.

A flight sequence or route is built for each individual aircraft so as to cover each flight exactly once at a minimum cost while satisfying maintenance requirements. Finally, in the crew scheduling or pairing optimization problem, a minimum cost set of crew rotations or pairings is constructed such that every flight is assigned a qualified crew and that work rules and collective agreements are satisfied. In practice, most airline companies solve these problems in a sequential manner to plan their operations, although recently, an increasing effort is being made to develop novel approaches for integrating some of the airline operations planning problems while retaining tractability.

The cost categories (Swan and Adler, 2006) include pilot, cabin crew, fuel, Landing fee, airframe maintenance, engine maintenance and the ownership costs of the aircraft. The flight crew costs include all costs (Ssamula and Mistro, 2004) associated with the flight and cabin crew including allowances, pensions, salaries, etc.

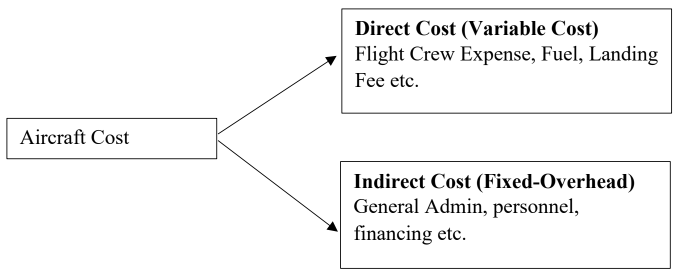

Figure 2: Types of cost

The costs of an airline incurs in producing available seat miles (ASM) depend upon the type of adjustments it is able to make in the amounts of the various resources it employs. The quantities of many resources used – labour, fuel and so forth-can be varied relatively quickly in the short run. But amounts of other resources demand more time of adjustment.

1.3 Customer Satisfaction - a primary Paramater

Introduction of wide body service in the early 1970s marked the climax of production –sales orientation in the air transport industry. Excess capacity and shortage of customer changed the marketing concept to a customer –oriented approach.

The industry entered into its matured stage since 1960s. Weaker competitors left the industry. The remaining competitors have become well entrenched, and the marketing policy and images are well known. Customer loyalties and market shares became stabilized.

Evaluation of customer satisfaction differs from one study to another. Studies have been differing with their focus and coverage. Most of the studies focused on evaluating factors influencing customer satisfaction or associated customer satisfaction and quality of services (Josephat and Ismail, 2012). Logistic regression was used to develop customer satisfaction model for Precision Air.

Customers' satisfaction degree is customers' comparative evaluation between expectation and perceived value for the products and the services after making relevant payment for their proceeds. Satisfaction or dissatisfaction after the purchase, depends not only on the difference between performance that customers actually feel and expected, but also upon their costs that they pay in order to get the profits, that is to make customers obtain the maximum discount. Customers' delivered value means the difference between the total value of customers and the total cost of customers.

Service encounters that do not meet expectations should have a bigger impact on customers than service encounters that exceed expectations. Furthermore, if customers are concerned about the possibility of service encounters that do not meet expectations, future sales and profitability may be negatively influenced (Shaun et al., 2005).

2 Theoretical Background

The flying performance of different aircraft model is different, for example, range of aircraft, flying altitude ceiling, maximum takeoff weight, maximum zero fuel weight, available cargo space and many more. So a particular route is not suitable for all models of the aircraft to perform. In addition, different models have different seating capacity, layout and their operating costs are not same (Li, and Tan, 2013). Profit maximization is the primary goal of an airline whereas customer satisfaction is considered to be the secondary goal through which strategic advantage can be achieved.

Conventionally, a computer operates through sequential linear processing technologies. They apply formulas, decision rules, and algorithms instructed by users to produce outputs from the inputs. Conventional computers are good at numerical computation. But ANNs improve their own rules; the more decisions they make, the better the decisions may become.

ANN can determine the optimal solution to an NP-complete (nondeterministic polynomial) problem, such as the travelling salesperson problem. This is equivalent to linear and integer programming in management sciences, where the objective functions are optimized using a heuristic search procedure. there is no doubt that ANNs are feasible for business applications. Many phenomena that are difficult to describe can be modeled by ANNs, if carefully designed.

Artificial Neural Networks have emerged as a very popular area of research, both from the design and the usage points of view. There is considerable research emphasis on designing better and more efficient neural networks, more powerful ”learning algorithms”, better transfer functions etc. On the other hand there is a great amount of academic interest in the applications of neural networks. Disciplines as diverse as the biological sciences and finance have applications that use neural networks. There is a significant volume of research on neural networks in the engineering and science literature. There also exists a reasonable body of neural network research as related to business.

2.1 Profit Maximization Model

Considering the features of a particular route and flight plan, under constraints of pre-announced flight schedules, not considering the flight stopovers and having enough airport capacity, the model (Pandit et al., 2010) which considers matched flying area, as well as the traffic match conditions can be proposed as follows:

$$\text{Max} \sum_{i=0}^{m} \sum_{j=1}^{n} P_{ij} x_{ij} \tag{1}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = m \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \tag{3}$$

$$x_{ij} d_j \geq D_j \qquad i = 1, 2, 3 \ldots, m; \; j = 1, 2, 3 \ldots, n \tag{4}$$

$$x_{ij} s_j \geq S_j \qquad i = 1, 2, 3 \ldots, m; \; j = 1, 2, 3 \ldots, n \tag{5}$$

$$x_{ij} r_j \geq R_j \qquad i = 1, 2, 3 \ldots, m; \; j = 1, 2, 3 \ldots, n \tag{6}$$

Where,

$i = 1, 2, 3 \ldots\ldots, m\, m$	is overall flight number
$j = 1, 2, 3 \ldots\ldots, n\, n$	is the number of aircraft model
P_{ij}	the revenue of aircraft model j to perform the flight i
	E_{ij} Revenue earned from model j to flight i
$P_{ij} = E_{ij} - F_{ij} - V_{ij}$	F_{ij} Fixed operating cost of model j to flight i
	V_{ij} is the variable operating cost of model j to fly flight i
$x_{ij} \begin{cases} 0 \\ 1 \end{cases}$	flight i is performed by the aircraft model j else otherwise
d_j	is the range of the aircraft model j
D_i	is the distance of the flight i
s_j	is the seating configuration of the aircraft model j
S_j	is the required traffic of the flight i
r_j	is the flying requirement (ETOPS, TCAS,..)of the model j
R_j	is the flying requirement (ETOPS, TCAS,..) of the route
g_j	is the cargo space available in model j
G_j	is the cargo space requirement in flight i

The objective function (1) means that the total income of all flights is largest, after the aircraft types are assigned to all flights considering the bulk of the flights of global optimization. Constraint (2) is to ensure that an equal number of models are selected for flights. Constraint (3) is to ensure that only one model is assigned to each flight. Constraint (4) is to ensure that the model assigned to the flight meets the flight distance requirements. Constraint (5) is to ensure that the model assigned to the flight meets the traffic requirement is fulfilled by the seating capacity. Constraint (6) is to ensure that the selected model meets the technical requirements of the route.

2.2 Integrated Fleet Planning Model

As a decision making process integrated fleet planning depends on Design characteristics, Physical Performance, Maintenance Needs, Acquisition cost, operating economics (Pandit and Hasin, 2010).

In this research, the fleet planning problem (FPP) has been defined as a multi-objective optimization function with cost minimization and satisfaction maximization as follows:

$$\text{FPP} = \text{Selection}\left[\text{Min}\sum C_{ij},\ \text{Max}\sum S_{ik}\right] \tag{7}$$

Where

i = alternative aircraft

j = cost parameters

k = satisfaction parameters

The constraints are the required Design characteristics, Physical Performance, Maintenance Needs, Operating Economics and availability of Acquisition Cost.

Selection of aircraft on the basis of optimal solution is the unique goal of this research. The input values are considered as fuzzy in nature. However, in contrast to neural networks, fuzzy decision logic systems are not capable of automatic learning. To solve this problem, this research utilized combined use of fuzzy logic systems and neural networks.

In this research, fuzzy neural network approach is used, where neural network part is primarily used for its learning and classification capabilities and for pattern association and retrieval. For neural network analysis, a two-layer hidden function is used which proves sufficient for learning. The data set for learning is derived from the available business results, which are optimized using conventional linear or integer programming approach, as used typically by some airlines research organizations.

The quantitative features, considered here, are costs and expenses of acquisition for purchase of aircraft, its spares, ground support equipment, maintenance training, flight training, financing, pre-payment, maintenance, fuel, general administrative activities, sales promotion activities, passenger service and handling, cockpit and cabin crew, dispatcher, insurance and rental charges, landing and navigation fees.

The fleet planning data used in this research are – available aircraft and specific requirement of fleet planning in terms of destination, type of load to be carried, time of aircraft acquisition.

Once these features were extracted, their probable fuzzy relations were determined. It is necessary to note that fuzzy relation provides an analyzer with a rich framework within which many problems emerging from practical applications of the theory are formulated.

This research also utilized this strength of fuzzy relations. However, the great utility of fuzzy relation equations was somewhat hampered by the rather high computational demand of conventional linear programming optimization models, which is supported by the existing literatures as well (Oliver, 1997).

A sensitivity analysis was also performed for minimization of deviations from desired outputs. The desired response of the network to which each input pattern and its comparison with the actual output of the network were used in the learning algorithm for appropriate adjustments of the weights. These adjustments whose purpose was to minimize the difference between the desired and actual outputs were made incrementally.

That is small adjustments in the weights are made in the desired direction for each training pair. This is essential for facilitating a convergence to a solution (specific values of the weight) in which patterns in the training set are recognized with high fidelity.

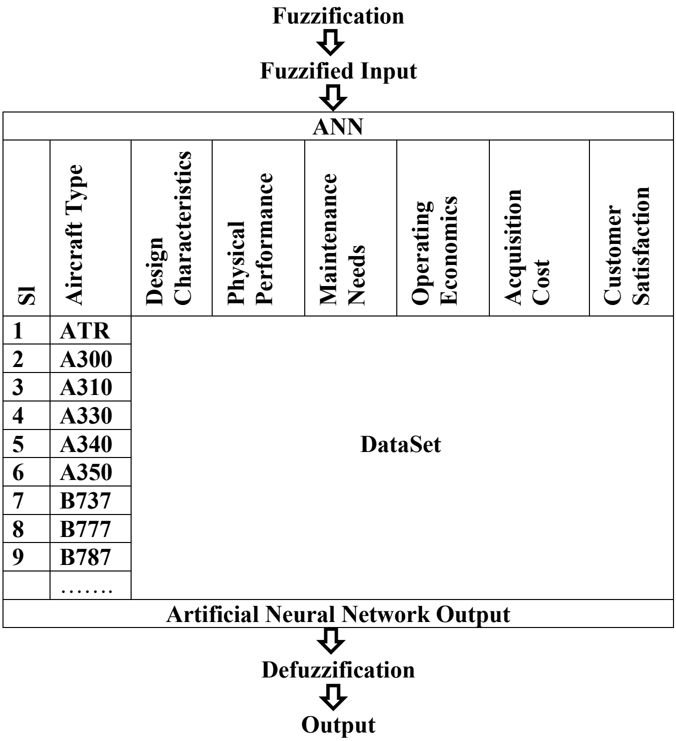

Figure 3: Detailed Model

3 Outline of Methodology

In order to carry out this research work, steps that have been adopted are mentioned below:-

3.1 Fuzzification

Uncertainties regarding all satisfaction data have been handled with the help of fuzzy membership function and finally Customer Satisfaction fuzzy ranking is prepared for different aircraft.

Passenger satisfaction data was collected from the reviews made by the passengers for different flights with different aircraft. In those reviews, they had options to give comment and make ranking on a number of issues like-seat comfort, satisfaction for Catering, satisfaction for entertainment, value for money and staff comfort.

3.2 Neural Network Design

The work flow for the general neural network design process has seven primary steps:

1. Collection of data
2. Creating the network
3. Configuring the network
4. Initializing the weights and biases
5. Training of the network
6. Validating the network (post-training analysis)
7. Using the network

Aircraft specification and data sheets have been collected from individual manufacturer and other sources. Aircraft parameters and cost related data have been collected from different airlines. Customer satisfaction fuzzy ranking is also being used as input of the ANN.

Database has been prepared and updated for all aircraft. Database has also been developed for customer satisfaction, taking into account factors like seat comfort, catering service, entertainment and overall remarks on different past flights.

Route data has been collected from flight history of aircraft. Route data have been collected for five routes- Dhaka-Bangkok, Dhaka-Dubai, Dhaka-Kathmandu, Dhaka-Kolkata and Dhaka-Kuala Lumpur. For selecting aircraft for a particular route, flight histories for five routes have been taken. The routes and the aerial distances are mentioned in Table 1.

Flight history has been taken from all these routes. Airline operating in these routes have different types of aircraft having differences in design data, performance data, seat capacity, cost data, satisfaction data. It is worthy to mention here that there are some common aircraft also being operated by different airlines.

Table 1: Routes used for flight history

Route No.	From	To	Distance KM
1	Dhaka (DAC)	Bangkok (BKK)	1533
2	Dhaka (DAC)	Dubai (DXB)	3555
3	Dhaka (DAC)	Kathmandu (KTM)	676
4	Dhaka (DAC)	Kolkata (CCU)	245
5	Dhaka (DAC)	Kuala Lumpur (KUL)	2579

Feed Forward network of Artificial Neural Network has been implemented for training, validating and finally testing. After establishment of network it was tested by different data sets to check its response.

3.3 Defuzzification

Defuzzification is the process of converting a fuzzified output into a single crisp value with respect to a fuzzy set. A common and useful defuzzification technique is center of gravity. The centroid of this shape, called the fuzzy centroid, is calculated. The x coordinate of the centroid is the defuzzified value.

4 Result

Satisfaction data is full of uncertainties. Application of fuzzy logic with a number of rules could provide a crisp result on ranking. This ranking was used as a special input for Artificial Neural Network.

4.1 Customer Satisfaction Fuzzy Ranking

The remarks given by the passengers were collected for preparing customer satisfaction fuzzy ranking. These remarks were made flight wise for a particular airline. Passengers put their recommendations on seat comfort, satisfaction for Catering, satisfaction for entertainment, value for money and staff comfort in a ranking scale of 10. Airlines wise such remarks were collected and categorized according to aircraft.

Two columns namely value for money and staff comfort have no direct correlation with the type of aircraft the airline used. So for the sake of this research, these two columns were omitted. For Seat comfort, catering and entertainment the linguistic variables are

Very Low	VL
Low	LO
Medium	MI
High	HI
Very High	VH

For final recommendations, following were the linguistic variables

Not recommended	NR
Recommended but needs improvement	RC
Highly Recommended	HR

The mode (with highest frequency) is considered. If the remarks are transferred into linguistic comments, the table becomes as follows.

Table 2: Linguistic expression of Satisfaction

ICAO Code	Seat Comfort	Catering Comfort	Entertai-nment	Satisfaction Fuzzy	Coding
A310	LO	MI	VL	1	NR
A319	MI	MI	VL	1	NR
A320	HI	HI	MI	2	RC
A333	LO	HI	MI	2	RC
A336	LO	HI	MI	2	RC
B735	HI	HI	MI	2	RC
B736	MI	LO	VL	1	NR
B737	HI	HI	MI	2	RC
B738	HI	HI	MI	2	RC
B739	HI	HI	HI	3	HR
B772	HI	HI	MI	2	RC
B77W	VH	VH	VH	3	HR
B762	LO	MI	VL	1	NR
DH8C	MI	MI	VL	1	NR
DH8D	MI	LO	VL	1	NR
E145	HI	MI	MI	2	RC
AT73	LO	HI	VL	1	NR
MD11	HI	MI	VL	1	NR

Fuzzy Inference System has been used in this situation. The system has three inputs (Seating, Catering and Entertainment) and one output (Satisfaction). 8 rules are used to setup the Inference system. The summary of the GUI system is placed here. Triangular membership function were used with the following parameters for the input variables

Table 3: Fuzzy Input Variable

Input Variable	MF	MF Definition	MF Type
Seating	VL	[0.037 0.602 1.24]	trimf
	LO	[0.7882 1.448 2.189]	trimf
	MI	[1.78 2.36 3.221]	trimf
	HI	[2.73 3.34 4.24]	trimf
	VH	[3.76 4.23 5.02]	trimf
Catering	VL	[0.0114 0.575 1.157]	trimf
	LO	[0.853 1.554 2.27]	trimf
	MI	[1.82 2.36 3.142]	trimf
	HI	[2.743 3.353 4.253]	trimf
	VH	[3.81 4.25 5.033]	trimf
Entertainment	VL	[-0.0331 0.5754 1.21]	trimf
	LO	[0.708 1.396 2.25]	trimf
	MI	[1.753 2.277 3.127]	trimf
	HI	[2.7 3.21 4.22]	trimf
	VH	[3.75 4.18 5.033]	trimf

Table 4: Fuzzy Output Variable (Triangular Membership)

Output Variable	MF	MF Definition	MF Type
Satisfaction	NR	[0.0104 0.853 2.03]	trimf
	LO	[1.52 2.44 3.485]	trimf
	MI	[3 3.909 5.01]	trimf

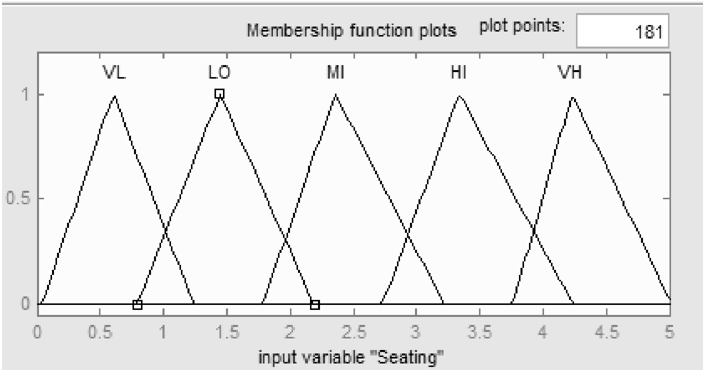

Figure 4: Membership Plot of input variable Seating

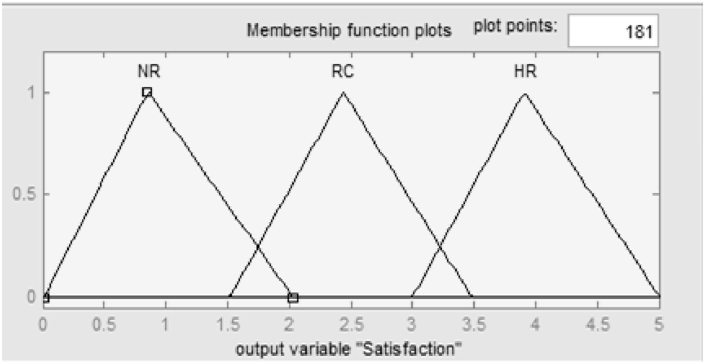

Figure 5: Membership Plot of output variable Satisfaction

The rules used in this FIS are

Rule 1. If (Seating is VL) or (Catering is VL) or (Entertainment is VL) then (Satisfaction is NR)

Rule 2. If (Seating is HI) and (Catering is not VL) and (Entertainment is not VL) then (Satisfaction is RC)

Rule 3. If (Seating is not VL) and (Catering is HI) and (Entertainment is not VL) then (Satisfaction is RC)

Rule 4. If (Seating is not VL) and (Catering is not VL) and (Entertainment is HI) then (Satisfaction is RC)

Rule 5. If (Seating is HI) and (Catering is HI) and (Entertainment is HI) then (Satisfaction is HR)

Rule 6. If (Seating is VH) and (Catering is not VL) and (Entertainment is not VL) then (Satisfaction is HR)

Rule 7. If (Seating is not VL) and (Catering is VH) and (Entertainment is not VL) then (Satisfaction is HR)

Rule 8. If (Seating is not VL) and (Catering is not VL) and (Entertainment is VH) then (Satisfaction is HR)

After fuzzification the output value is now ready to be used for Artificial Neural Network as described in the detailed model in figure 3.

4.2 Artificial Neural Network

The nftool of MATLAB is used for the Artificial Neural Network. nftool leads through solving a data fitting problem, solving it with a two-layer feed-forward network using Levenberg-Marquardt Algorithm and trained with trainlm algorithm.

4.2.1 Neural Network Summary

Input Layer :	26 Neurons
Hidden Layer:	10 Neurons
Output Layer :	1 neuron
Algorithm used:	Levenberg-Marquardt Algorithm

Table 5: Satisfaction Ranking

ICAO Code	Seating	Catering	Ent.	Sat.	Sat. Rank
A310	1.67	2.3	0.3	0.981	3
A319	1.9	3.1	0.45	1.37	6
A320	2.85	3.9	2.88	3.04	17
A333	1.1	2.9	2.8	1.8	9
A336	0.89	3.56	3	1.67	8
B735	3.12	2.9	2.87	2.99	16
B736	2.25	1.45	0.6	0.965	1
B737	2.85	3.4	2.33	2.48	11
B738	2.85	2.87	2.29	2.5	13
B739	2.88	3.4	3.4	2.93	15
B772	3.5	3.83	2.26	2.57	14
B77W	4.1	3.9	3.85	3.39	18
B762	1.2	1.9	0.45	0.969	2
DH8C	2.4	1.9	1.1	1.01	5
DH8D	1.8	1.7	1	0.995	4
E145	2.9	2.8	2.28	2.49	12
AT73	1.4	2.99	0.45	1.37	7
MD11	3.23	1.93	1.1	2.13	10

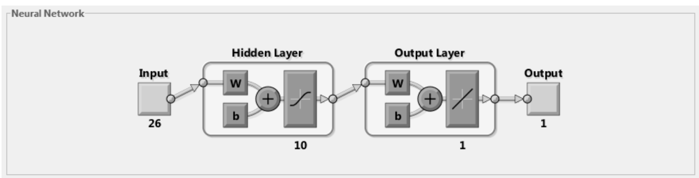

Figure 6: Neural Network Layers

After establishing the network it needs training. For that purpose developed data sets are provided to the network as data_in from a data file. Also the target was provided through another data file called data_out. 70% data (772 Samples) are used for training, 15% (166 Samples) for validation and another 15% (166 Samples) are used for testing purpose.

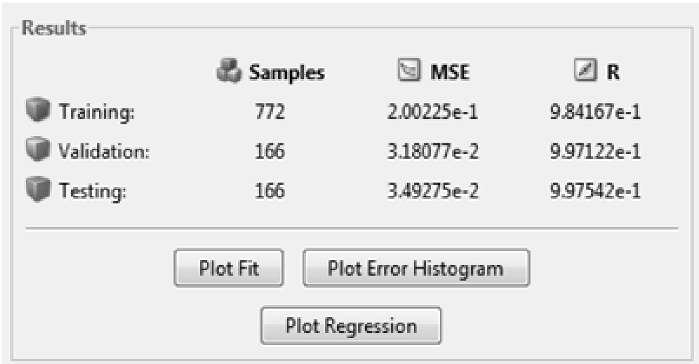

Figure 7: Training, Validation and Testing data samples

4.2.2 Training Summary

The process to train a neural network involves tuning the values of the weights and biases of the network to optimize network performance, as defined by the network performance function. The training of neural network depends on many factors - complexity of the problem, the number of data points in the training set, the number of weights and biases in the network, the error goal and whether the network is being used for function approximation (regression).

In Levenberg-Marquardt Algorithm of feed forward network, trainlm algorithm is used for training. Iteration is one step taken in the gradient descent algorithm towards minimizing the loss function using a mini-batch. An epoch is the full pass of the training algorithm over the entire training set. The training state is presented in Figure 8.

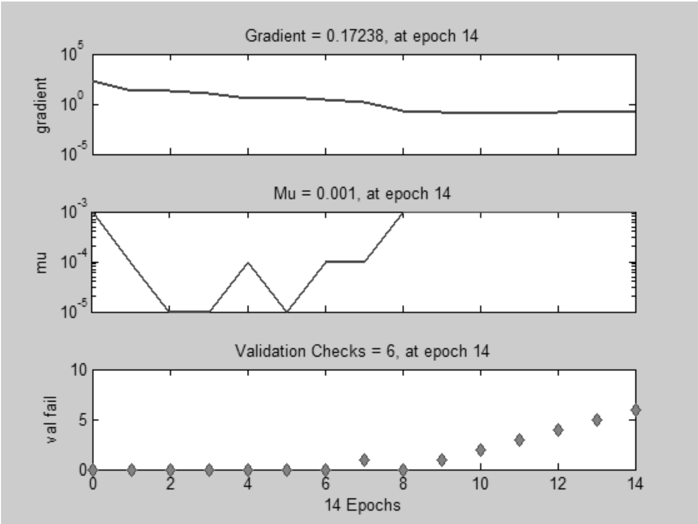

Figure 8: Training State of the network

4.2.3 Result of Regression Analysis

The neural network randomly selects data from the given data set for training, testing and validating. In each set of data the relationship between target and actual output exists which is performed by a correlation analysis to establish a linear relationship.

Regression analysis describes a relationship between target and actual output of the developed network. Regression analysis in Figure 9, presents least-squares fit for four distinct situation of Training, Validation, Testing and All samples.

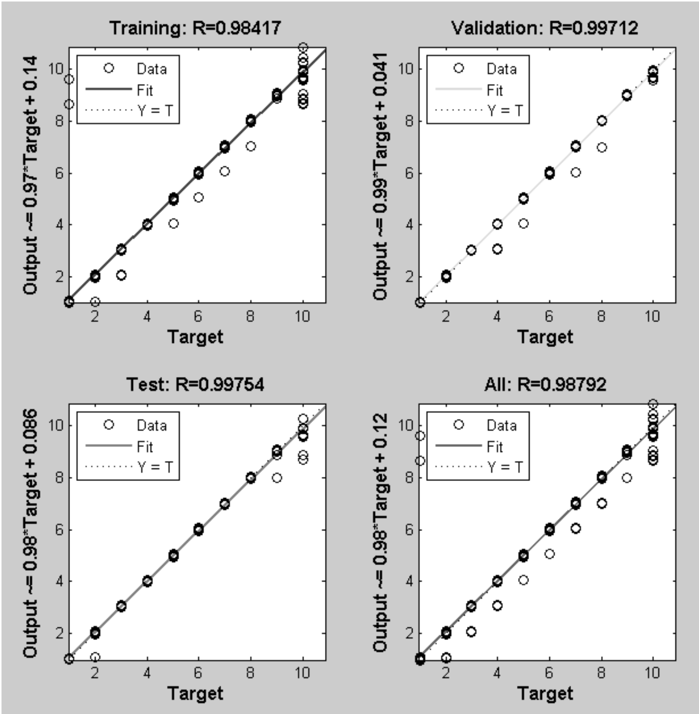

Figure 9: Regression Analysis

4.2.4 Performance of Network

When the training in is complete, the network performance is checked and determined if any changes need to be made to the training process, the network architecture, or the data sets. The performance of the network is shown in Figure 10.

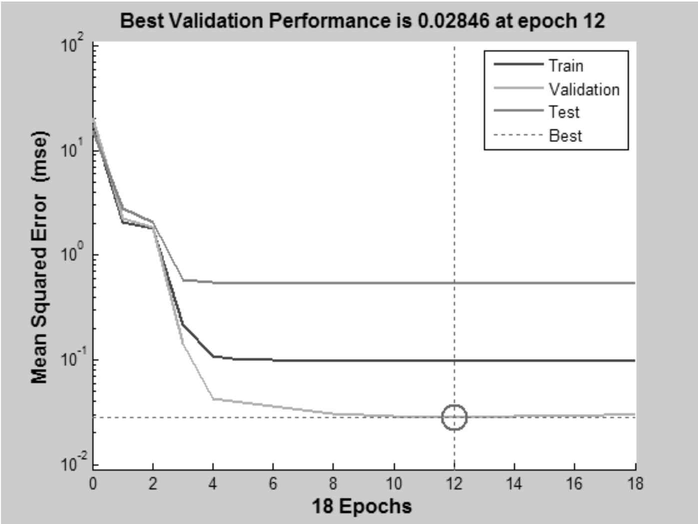

Figure 10: Performance of the network

4.2.5 Simulink

With the help of Simulink, the system is simulated interactively and viewed the results on scopes and graphical displays. The integration of Simulink and MATLAB enables to run unattended batch simulations of Simulink models using MATLAB commands.

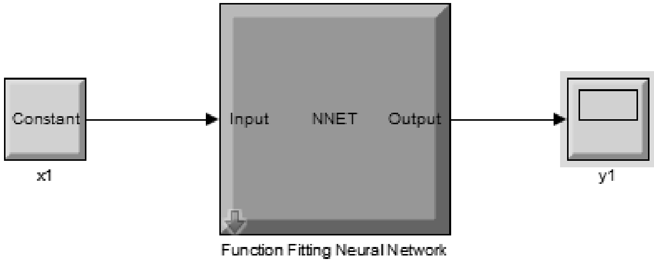

Figure 11: Simulink Diagram

5 Findings

Main objectives of this research were to develop a fleet planning model for selecting aircraft in a particular route where cost is minimized and customer satisfaction is maximum. By using fuzzy logic for customer satisfaction ranking and Artificial Neural Network for the established databases.

The Artificial Neural Network has been established with 26 neurons in the input layer, 10 neurons in the middle hidden layer and 1 output neuron. The network has been trained, validated and tested for being used by the user.

Feed Forward network using Levenberg-Marquardt Algorithm do not show always the same accuracy as the human brain. Generally it is a very good algorithm to reach its global minima when the error learning is concerned. Summary of the

Table 6: List of Sample used

Sample Type	Number of Sample
Total	1104
Training -70%	772
Validation -15%	166
Testing -15%	166

Table 7: Network Accuracy

Epoch	MSE			Regression			
	Train	Valid	Test	Train	Valid	Test	All
13	0.0736	0.0346	0.0422	0.988	0.9635	0.9976	0.985
20	0.0402	0.0278	0.0624	0.984	0.9968	0.9968	0.988
18	0.0976	0.0284	0.0536	0.992	0.9975	0.9543	0.987
14	0.2002	0.0318	0.0342	0.984	0.9971	0.9975	0.987

Mean squared Errors (MSE) and network accuracy (Regression-R) values are as follows:

The network has been tested for known and unknown inputs for recognizing the output.

Sample Input

[5; 202; 2579; 2;56000; 897; 5170; 80142; 142000; 41000; 280; 1204; 5.82; 23591.176; 940.65; 1457.43; 320; 26309.256; 1827.92; 28137.176; 280; 100.4899143; 0.981; 3; 25.7; 10]

From the Simulink output window, the output is 1 and when it is decoded for finding the real value of 1, it is found that the selected aircraft is A310.

Aircraft specification, design characteristics, aircraft performance data, power plant data, customer satisfaction data needs regular updating for correct decision making by the neural network.

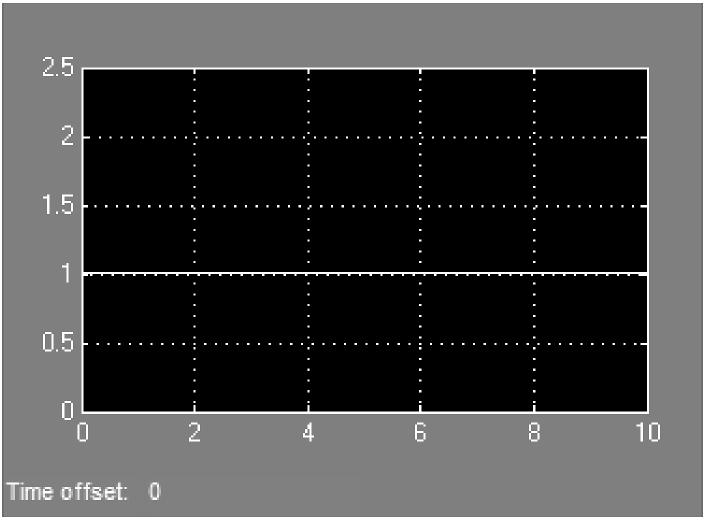

Figure 12: Simulink Output window

6 Conclusion

Airline industry is suffering from lack of integrated fleet planning mechanism, considering multiple input factors, along with uncertainties in different forms and at various stages. This research developed a mathematical model with dual objectives of minimizing operating costs and maximizing customer satisfaction. In this perspective the model developed by the researcher and its implementation through fuzzy logic and artificial neural network has given good results with respect to both objectives. Computer simulation has provided useful sensitivity with respect to varied input data sets. With slight modifications and updating of data on a regular basis, the model can serve the purposes of other regions of the world.

For specific optimization problem, other optimization algorithms may find better solutions than Fuzzy Neural Network combination (given the same amount of computation time). In this particular fleet planning problem, future research potential lies in the area of using other algorithms like evolution strategies, evolutionary programming, simulated annealing, Gaussian adaptation, hill climbing and swarm intelligence and methods based on integer linear programming.

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Part IV

Risk and Security Management

Adequate Flexibility Potential to handle Supply Chain Uncertainties

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Risks and uncertainties (e.g. IT-system failure or demand fluctuation) threaten the performance of supply chains. This paper gives insight into the planning of flexibility potential as a crucial tool for managing the consequences of operational and disruptive uncertainties. A simulation study of lot-sizing decisions in a two-stage decentralised supply chain is used. The modelled supply chain faces operational as well as disruptive uncertainties. It is analysed how capacity and/or stock flexibility on each stage cope with unexpected events. The location of flexibility within the supply chain is key for its ability to handle uncertainties. The paper shows that stock flexibility can substitute capacity flexibility to a certain degree. However, disruptive uncertainties cannot be handled by stock flexibility alone. Therefore, trade-offs in flexibility potential have to be considered. In contrast to other studies, this simulation models operational and disruptive uncertainties in three areas: internal processes, supply side and demand side. Also flexibility management in a decentralised decision making process is analysed. Contrary to the lean thinking approach it is shown that inventory plays an important role in managing uncertainties. Therefore, management should use the right amount of inventory to create flexibility depending on the individual risk situation.

Keywords: Uncertainty; Supply Chain; Flexibility; Simulation Study

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1 Introduction

Globalisation, digitalisation and new technologies change the processes of value creation. As a result, global and complex supply chains can be observed (Meixell and Gargeya, 2005). The scale of these value creating networks makes them vulnerable (Peck, 2005; Peck, 2006). They are not only affected by unexpected events geographically near to the final consumer but also by incidents that occur on the other side of the world (Simangunsong et al., 2012). Examples for such events are the eruption of the volcano Eyjafjallajökull on Iceland in 2010 or an earthquake in Taiwan (Papadakis and Ziemba, 2001). In addition to those low-probability/high-impact risks operational uncertainties jeopardize supply chains (Tang and Tomlin, 2008; Sodhi and Tang, 2012). The focus on efficiency has led to supply chains which are not able to compensate even small disorders like delayed delivery or fluctuation in production rates and consumer demand (Craighead et al., 2007).

The literature on supply chain risks and uncertainties mentions different approaches to handle unexpected situations. Thus, a supply chain should be robust, resilient and agile (Naylor et al., 1999; Christopher and Peck, 2004; Klibi et al., 2010). The importance of each aspect depends on the individual circumstances of a supply chain (Cabral et al., 2012). However, all three concepts need flexibility to be utilised (Zitzmann, 2014; Zitzmann, 2016). It is the key ability to handle risks and uncertainties in supply chains and to use opportunities which emerge from unexpected situations.

Regarding flexibility management and flexibility in supply chains many research questions can be explored (Stevenson and Spring, 2007). The focus of this paper is to look into planning flexibility potential. In particular, we aim to give answers on the following questions: Where in the supply chain is flexibility needed? How can capacity and stock flexibility substitute each other?

This article is structured as follows. First, we provide background information on risk and uncertainties in supply chains as well as on flexibility and its creation. Subsequently, in the methodology section a simulation study is introduced. Section 4 presents the results of the simulation study and discuss its implications. The final section summarises the findings of the paper.

2 Review of Relevant Literature

This paper builds on existing literature regarding risks and uncertainties as well as flexibility in the context of supply chains. First, the terms risk and uncertainty will be distinguished in section 2.1 as they are often used interchangeably. Afterwards, section 2.2 will consider the complex concept of flexibility, especially flexibility in supply chains. How flexibility can be created will be the subject of section 2.3

2.1 Risk and Uncertainties in Supply Chains

Making decisions under uncertainty is part of every management process and therefore in supply chain management as well. Uncertainty can be described as inability to predict something (Milliken, 1987). The term risk is often used interchangeably with uncertainty, but they differ. Figure 1 shows two opinions how the terms can be distinguished. In both cases, uncertainty encompasses more than risk. According to decision theory, risk and uncertainty can be differentiated according to their predictability. If it is possible to quantify a probability of occurrence, it is called risk; if not it is called uncertainty (Knight, 1971). The second approach, which will be followed in this paper, considers the consequences of uncertainty. If they are positive, they are called chances; if they may be negative, then they are risks (Simangunsong et al., 2012).

The literature review of Simangunsong et al. (2012) identifies 14 sources of uncertainties in supply chains which can be classified into three groups: within an institution of a supply chain, within the regarded supply chain, or external to the value creating network. Chopra and Sodhi (2004), Jüttner (2005), Tang and Tomlin (2008), Sodhi and Tang (2012) as well as Tiwari et al. (2015) also identify these sources of uncertainties for supply chains.

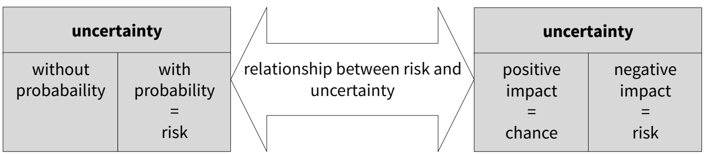

Figure 1: Relationship between risk and uncertainty

The focus of this paper is flexibility in supply chains and its ability to handle uncertainties, and not about reducing uncertainties, as it is done in (supply chain) risk management. Therefore, more important than the sources of uncertainties are their impact on the supply chain. According to their magnitude it can be distinguished between operational and disruptive uncertainties (Chopra and Sodhi, 2004; Tang, 2006; Tang and Tomlin, 2008; Sodhi and Tang, 2012):

Operational uncertainties are inherent fluctuations in the processes of a supply chain, e.g. uncertain customer demand, variations in production rate or delays in transportation. Uncertainties are operational when fluctuations are limited to a certain range around an average value.

Disruptive uncertainties refer to events with major impact on the supply chain. These are natural or man-made disruptions that happen rarely like earthquakes, floods, terrorist attacks or machine breakdowns. Their consequences for the supply chain are massive and cannot be predicted to a certain degree.

Operational as well as disruptive uncertainties can result from the sources mentioned previously and can affect the flow of goods, information and finance within a supply chain. This paper considers the flow of goods and how flexibility can handle the impact of emerging uncertainties. Usually, no organisation exists that manages the whole supply chain. Therefore, decisions about flexibility management are made on the institutional level (Lummus et al., 2003). Taking this viewpoint, supply chain uncertainties have impact on three different areas: the supply side, the process of value creation within the regarded institution itself and the demand side (Chopra and Sodhi, 2004; Tang and Tomlin, 2009). Even a single source of uncertainty can lead to consequences in more than one area, e.g. the breakdown of a machine is an uncertainty located within the manufacturing process. When it happens in the regarded institution, it affects the process of value creation. The supply process is affected when the breakdown occurs at the side of a vendor. Natural disasters which are external uncertainties often affect all three areas of uncertainty impact. An earthquake may not only destroy factories as well as streets and therefore, endanger the supply and manufacturing process, it also affects the demand side.

2.2 Flexibility in Supply Chains

According to Garavelli (2003), "[…] flexibility reflects the ability of a system to properly and rapidly respond to changes, coming from inside as well as outside the system […]“. As supply chains are the considered system in the context of supply chain flexibility, this definition shows that flexibility is a suitable instrument to handle uncertainties which may be internal or external to a supply chain (Tang, 2006). Flexibility is topic in economic and organizational literature as well as in the context of manufacturing (Sethi and Sethi, 1990; Jain et al., 2013). So far, a holistic flexibility theory does not exist (Yu et al., 2015). Sánchez and Pérez (2005), as well as Garavelli (2003), summarize the aspects of flexibility according to six dimensions. These include functional, hierarchical, measurement and strategic aspects as well as the time horizon and the object of change. Different approaches exist on how flexibility may be achieved. The models of Vickery et al. (1999) and Duclos et al. (2003) are the most common concepts (Singer, 2012). Due to a more process orientated view, the latter is more suited when looking at supply chains.

The dimensions of Duclos et al. (2003) as well as the attributes of other approaches (Pujawan, 2004; Kumar et al., 2006; Stevenson and Spring, 2007; Manders et al., 2017), describe features of a flexible supply chain. They also explain what these dimensions are used for, yet no guideline is given how planning flexibility works and how the right scale of flexibility is established. Also, these categorisations and frameworks do not solve some of the major issues in managing flexibility. There is still the problem that no independent measure for flexibility exists (Stevenson and Spring, 2007). Due to multiple dimensions, indicator systems have to be applied to measure flexibility. These indicators cannot be used universally but rather have to be developed for each regarded system individually. Therefore, they are subjective and situational (Gerwin, 1993; Koste et al., 2004). Additionally, it is not possible to determine the benefit of flexibility in advance (Jain et al., 2013). Only in retrospect the contribution of flexible components to the supply chain performance can be evaluated.

flexibility potential	
strategic flexibility = redundant capacity	operational flexibility = redundant stock

Figure 2: Flexibility potential

Planning flexibility on a strategic level means creating potential through additional capacity in the regarded system. Thus, we describe it as capacity flexibility. It may be established by an additional production line, spare transportation vehicles or a multiple instead of a single sourcing concept. Alternative or additional to strategic flexibility capabilities flexibility potential can also be created on the operational level. This operational flexibility is established through stock flexibility (Vickery et al., 1999; Wang, 2008). Thereby, a certain amount of inventory is hold on purpose to react to uncertainties. Safety stocks are an example of flexibility created by inventory. Thus, flexibility potential can be created by capacity or stock potential as shown in Figure 2. What kind of flexibility is more useful in a supply chain to handle uncertainties and where it should be established is considered in the simulation study in section 3 and 4 of this paper.

3 Simulation

As we look at situations where operational as well as disruptive uncertainties may occur at multiple places within a supply chain an analytical analysis is not possible. To investigate if capacity and/or stock flexibility are adequate approaches to handle uncertainties in supply chains we therefore conducted a simulation study. The supply chain considered in the study is introduced in section 3.1, whereas, the modelling of strategic and operational flexibility in the supply chain is explained in section 3.2.

3.1 Two-stage Supply Chain as Object of Analysis

A two-stage supply chain is the object of the simulation. Its structure is based on the supply chain introduced by Banerjee (1986). The author analysed joint lot-sizing in a producer-retailer relationship. This case will be modified to the purpose of the simulation study. Figure 3 summarises the structure of the modelled supply chain. Additional to Banerjee's case a transportation process is added. Hence, the modelled supply chain includes three processes: The first one is the production of goods at the place of the producer that is followed by the transportation process. Thereby, the finished goods are carried from the warehouse of the producer to the warehouse of the retailer. The third modelled process of the supply chain is the customer demand which is satisfied at the place of the retailer. In this supply chain the producer as well as the retailer determine their individual lot size which will then be produced and transported. The planning as well as the execution process is rolling and consists of six periods. In each period with the length of a month decisions about production and order sizes have to be made. In all three processes of the supply chain operational and possibly disruptive uncertainties exist. The study analyses the effect of capacity as well as safety stock to handle such uncertainties.

Operational uncertainties are modelled with the help of probability distributions. In all three processes – production, transport and demand – the production and transport performance or request for goods can differ from the average rates. In production as well as in transport triangular distributions are used. Table 1 presents the basic parameters with operational uncertainties used for the simulation model.

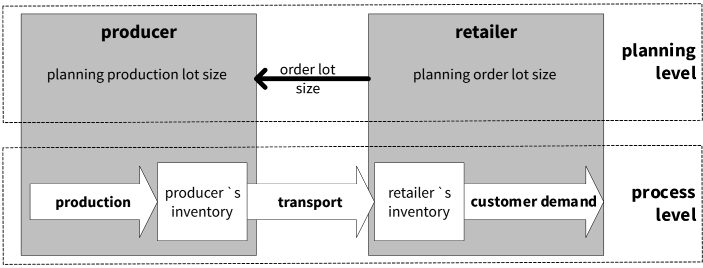

Figure 3: Supply chain of the simulation study

Table 1: Model parameters including operational uncertainties

Parameter	Value (Explanation)
Production time	Triangular distributed, mode 36 minutes/piece, lower bound 32.4 minutes/piece (-10 %), upper bound 54 minutes/piece (+50 %)
Warehouse capacity (producer or retailer)	unlimited
Transportation time	Triangular distributed (-10 %/+50 %): mode 120 hours, lower bound 108 hours, upper bound 180 hours/piece (e.g. 1 month for carrying goods from Asia to Europe by ship)
Demand	Normal distributed: mean 100 pieces/month, S.D. 20 pieces/month, lower bound 0 pieces/month

Additional to operational uncertainties disruptive events are possible in some simulation models. They are also modelled in all three processes. Within production and transport disruptive uncertainties will lead to an interruption of the respective process. The nature of unexpected events is that their occurrence cannot be predicted. Nevertheless, they happen. Table 2 explains possible disruptive events for the different supply chain processes.

Table 2: Model parameters regarding disruptive events

Event	Probability	Impact
Production interruption	0.1 %/hour	Interruption for a uniformly distributed length of at least one day (6 working hours) up to 10 days (60 working hours)
Transportation interruption	0.1 %/hour	Interruption for a uniformly distributed length of at least one day (6 working hours) up to 10 days (60 working hours)
Unexpected demand peak	0.05 %/hour	Uniformly distributed demand from 120 % up to 200 % of the actual demand of the period
Unexpected demand drop	0.05 %/hour	Uniformly distributed demand from 0 % up to 80 % of the actual demand of the period

We assume minimum costs for the retailer at an order size of 80 pieces/shipment. Depending on the disposable inventory in its warehouse and the expected demand in two months the retailer will therefore order nothing or a multiple number of the lot size every month. The order must be placed two months in advance because of the production and transport time. The producer uses the order quantities of the retailer and its own disposable inventory to decide if production is necessary or not. When production is started the production lot size is 200 pieces.

3.2 Modelling Flexibility Potential in the Supply Chain

Flexibility potential can be created at four points in the observed supply chain. In two cases it is capacity flexibility and the others are stock flexibility, which are implemented in the simulation model according to Table 3.

The first point for capacity flexibility is the place of the producer. If uncertainties occur the flexibility potential can be used to compensate them. The transportation process is the second point where capacity flexibility can be integrated in the process. Stock flexibility can be created in both, the producer's and the retailer's warehouse. In this case a certain level of additional inventory is defined. It is used as safety stock to handle unexpected events and uncertainties. The producer as well as the retailer have to consider the defined level of safety stock within their planning process. That is done by reducing the disposable inventory by the amount of additional inventory.

Table 3: Flexibility potential in the simulation model

Event	Probability	Impact
Production	Reduction of production time by 33 % = average production capacity increases to 300 pieces/month (additional production lines and work force)	Safety stock: 20 % of the average demand (= 20 pieces)
Transportation	Reduction of transportation time by 33 % (faster ship or use of an alternative means of transportation)	–
Demand	–	Safety stock: 20 % of the average demand (= 20 pieces)

Producer and retailer can use capacity and stock flexibility. Nevertheless, it is also possible to use just one kind of flexibility potential or none at all. Therefore, 16 alternative combinations of creating flexibility potential are possible in the observed supply chain. For each of them a simulation model was created. Additionally, we distinguish between situations where only operational uncertainties exist and such where operational as well as disruptive uncertainties occur. This differentiation leads to additional simulation models. The models -1- to -16- are regarding operational uncertainties alone, whereas the models -17- to -32- consider operational as well as disruptive uncertainties. Each model will run for 10,000 iterations. Supplementary to the 32 supply chain configurations we model a supply chain with no flexibility potential and no uncertainties. This deterministic model (-0-) is used to verify the correct modelling.

4 Results and Findings

To analyse what kind of flexibility is best to handle uncertainties in the regarded supply chain and at which process it should be created a performance index is needed. As the purpose of a supply chain is to match supply with customer demand we will use hours with out-of-stock situations at the retailer as performance indicator for the whole supply chain. The simulation calculates the performance within six periods which are 720 working hours (6 hours per day). We use this time as basis to calculate the service level. As the focus of the study is on the benefit and location of flexibility, we do not consider the costs of implementing flexibility (Tang and Tomlin, 2008).

Since there are no uncertainties in the deterministic model -0- the demand can always be satisfied (service level = 100 %). Such a situation with no uncertainties is not possible in a real world supply chain.

Section 4.1 presents the performance of the supply chain with uncertainties. The implications of the results are explained in section 4.2.

4.1 Simulation Results

Figure 4 shows the performance of the supply chain with operational uncertainties (flexibility configurations -1- to -16-) The amount of hours with out-of-stock situations given in Figure 4 is the mean of 10,000 iterations.

With a mean of 70 hours of out-of-stock situations, the performance of a supply chain with operational uncertainties and no flexibility at all (-13-) is the lowest. Thus, the service level is 90 %. The highest service level of 97 % can be achieved in the models -7-, -8- as well as -11- and -12-. These configurations have in common that capacity flexibility in the transportation process and stock flexibility at the retailer exists. This is the first indication that the other forms of flexibility are not as important. Especially stock flexibility of 20 % at the producer has low benefit to handle uncertainties in the supply chain. The service level of model -14- which simulates a situation where only this kind of flexibility exists is just 1 % above model -13- with no flexibility at all.

Comparing simulations with and without stock flexibility at the place of the producer but otherwise similar configurations (e.g. -1- with -2-, -3- with -4- or -15 with -16-) confirms the small benefit of stock flexibility at the producer.

Simulation model	Capacity flexibility– producer	Capacity flexibility– transport	Stock flexibility – producer	Stock flexibility – retailer	Out-of-stock situations	Service level
-1-	X				65	91 %
-2-	X		X		63	91 %
-3-	X			X	27	96 %
-4-	X		X	X	26	96 %
-5-		X			45	94 %
-6-		X	X		43	94 %
-7-		X		X	23	97 %
-8-		X	X	X	21	97 %
-9-	X	X			42	94 %
-10-	X	X	X		45	94 %
-11-	X	X		X	21	97 %
-12-	X	X	X	X	23	97 %
-13-					70	90 %
-14-			X		67	91 %
-15-				X	31	96 %
-16-			X	X	30	96 %

Figure 4: Supply chain performance with operational uncertainties (mean out of 10,000 simulation runs)

The same can be said about capacity flexibility of the producer. Comparing the models -2- with -14-, -4- with -16- or -6- with -10- the service levels are identical. These configurations only differ in the regard of capacity flexibility at the producer. In models that have this flexibility the amount of out-of-stock hours is lower. Therefore, it can be noted that capacity flexibility helps to handle uncertainties. However, the benefit is equally small like the one of stock flexibility at the producer. In both cases the reduction of out-of-stock hours does not affect the service level. It only changes compared to a supply chain with no flexibility potential.

The kind of flexibility that increases supply chain performance the most is stock flexibility at the retailer. In this simulation model (-15-) a service level of 96 % can be achieved. That is just 1 % below the highest level of models that consider operational uncertainties alone.

The results of the supply chain with operational as well as disruptive uncertainties simulated in the models -17- till -32- can be seen in table 4.2. Again, with one exception the service level does not change when stock flexibility at the producer exists or not (e.g. comparing -17- with -18; -19- with -20- or -31- with -32-). This statement also applies to the comparison of a situation with no flexibility potential and stock flexibility at the producer alone. Overall, the analyses of situations with operational and disruptive uncertainties together confirm the findings regarding stock flexibility at the producer that were made by analyzing service levels when only operational uncertainties exists. The results of table 4.2 also confirm that the capacity flexibility in transport together with stock flexibility at the retailer lead to the highest service levels (95 % or 94 %). Regarding capacity flexibility at the producer the results of table 4.2 differ from them in table 4.1. The performance of models without this flexibility potential (e.g. -29- till -32-) is nearly as good as in models with capacity flexibility at the producer (-17- till -20-). Therefore, it can again be noted that capacity flexibility at the producer does not play an imported role by handling uncertainties.

Simulation model	Capacity flexibility– producer	Capacity flexibility– transport	Stock flexibility – producer	Stock flexibility – retailer	Out-of-stock situations	Service level
-17-	X				97	87 %
-18-	X		X		94	87 %
-19-	X			X	52	93 %
-20-	X		X	X	51	93 %
-21-		X			74	90 %
-22-		X	X		69	90 %
-23-		X		X	46	94 %
-24-		X	X	X	41	94 %
-25-	X	X			63	91 %
-26-	X	X	X		63	91 %
-27-	X	X		X	40	94 %
-28-	X	X	X	X	39	95 %
-29-					104	86 %
-30-			X		98	86 %
-31-				X	58	92 %
-32-			X	X	57	92 %

Figure 5: Supply chain performance with operational and disruptive uncertainties (mean out of 10,000 simulation runs)

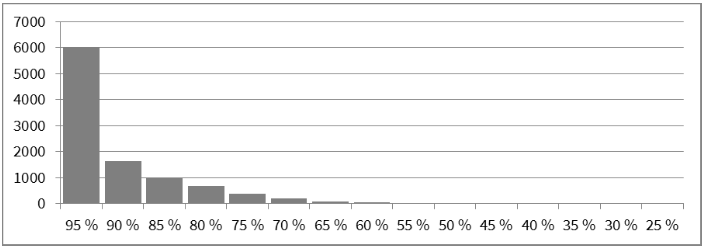

Figure 6: Achieved service level in 10,000 simulation runs in a supply chain with operational uncertainties and no flexibility

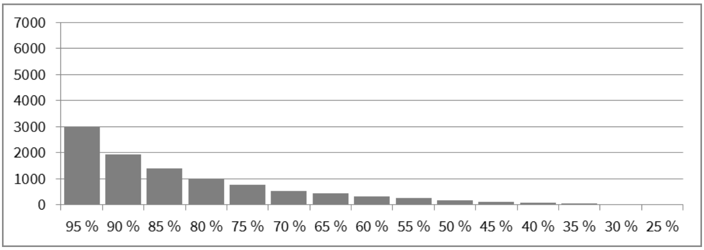

Figure 7: Achieved service level in 10,000 simulation runs in a supply chain with operational and disruptive uncertainties and no flexibility

The simulation models -1- to -16- in Figure 4 consider only operational uncertainties. Therefore, it is expected that the amount of out-of-stock hours is lower than in the simulations models -17- to -32- of Figure 5 which consider operational as well as disruptive uncertainties. This can be confirmed. The service level of models with operational as well as disruptive uncertainties is about two till five percentage points below the one that can be achieved when only operational uncertainties. This is also illustrated by comparing Figure 6 and Figure 7 which show the achieved service levels of the supply chain with no flexibility within 10,000 simulation runs. When only operational uncertainties exist it is possible to achieve a service level of 95 % in 6,035 simulation runs (Figure 6). In one run the lowest service level of 44 % occurs. When operational as well as disruptive uncertainties exist a service level of 95 % can only be achieved in 2,983 runs (Figure 7). The lowest performance is a service level of 11 %. This shows that it is a huge difference if a mean service level of 90 % like in model -13- or of 86 % (model -29-) can be achieved.

4.2 Implications of Results

The simulation study shows how important it is to consider uncertainties in all stages of supply chains. The modelled uncertainties are independent from each other. However, at the final stage of a supply chain all effects of uncertainties may add up and interrupt customer satisfaction. The study shows that flexibility potential at the retailer is most effective. It is able to compensate not only uncertainties in demand but also in processes upstream. If sufficient flexibility potential is available here it can compensate nearly all uncertainties. In the simulation study, the stock flexibility at the retailer is not dimensioned to handle all uncertainties. But operational flexibility potential in the amount of 20 % from the average demand can already reduce out-of-stock hours tremendously. As stock flexibility as operational flexibility potential is the only way to handle short-term uncertainties at the end of a supply chain, it is highly important.

Capacity as well as stock flexibility at previous stages of the supply chain can handle uncertainties as well. But their effect is limited to uncertainties that occur at the place of the flexibility potential or upstream from it. Uncertainties downstream of flexibility potential cannot be handled by this capability. But it is still needed. It protects the final stage from situations where uncertainties of the whole supply chain add up. Such situations could only be managed by huge inventory levels which are undesirable considering cost efficiency and other supply chain objectives. However, medium levels are not able to handle situations where effects of different sources of uncertainties add up.

It can be noted that every kind of flexibility helps in handling uncertainties and will increase supply chain performance (Sánchez and Pérez, 2005). That is confirmed by the study. A small degree of flexibility can increase performance enormous when it is located at the right place. As Garavelli (2003) as well as Graves and Tomlin (2003) already pointed out it is not necessary to build total flexibility into a system. Crucial in handling uncertainties is stock flexibility (Tsay and Lovejoy, 1999). It is available immediately and has its biggest impact when located at the end of a supply chain. The respective models of the simulation study have the highest service levels.

5 Conclusions

This paper presented insights into handling uncertainties in supply chains with the help of flexibility. It regarded the effects of existing uncertainties. To overcome them a supply chain needs flexibility potential which has to be created proactive. As the study shows, the location of flexibility within the supply chain is key for its ability to handle uncertainties. The further down in the supply chain the potential is located the more effective it is in compensating uncertainties that occur somewhere in the value creation process. Nevertheless, flexibility only in the last stage of a supply chain is not sufficient to achieve the best performance regarding the matching of supply and customer demand. As uncertainties cumulate during the processes of value creation they may be too much to be handled at just one point in the supply chain. Therefore, flexibility potential should be established at the end of the supply chain but also at other critical processes.

Our study has a number of limitations. While the results of the simulation fit into existing literature on flexibility in supply chains the findings are limited to the observed two-stage supply chain. Analyses of different supply chain structures could validate and generalise our findings. Furthermore, strategic as well as operational flexibility is modelled by a certain amount of redundant capacity and additional stock. Different levels of flexibility were not considered. How variations in the level of flexibility potential influences the ability of handling uncertainties therefore still have to be studied. As investments in additional capacity are probably more expensive then into stock flexibility cost considerations may be another point of further research.

If management faces the challenge of handling uncertainties it therefore should first of all define levels of safety stock near the end customer. To a certain degree they have to abandon the lean thinking approach. After defining a base level of stock flexibility the supply chain has to be analysed to identify critical processes. At these processes, additional flexibility potential should be created. This can be capacity and/or stock flexibility. These steps have to be integrated not only in the management process of the individual institutions within the supply chain but also in the process of coordination and collaboration between institutions. By integrating considerations about flexibility into cross-institutional supply chain management the full benefit of flexibility potential can only be utilised.

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Remote Sensing in Humanitarian Logistics: An Integrative Approach

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Remote sensing is becoming increasingly important for the acquisition of information in humanitarian logistics. While different platforms (e.g. satellites, drones) with their own characteristics and advantages exist, the literature often refers to just one of them. This paper aims at integrating platforms, making full use of their specific advantages. The work is conceptual, comparing different remote sensing platforms according to their advantages and limitations as well as evaluating the potentials of their combination drawing on both academic and practitioner literature. Moreover, drone test flights (hexacopter) demonstrate the practical implementation of data acquisition, processing, as well as their integration. The results show that the combination of data gathered via different remote sensing platforms is highly beneficial for the management of humanitarian logistics in terms of quality, time, flexibility, and cost. Furthermore, the feasibility has been demonstrated by the drone experiment and the respective data processing and integration. To the best of our knowledge, this is the first work systematically examining the integration of data acquired via different remote sensing platforms considering their specific advantages and the area of application in the context of humanitarian logistics as well as demonstrating the feasibility through the use of an experimental drone flight. The results discussed represent the first step in the use of combined remote sensing data in humanitarian logistics; specific applications should be examined more in detail. Furthermore, challenges in the use of such data have to be overcome, such as their integration into the information management processes of humanitarian actors.

Keywords: Humanitarian Logistics; Humanitarian Operations; Remote Sensing; Drones

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1 Introduction

Natural and human-made disasters have unfortunately become almost commonplace. Even though some of these tragedies might be preventable, the occurrence of others cannot be influenced. Extensive multifaceted responses are coordinated by the international community, represented by numerous of humanitarian organizations or agencies, in order to alleviate the suffering of those affected. In this context, logistics plays a crucial role (Kovács and Spens, 2011). Information is increasingly recognized as a key factor of successful humanitarian operations (Altay & Pal, 2014; Kim et al., 2012), whereas, at the same time, information management is recognized as underresearched (Gupta et al., 2016). Concerning the rapid acquisition of profound data, remote sensing technologies are of rising importance. Different platforms are applicable, such as satellites, aircrafts, and drones, to gather remote sensing data. Previous work consider only one of these remote sensing platforms (Delmonteil and Rancourt, 2017; Tatham et al., 2017). As each platform inheres specific advantages and limitations, this paper aims to combine them. Therefore, the different remote sensing platforms will be examined and compared comprehensively in order to answer the following research questions: Which are the specific advantages and limitations of different remote sensing platforms in the context humanitarian logistics and are there potentials of combining data from these platforms? And how can such an integrative approach be realized practically by utilizing drones? The remainder of this work is organized as follows: After introducing humanitarian logistics and remote sensing in the second section, a systematic overview of the potential humanitarian uses of remote sensing technology is given by not distinguishing between the different platforms. In section three, the different platforms are compared according to their advantages and limitations and the potentials of integration are examined. Following, the experimental drone flight is described concerning the methodology, the technical realization, as well as the results in section four. Finally, the conclusion and an outlook are provided.

1.1 Humanitarian Logistics

Although logistics has always been involved in relief operations, its appearance in practice and academic literature was very limited before the beginning of the 21st century (Kovács and Spens, 2011). This recognition seems overdue since logistics plays a particularly important role in humanitarian operations, as it influences their effectiveness significantly and determines the speed, the coverage, and the costs of humanitarian organizations (Baumgarten, 2011). Although commercial and humanitarian logistics are closely related, there are significant differences which characterize the humanitarian relief work environment and pose specific challenges. Nevertheless, humanitarian logistics definitions resemble those of logistics in general. Thomas and Kopczak (2005) specify humanitarian logistics as 'the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people'. In contrast to commercial logistics, attention here is placed on the reduction of people's suffering. Humanitarian logistics includes a wide range of activities and processes such as preparedness, procurement, transport, warehousing, and training (Schwarz, 2012). In order to visualize relief chain management and humanitarian logistics tasks and to contribute a standardization of terms, definitions, and activities, Blecken (2009) developed a reference task model. He describes the two dimensions of hierarchical and structural decomposition (Figure 1). Within the dimension of the structural decomposition it is distinguished between assessment, procurement, warehousing and transport activities. Assessment is required to identify the affected people or the community needs; procurement tasks ensure the availability of all required material resources. Warehousing tasks are related to the storage and the transshipment of supplies; transportation includes all distribution activities. Finally, vertical and horizontal cross-section functions accompany these tasks. In disaster management, there is often a distinction between different phases. While diverse approaches exist, the cyclic classification into the phases mitigation, preparedness, response, and recovery has become commonplace (OCHA, 2013). The first two phases relate to the pre-disaster and the others to the post-disaster phase. The activities cannot be modeled strictly in sequence, as they might vary, repeat, or overlap according to the disaster scenario.

	Assessment	Procurement	Warehousing	Transport	Reporting
Strategic level	Create mission statement Plan emergency preparedness Plan program strategy	Negotiate framework agr. Plan emergency supply strat. Plan kits Plan standard item catalogue	Plan warehouse capacities Plan warehouse network	Plan transport capacities Plan transport network Plan transport strategy	Donor report Inventory report Damage/loss rep. Needs assess. rep.
Tactical level	Plan demand Plan emergency team Plan project activities Plan standard item list	Plan program item list Plan purchasing methods Plan sourcing methods Plan tender procedures	Plan emergency stock pos. Plan quality assurance Plan warehouse layout	Plan consolidation policy Plan transport goods Plan transport modes Plan transport routes	
Operational level	Assess local capacities Assess local sources of supply Forecast demand Identify number of benefic.	Mobilize supplies (ad-hoc) Qualify suppliers Record order/shipment info. Select supplier	Mark and label goods Monitor stock Pick and pack goods Receive/store goods	Load goods Schedule transport/deliveries Select transport mode/route Track and trace shipment	
Operations support	Implement basic infrastructure; mobilize equipment; mobilize personnel; operate support systems				

Figure 1: Humanitarian logistics framework with task samples (Blecken, 2009)

1.2 Remote Sensing

Remote sensing involves the contactless and areal extensive exploration of the earth´s surface (Heipke, 2017). Chen et al. (2016) define this as ”the science and technology of capturing, processing and analyzing imagery […] of the earth […], from sensors in space, in the air and on the ground”. Further terms are commonly utilized: Photogrammetry, which describes the part of remote sensing focusing mainly on analysis (Toth and Jutzi, 2017), and earth observation, often used interchangeably with remote sensing, but in a more comprehensive way (McInerney and Kempeneers, 2015).

A key component of remote sensing systems are the sensors. They are determined by their spatial, temporal, and spectral resolution. Passive sensors record the visible environment - such as photo cameras - and can represent different spectral bandwidths. Active sensors - mainly LiDAR (Light Detection and Ranging) and Radar (Radio Detection and Ranging) - are less determined by visual contact, as they send electromagnetic waves, which they receive in turn. Hence, they are applicable in cloudy environments or even at night (Toth and Jutzi, 2017). Remote sensing sensors are installed on so called platforms, which can be divided into satellite-based, airborne, and drones. Furthermore, there also exist terrestrial (mobile and static) platforms (Toth and Jutzi, 2017). Satellites are very common in remote sensing. Today, approximately 50 countries operate earth observation satellites, which can differ in their constellation, sensor type, resolution, strip width, their altitude, and their orbit. Airborne platforms have been deployed for quite some time, exclusively in remote sensing. Most common are aircrafts and helicopters. Drones represent a relatively new form of platform. Here, there are a number of terms which can be identified: Often used are also the terms unmanned aircraft systems (UAS), remotely piloted aircraft system (RPAS) and unmanned aerial vehicle (UAV) (Heipke, 2017). The range of drones is very diverse, including micro very light weight (under 1 kg) drones, having only a short range and altitude, up to drones with the size and capabilities of conventional aircraft. Hence, there is no commonly accepted classification as of yet. Griffin (2014) distinguishes four types of drones: Fixed wing, rotary wing, multi-rotary wing, and airships. In summary, a wide range of technological solutions exists which can be applied in humanitarian context.

2 Humanitarian Uses of Remote Sensing

The area of application for remote sensing in humanitarian operations is manifold and will be outlined systematically in this section. As stated above, there exists a variety of different platforms for remote sensing. It should be mentioned that all these platforms are also characterized by multiple uses, as they can be utilized in areas other than remote sensing as well. Satellites, for example, enable the functionality of positioning technologies, such as portable GPS devices or vehicle tracking systems. Further, telecommunication satellites often provide the only reliable form of communication in certain disaster situations (Delmonteil and Rancourt, 2017). Aircrafts and helicopters are mainly used for tasks other than remote sensing, primarily for transportation and evacuation services in disasters scenes. The application of drones is relatively new in humanitarian operations. In addition to their application in remote sensing, they can be used for communication support as well as (small) package delivery (Soesilo and Sandvik, 2016). All these other applications are of course of high importance for humanitarian operations and particularly in humanitarian logistics. However, as this article concentrates on remote sensing, in the following possible humanitarian uses of this specific technology will be examined.

A uniform systematization of remote sensing applications in humanitarian operations does not yet exist. Terms such as assessment, mapping, or monitoring are used inconsistently and often without any definition. For the following description of humanitarian uses, the relevant terminology will be outlined briefly. One of the most common applications of remote sensing can be seen in the field of assessments. Aerial images and the resulting maps are used to evaluate the (potential) extent of disasters and to determine the scope of the required help. Assessments are regularly performed in the context of humanitarian operations. Risk and vulnerability assessments pertain to the pre-disaster phase and aim to detect the exposure to hazards and to determine the vulnerability of people regarding the identified risks (Bündnis Entwicklung Hilft, 2017). Needs assessments are mainly performed after the onset of disasters and have an enormous importance in international relief operations. They should make clear whether an intervention is needed and how to best being performed. Further, needs assessments can be useful for the determination of demand regarding relief commodities. However, the main aim of assessments is to understand the situation and to identify the problems, their sources, as well as their consequences (ICRC and IFRC, 2008). Via data acquired and processed by remote sensing, adjustments can be made to these assessment processes. In the context of this work, the term assessment will be understood as an umbrella term for all activities related to these tasks. In order to specify assessments more in detail, the term mapping will be used if the concerning activities relate to remotely acquired and accordingly processed map material. The detection of changes by comparing data over a period of time will correspond to the term monitoring. Finally, the use of remote sensing material for management and illustration purposes will relate to the term visualization. As remote sensing techniques can be applied across all disaster management phases, a respective differentiation is helpful.

2.1 Assessment

Concerning the published works, assessments are the largest and also most diverse area of application for remote sensing in humanitarian operations. In their simplest form, remotely acquired images or videos can be used to get an overview of disaster scenes and to estimate the extent of a disaster (Tatham et al., 2017). Immediately after the onset of a disaster, remote sensing can be applied particularly in search and rescue activities. Special sensors are often required for these operations. However, for deeper analysis, further processing steps are necessary, such as creating maps or time series material.

2.1.1 Mapping

Cartographic representation and the related processing of this material can be utilized in manifold ways across the different phases of disaster management. In the pre-disaster phase, the main objective is to detect hazards, determine risks, and finally to develop disaster response plans. Hence, remote sensing supports both the mitigation and preparedness phase. Flood management can be supported by remotely acquired map material in order to detect potential breaches in dike systems or to identify flooding areas (Sharma et al., 2017). Sambah and Miura (2014) propose a tsunami vulnerability assessment by utilizing satellite images and processed digital elevation models (DEM). Further, for forest fire susceptibility and risk mapping, remote sensing has been proposed (Pradhan et al., 2007).

In post-disaster scenarios, remote sensing is mostly applied in the response phase immediately after the disaster's onset. Rapid post-disaster assessments are applicable in the management of the aftermaths of various disaster types, such as earthquakes, floods, storms, and fire as well as in the case of man-made disasters

(Griffin, 2014). Automated building damage assessments using remotely acquired data are proposed by different authors, e.g. Dinesh el al. (2013) for a tsunami case or Kakooei and Baleghi (2017) for earthquake and hurricane cases. Concerning logistics activities, the assessment of infrastructure can be beneficial, e.g. for route planning. Wang, J. et al. (2015) propose a road damage assessment by using high resolution remote sensing images. Also the identification of best locations for facilities can be supported by mapping activities. A further application is the estimation of displaced populations (Wang, S. et al., 2015). In the recovery phase, post-disaster restoration and reconstruction assessments are suggested (Adams and Friedland, 2011).

2.1.2 Monitoring

While the above mentioned mapping applications of remote sensing relate to the situation analysis at one specific time, monitoring activities are performed continuously over a longer period, comparing different stages. In the pre-disaster phase, a typical application can be found in food security management, monitoring agriculture assets and warning in the case of critical developments (Enenkel et al., 2015). Generally, warning is a highly beneficial field of application for remote sensing (Strunz et al., 2017); it might be particularly suitable for some specific disaster types with a certain lead time or specific indicators, such as tsunamis, hurricanes, or floods. In the post-disaster phase, dynamic disaster events are critical for monitoring activities. Multitemporal satellite images can be used for the watershed and flood monitoring (Rau et al., 2007). In relation to a longer time horizon, Guo et al. (2010) propose a method for monitoring the damage reduction and reconstruction after the Wenchuan earthquake via satellite imagery.

2.2 Visualization

In contrast to the above stated areas of applications, remote sensing material can also be used in order to support general management processes. On this occasion, the visual presentation of cartographic material is used for the development of emergency plans or for communication aspects (Voigt et al., 2007). Providing near time information after the onset of a disaster supports the collaboration efforts of the different humanitarian organizations (Strunz et al., 2017). These activities can be performed in both pre-disaster and post-disaster phase.

3 Comparison of Platforms

Following the systematic description of the manifold uses of remote sensing in humanitarian operations and logistics, this section aims to compare the different platforms and describe advantages and disadvantages in order to subsequently discuss the potentials of their integration.

3.1 Advantages and Limitations

The comparison of the different remote sensing platforms is to be executed keeping various aspects in mind. A complete list of these criteria can be found in Table 1. Even though the spatial resolution of satellite images has increased in recent years, their maximum is with 30 cm (for some specific satellite sensors) still lower than those of airborne and drone platforms, whose resolution can be up to 1 cm; also the spatial accuracy of geo-positions in the acquired data is higher for the latter (Toth and Jutzi, 2017). Furthermore, airborne and drone platforms provide the opportunity to acquire oblique images for more specific processing and analysis methods. Moreover, drones can be applied for ad hoc, quick response assessments with live broadcasts in a 360° angle and their susceptibility to cloudy weather situations is lower (Kakooei and Baleghi, 2017; Toth and Jutzi, 2017). The higher spatial resolution and accuracy of airborne and drone platforms result from the fact that their flying altitude is significantly lower, particularly those of small drones. As one would expect, the observed space and the resulting surface coverage is substantially lower as well (Toth and Jutzi, 2017). Here, satellites make use of their inherent advantages. Contrarily, satellites are restricted by their predefined orbit and speed, which consequently limits their repetition rate and their preparation time compared to other platforms. The periodic flight path of satellites might be a disadvantage regarding their flexibility; however, it enables the availability of pre-disaster images, which is beneficial for comparison reasons and necessary for specific map analysis methods. Advantages of drones arise from their high flexibility; they are rapidly deployable and their application can be adjusted to the operations' requirements easily (Kakooei and Baleghi, 2017). Boccardo et al. (2015) note that drones are only rapidly deployed if they are already on site. Otherwise, the transportation to the disaster scene can restrict their short preparation time. Furthermore, the complexity of use as well as the operational risk is lower for drones than for the other platforms, whereas skilled personnel is generally required for remote sensing applications. However, whereas the deployment of satellite technology and airborne platforms has been established in the humanitarian context, the use of drones implies several legal and ethical issues. Most countries do not have any legal framework for the use of drones and also questions regarding privacy issues have not yet been answered. Moreover, the utilization of drones particularly in conflict-based disasters is seen as problematic (Tatham et al., 2017). Finally, the costs of the different remote sensing platforms vary significantly. Regarding the cost aspect, drones are the most favorable platform (Toth and Jutzi, 2017). Considering all these advantages and limitations, the potential of integrating several platforms is discussed briefly.

Table 1: Platform comparison (Kakooei and Baleghi, 2017; Toth and Jutzi, 2017)

	Satellite	Airborne	Drone
Spatial resolution	0.3-300 m	0.5-0.25 m	0.01-0.05 m
Spatial accuracy	1-3 m	0.05-0.1 m	0.01-0.25 m
Angle of view	Vertical	Vertical/oblique	360°
Weather susceptibility	High	Medium	Medium
Space of observation	Global	Regional	Local
Surface coverage	High (>10 km)	Medium (1 km)	Low (0.1 km)
Repetition rate	Day(s)	Hours	Minutes
Preparation time	1-2 days	Several hours	Within an hour
Pre-disaster image	Available	Probable	No
Maneuverability	No/limited	Medium	High
Usability	Difficult	Complex	Easy
Operational risk	Medium	High	Low
Operat. conditions	Established	Well established	Immature
Costs	High	Medium	Low

3.2 Potentials of Integration

Concerning the differences between the platforms for remote sensing, it has been shown that the disadvantages of the one platform are often the advantages of the other one. Hence, it seems plausible to consider the integration or combination of remote sensing data acquired via different platforms. In academic literature, a systematic discussion about such an integration for the humanitarian context does not yet exist. To the best of our knowledge, only Kakooei and Baleghi (2017) demonstrated the integration for the specific application of building damage assessments. However, the opportunities of an integrated approach are greater.

The benefits of integration can be systemized according to quality, time, flexibility, and cost aspects. In terms of quality the application of drones might be more reasonable due to their higher resolution. However, according to the performed task, it might be more important to get an overview of a specific region. For example, the condition of the road network and the related infrastructure could be assessed via drone, whereas the rest of the environment is gathered via satellite. In addition, oblique images from airborne and drone platforms can result in enhanced damage scale estimations but in turn they are limited in its spatial extension. On this occasion, the time aspect is critical as well. Considering the above stated uses of remote sensing in humanitarian operations, satellites could be mainly deployed for monitoring and to generate baseline material in the pre-disaster phase which can be used for comparison. The post-disaster data might be gathered via airborne or drone platforms as they inhere a higher repetition rate and a lower preparation time. On the one hand, this might be applicable for the assessment of critical logistical infrastructure, such as airports, ports, or warehouses. On the other hand, enhanced assessments can be useful for rapid demand determination. This flexibility is also a benefit of an integrated consideration of multiple platforms. Drones and airborne platforms are rapidly deployable after the disaster's onset and easier in use than satellites. They can therefore support the immediate response phase whereas the latter one are favorable in the longer term. Finally, cost aspects can be considered as well. Using the most reasonable platform for each task, can reduce the cost of remote sensing activities significantly.

4 Experimental Remote Sensing by Drone

In order to demonstrate the practical application of the integration of remote sensing data, experimental drone flights have been performed and the acquired data processed. The aim is to shown how the data acquired by drone can be processed. Therefore, a 3D model will be computed in order to generate orthoimages as well as elevation models, which in turn can be integrated into a Geographic Information System (GIS). These systems are capable of combining data from different remote sensing platforms. The technical realization of these tasks includes the three main working steps of data acquisition, processing, as well as their integration and will be demonstrated more in detail in the following. Finally, results are presented and compared and a judgment in terms of the applicability of the proposed integration will be given.

4.1 Technical Realization

The technical realization includes the following three main steps: First of all, the data has to be acquired, followed by the steps of data processing and the integration into a GIS.

4.1.1 Data Acquisition

For data acquisition, a commercially available hexacoper (Airborne Robotics XR6, diameter : 950 mm, max. payload: 1.2 kg, max. speed: 15 m/s, max. flight time: 15 min) was used. The Sony NEX-7 Alpha camera was utilized with a fixed focal-length of 19 mm, providing pictures with a resolution of 24 megapixels. With its 25-area contrast autofocus and the quick shutter lag, this camera is particularly suitable for remote sensing. For flight planning, the software MissionPlanner (1.3.49) was applied. By compiling waypoints, this plan can be transmitted to the flight-control device of the drone, specifying its precise flight route. For the experimental flights, a test area was chosen, which meets specific requirements. At a minimum, this area should include one street with one intersection, as well as accompanying infrastructure (e.g. power cables) and vegetation within a small range of about two hectares (this limitation is set by the technical range of the drone). Optimally, the area further includes different forms of vegetation and different types of streets as well as buildings. Such an area, meeting almost all

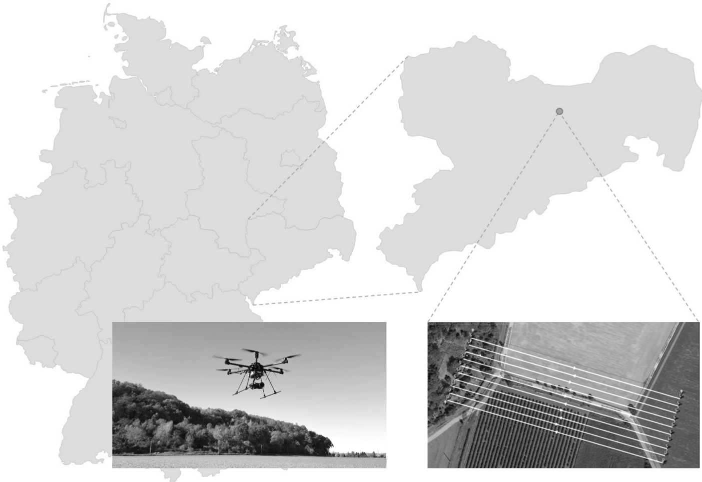

Figure 2: Test flight area and drone (own figure)

these requirements, was found in the district of Meißen (Germany) north of the municipality of Sörnewitz. Figure 2 illustrates the location of the flight area and the flight plan as well as the used drone. The drone flights were performed on a sunny day in October 2017. Two flights at different altitudes were conducted: The first flight at an altitude of 40 m (total flight duration: 12:00 min) and the second flight at an altitude of 80 m (total flight duration: 7:10 min).

4.1.2 Processing

A first evaluation of the acquired data already took place on site in order to decide whether enough images were produced and if their quality was sufficient. During the flights an adequate number images for the given tasks were taken; only a small number had to be removed due to fuzziness. First of all, the taken pictures had to be geo-referenced, which was done by utilizing the GPS data of the drone. Therefore, a camera position tool was used. This step can be omitted if the camera

Figure 3: Thick point cloud generated by Agisoft Photoscan (screenshot)

already contains a GPS function (which was not the case for the utilized camera). For the 3D model generation, the software Agisoft PhotoScan (1.3.4) was applied. Agisoft is able to use the taken 2D images in order to generate a geo-referenced point cloud (Figure 3). This step is essential for generating orthoimages and DEMs, which in turn are needed to embed the data into a GIS. Orthoimages are straight, distortion-free and scaled illustrations of the earth's surface, whereas DEMs contain the respective elevation information. For their generation, the 2D images have to be aligned to create a thin point cloud in a first step, followed by the creation of the thick point cloud and the polygon mesh.

4.1.3 Integration

For the final step, the integration into a GIS, the software QGIS (2.18.13) was used. It is one of the most common open source GISs and enables the recording, manipulation, management, and presentation of spatial data. The system's capabilities go far beyond the demonstrated aspects here. However, in our case the GIS was used for the integration of the previously generated orthoimage, the refining of the respective geo-references, and the representation of the DEM. A GIS enables the combination of different remote sensing data, such as satellite or airborne

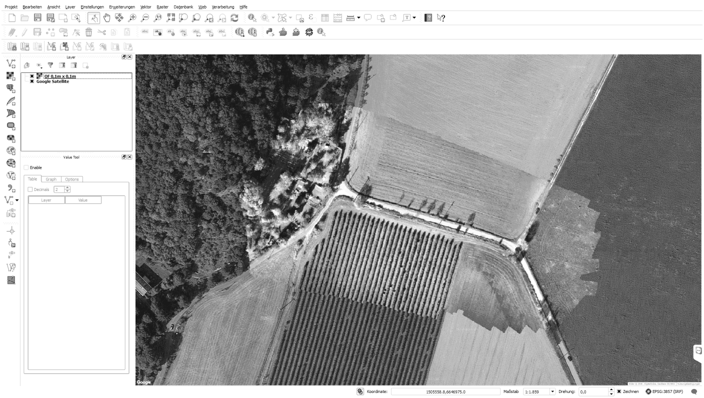

Figure 4: QGIS with Google layer and orthoimage, 0.1 x 0.1m (screenshot)

images, as well as geographical maps. In this case, a referenced, freely available Google Maps layer (airborne images) and the orthoimage were imported. The result of the integration within QGIS with our own layer in the foreground can be seen in Figure 4. As the geo-references of the drone's positioning system are not sufficient in all cases, a refining can be performed. Therefore, the two layers can be aligned according to distinctive points.

4.2 Results

As a result of the two drone test flights and the subsequent processing of the acquired remote sensing data, orthoimages and DEMs with a resolution of up 1 cm2/Px could be generated. The quality of geo-referencing can also be stated as high-grade, as their deviation is less than 20 cm (absolute) and the total computing time was between 107 and 165 min. All data could be processed by the GIS without any difficulties and obvious errors. The high level of detail is shown in Figure 5 which presents the resulting orthoimage. The resolution of the overview orthoimage corresponds approximately with the quality of the airborne image of the freely available Google Maps layer. The enlarged image details make clear one of the main advantages of drones compared to other remote sensing platforms. It is demonstrated that even cracks in the asphalt or mud holes as well as power cables can be detected.

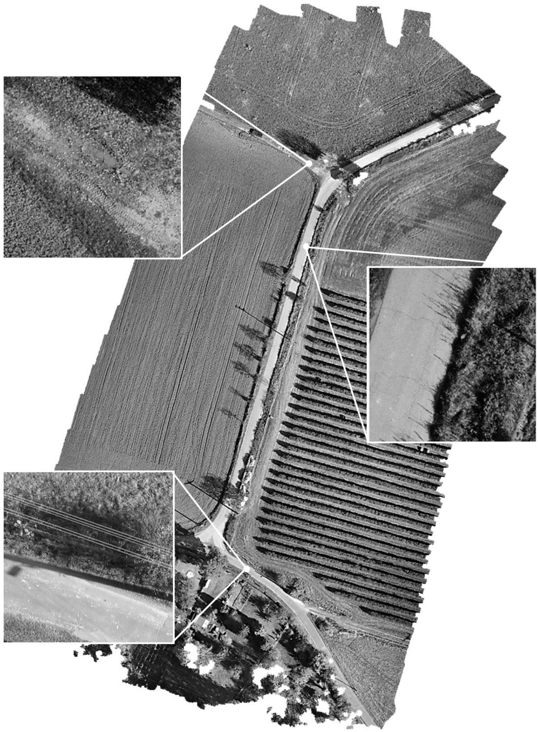

Figure 5: Orthoimage (40 m, 1 cm^2/Px) (own figure)

5 Conclusion

Remote sensing platforms inhere their specific advantages and limitations as shown in section 3. Hence, it can be assumed that an integrated approach in terms of combining data from different platforms will be beneficial for remote sensing activities in humanitarian context. The practical applicability of such an integration has been demonstrated in section 4. In the following, possible application of an integrated view in humanitarian logistics will be discussed. Moreover, a summary and an outlook for further research will be given.

5.1 Discussion

The above stated integrated approach in remote sensing can be supportive for different humanitarian logistics tasks. First of all, procurement and distribution processes are highly affected by sound information beneficiaries' needs. Knowing which and where these needs exist is crucial for logistical activities. Here, improved procedures comparing pre-disaster (generated by satellite) and post-disaster data (airborne or drone) could be applied for damage and needs assessments. Furthermore, the utilization of remote sensing for mapping task should be highlighted. In humanitarian operations, the integrated view could be beneficial in the distribution context. Infrastructure assessments are of high importance and they should be balanced regarding high surface coverage and high level of detail. Hence, satellite data could be used for general overview assessments, extended by drone data for detailed infrastructure assessment. According to different types of disasters, the possible applications are manifold, for example concerning the accessibility of certain areas by roads blocked by landslides, water or fire. The strength of satellite images in getting an overview and drones in providing detailed data can be mutual supportive. Further application areas can be found in warehousing concerning the facility location. Similar aspects as mentioned above can be beneficial. The initial assessment of best locations for transit points or warehouses could be done by satellite, whereas the detailed analysis will be supported by drone images. Finally, the visualization aspect can be mentioned. Decision makers in humanitarian logistics need to be provided with detailed information from the site. As drones are not capable to provide images from all areas, particularly in disasters with a high coverage, the supplement with according satellite images is appropriate. This approach should not be limited solely to the different remote sensing platforms, but should also consider data from different humanitarian actors.

5.2 Summary and Outlook

This work shows that the combination of different remote sensing platforms is highly beneficial in the context of humanitarian operations and logistics. Therefore, the possible areas for application have been categorized and outlined regarding certain assessment tasks, including mapping and monitoring activities as well as visualization tasks. Following, the advantages and limitations of the platforms were highlighted. It was shown that the platforms are mutually supportive. Hence, an integration of remote sensing data from different sources can be highly beneficial as support for humanitarian logistics activities such as procurement, distribution and warehousing in terms of quality, time, flexibility, and cost. In the last section, the practical implementation of such an integrative approach was demonstrated. Therefore, drone test flights were conducted and the gathered material processed and integrated.

The area of application for remote sensing in humanitarian operations and particularly for logistics activities is manifold. Further research is necessary to systematically identify the potentials of remote sensing, regardless of their platform, and according to the disaster management phases, on the one hand, and the different disaster types, on the other. Moreover, the requirements regarding these areas of applications have to be identified. This relates mainly to the necessary resolution and the time horizon concerning the gathered data. Finally, the integration into the information management processes of humanitarian organizations and the sharing of information amongst the various actors should be evaluated. Investigating these questions could lead to more efficient and expedient humanitarian operations, not just in terms of logistical aspects.

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Impact of Managerial Risk-taking and IRM on Innovation

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Innovation in any business comes with risk. This study aimed to explore the role of managerial risk-taking and integrated risk management (IRM) on innovation. To verify the hypotheses, a questionnaire was designed. Data were collected from 109 Insurance Managers from Iran Insurance Companies. PLS structural equation modeling was employed to test both measurement and structural model. The results demonstrate that integrated risk management and managers' risk-taking have a positive impact on innovation. This is the first study to explicitly and separately consider the effects of managerial risk-taking and integrated risk management (IRM) on innovation in the Insurance sector. Due to the lack of scales to analyze IRM, questionnaires which adopted from previous studies may not be the best scales to measure variables. This study focuses on Iran insurance industry, which limits its generalizability. Our findings highlight the need for managers in high risk-taking behavior to encourage employees to be more creative and develop organizational innovation. The authors discovered that firms should perform an effective IRM system that oversees many systematic risks through organization innovation process.

Keywords: Innovation; Managerial risk-taking; IRM; PLS-SEM

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1 Introduction

Innovation is a popular concept that has attracted the interest of both academic and business communities (Santos et al., 2014). In addition, Innovation is critically important and necessary for firms to respond to rapid changes (Kwak, Seo, and Mason, 2018), and dynamic competitive business environment in order to grow and survive (Tushman and O'Reilly III, 1996; Dess and Picken, 2000; Bowers and Khorakian, 2014; Wu and Wu, 2014; Kim, Choi and Skilton, 2015). Innovation is a high-risk process and is prone to uncertainty in business.

On the other hand, risk management is emerging as an essential contributor to most fields of decision making and firm's control in any business at the complexity and uncertainty business environment (Giannakis, Croom, and Slack, 2004; Ritchie and Brindley, 2007; Eckles, Hoyt, and Miller, 2014). This complexity shows that risks arise from various sources. Scholars believe that the extensive use of explicit risk managing might reduce expenditure on innovation failure and if it is well implemented, firms will reach their innovative plans more accelerator (Bowers and Khorakian, 2014; Stosic et al., 2017). Clearly, appropriate risk management would encourage innovation in the organization.

March (1996), argues that risk-taking is necessary for innovation. Confirming March's argument, previous research has shown that there exists a close relationship between risk-taking and innovation. Researchers believe that managers play the role of strategic decision-makers, capable of identifying opportunities and making the right decisions about innovation within the organization (García-Granero et al., 2015). In fact, managerial risk-taking requires significant investment that hopes to bring out success or profit, with a high possibility of failure or heavy debt(Latham and Braun, 2008).

Additionally, not only managers and CEO's risk-taking stimulate innovation, but also firms need to manage all sorts of risks surrounded an innovation project from planning to implementation (Wu and Wu, 2014). Integrating all risks through the different phases of innovation can (Wu and Wu 2014) help managers make the critical decision to abandon poor innovation plan (Bowers and Khorakian,2014). This integrated approach provides for real risk management that is coordinated among all parties involved in the control of innovation's risk. It also provides management with the capacity to monitor risk mitigation performance. Besides, the potency of the risk management within an integrated approach is determined by its clear classification of any levels of business (Bilgin and Danis, 2016).

The integrated risk-taking management encompasses operational risks. According to Meulbroek(2002a), operational risks, generated from individuals, processes, and physical properties, can exert influence on innovation performance. Thus, such risks need to be carefully managed.

Although the effect of risk-taking on innovation has been well documented in various studies, research has failed to examine the impact of integrated risk-taking management on innovation. Moreover, the effect of these two types of approach on innovation has remained underexplored.

Accordingly, since innovation in the insurance industry has received little attention, the chief aim of this article is to fill the gap and to examine the effect of managerial risk-taking and IRM on innovation. The study, therefore, attempts to provide answers to the following research questions:

1. What is the effect of managers' risk-taking on insurance companies' innovation?

2. What is the effect of integrated risk-taking management on insurance companies' innovation?

The article is structured as follows. First, reviewed the literature . Next, a hypothetical model will be presented. The SEM model will be tested using data from 109 insurance managers working in Iran Insurance Companies. The article concludes with discussion, conclusion, managerial implications, and limitations of the study.

2 Literature Review

This chapter, briefly explain innovation within the context of the organization. Then it provides an introduction to the relationship between managers' risk-taking and integrated risk management which aim at promoting organizational innovation.

2.1 Innovation

Within the service industry, the primary way to gain a competitive advantage is innovation. Birkinshaw et al.,(2011) showed that product/service innovations are just the tip of the innovation iceberg (Medrano and Olarte-Pascual, 2016).Scholars have thoroughly mentioned that the quest for innovation can be an important strategy which organizations with hyper-competitive characteristics use to remain competitive in a progressively dynamic, speedily changing and complicated market (Liu et al., 2017). In the innovation literature, various types of innovation have been considered. It can be product, process, administrative, technological, marketing, radical or incremental, (García-Granero et al., 2015; Liu et al., 2017). Service or product innovation is the first-time commercial usage of a product or service, which is new to the marketplace, whereas process innovation is the execution of methods that are new to the company, but not necessarily new on the market (Jeschke et al., 2017). Hence, this process requires clearness of thought and the capability to get things done. Evan(1966), pointed out that administrative innovation can be a concept for new policy, the allocation of resources, the structuring of responsibilities, of authority, of rewards (Pauget and Dammak, 2018). Administrative innovation increases productivity by guaranteeing efficiency in internal processes and individuals and business. Specifically, administrative innovation refers to changes in the characteristics of organizational or institutional elements. Then, adoption of any types of innovation is determined by an attitude towards the organization innovation partially.

2.2 Managing Risk-taking

Risk-taking is considered as one of the most important activities of managers to encourage innovation throughout the organization. Risk-Taking behavior is an individual's behavior in risky conditions, which is characterized by using the degree of risks involved in decision-making (Nkundabanyanga et al., 2015).

Research has shown that managers' inclination toward risk-taking has considerable influence on a company's capacity for innovation. As noted earlier, managerial risk-taking "involves investing significant resources in activities with a high possibility of failure, which includes incurring heavy debt or making large resource commitments in the hope of reaping potentially high benefits" (García-Granero et al., 2015). Hence, if expected values of taking risks for two strategies are comparable, but one is a considerable uncertain, managers will choose the one with a more specific result.

2.3 Integrated Risk Management (IRM)

Typically, RM has been about each administrator dealing with specific risks which might affect some firms' goals. In a very meanwhile, regarding risk literature, RM methods are changing from controlling risk independently and departments and in a Silo-based approach to an integrated risk approach (Tommerberg, 2010; Meulbroek, 2001, 2002b). An IRM allows firms to control a wide array of risks holistically (Togok, Isa, and Zainuddin, 2016) and consists of many different facets of an organization's activities (Wu and Wu, 2014). Such an integrated risk model combines all sorts of risks with an integrative focus (Andersen, 2008) and helps managers to identify, control, evaluate, and monitor all risks on the specific categories to make a great decision. Thus, IRM offers a steady picture of risk within the entire organization.

Accordingly, since the integrated approach to managerial risk-taking includes differing facets of the organization, companies adopting this approach, are capable of dealing with the skills and expertise necessary to face potential risks.

Although integrated risk management differs from Enterprise risk management (ERM), the other concept of holistic risk procedure, both add a wide variety of strategic, functional, and financial decisions for handling risk (Oxelheim, Wihlborg and Thorsheim, 2011; (Meulbroek, 2002b). Table 1 provides some recent definitions of IRM. Some scholars maintained that the success of IRM is greatly dependent on how proficiently it is applied in an organization(Nocco and Stulz, 2006). Meulbroek, (2002a, 2002b), observed that there are three ways of employing risk management aims: modifying the firm's procedure, altering its capital structure and utilizing targeted financial instruments. IRM identifies a theory that managers must weigh the advantages and disadvantages of the various approaches, and they must also consider the aggregation of all risks encountered by the business for choosing the perfect solutions (Tommerberg, 2010). To put it simply, IRM implementation elements depict the critical path that a comprehensive risk containment program should take to ensure proactive well as reactive measures to lessen systematic risk exposures.

Comprehensive risk containment program should take to ensure proactive well as reactive measures to lessen systematic risk exposures.

Table 1: IRM definitions and descriptions

Scholars	Definitions
Meulbroek (2002a); Bromiley et al., (2015)	IRM is the identification and evaluation of the common risks that affect the significant value and enforcing a company-wide approach to managing those risks.
Miller and Waller, (2003)	IRM is the consideration of a full variety of uncertain contingencies that affect enterprise overall performance.
(Andersen, 2008)	Activities into one unified framework and enables identification of such interdependencies as a consequence.
(Wu and Wu, 2014)	IRM entails identity of unique activities or situations applicable to product innovation's risks and possibilities typically, assessing and measuring them, integrating the risks, and formulating plans to restrict them. The process additionally consists of executing those plans and tracking development.

3 Developing Hypotheses

According to the above-stated discussion, a hypothetical model is presented in Figure 1 illustrates the effect of managers' inclination towards risk-taking and integrated risk-taking management on innovation.

3.1 Risk-appetite and Innovation

Risk-taking comes with an essential influence on organizations' long-term development and innovative activities (Li and Tang, 2010). Consequently, risk-taking is manifested in the managers' willingness to utilize opportunities, aiding their firms in getting competitive advantages through innovation activities (Faccio, Marchica and Mura, 2011). Researchers on innovation literature agree that innovations and creative behaviors are closely associated with risk-taking. In the primary, however, risk-taking should be considered as a relevant attribute of managers to accomplish innovation. In addition, managers have the authority to improve and shape the organization by their high-risk decisions. Therefore, we put forward the following hypothesis:

Hypothesis 1: Managerial risk-taking has a positive impact on innovation.

3.2 IRM and Innovation

Innovation aligns with actions that possess an excessive degree of risk, and to be successful; managers ought to manipulate this procedure and eliminate the risks into account. Tidd, Bessant, and Pavitt (2005) emphasized that even though innovation has different types, scales, and sectors, it is a process, which needs to be managed. Johnson(2010), believed that not only does risk management circulate innovation in advance, but it additionally increases its speed (Bowers and Khorakian, 2014). IRM is set the recognition and assessment of precise events or conditions related to products' risks and possibilities for innovation, integrating risks and plans to reduce risks. Implementation of those packages and their progress is likewise part of this procedure. As a result, even though each risk control hobby reduces dangers one after the other (e.g., Technical risks), integrated hazard control eliminates a few risks and preserves others by growing risk

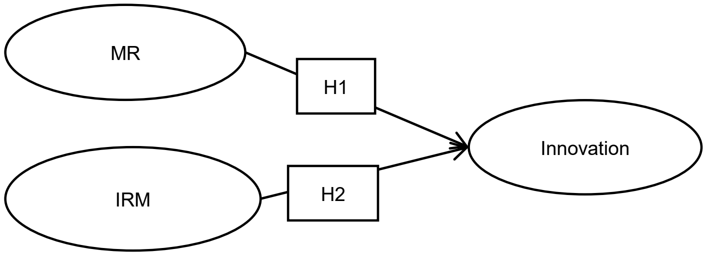

Figure 1: Conceptual model

graphs (Meulbroek, 2002b). Because of different risks in the innovation procedure, the IRM approach has emerged as one of the very most essential additives of innovation. Therefore, we formulated the second hypothesis as follows:

Hypothesis 2: integrated risk management has a positive impact on innovation

4 Methodology

The authors verified the research hypotheses based on the data obtained from insurance companies in Iran. Information in the present research was gathered from human-resource, risk, research and development managers, and managers who somehow handle innovation of insurance, and assessment of its related risks in Iran's insurance companies.

Focusing on one industry, closely examined its specific characteristics associated with innovation. The reason was that, according to Santarelli and Piergiovanni, (1996), researching a small unit make differences get reduced in data.

4.1 Data Collection

To increase response rates, and to ensure the participation of the managers, emails were sent to some managers of insurance companies. The aim of the study was explained in those emails. After receiving the managers' agreement, a questionnaire was sent to them. In addition to sending emails to some directors, some phone calls were made to directors and deputies, and they were asked to participate in the study. Moreover, some meetings were arranged with respondents to complete questionnaires. This method ensured sufficient access to the right audience, proper use, and understanding of words, and increased the response rate. Finally, 109 valid responses were obtained, equivalent to a response rate of 94.78% (out of 115 distributed questionnaires).

4.2 Questionnaire Development

There were three primary variables in this study, including the manager's risk-taking, integrated risk management (IRM) and Innovation. A seven-point Likert-scale ranging from "1" (strongly disagree) to "7" (strongly agree) was used to measure the existing variables. Three constructs for innovation, were adapted from Jimenez-Jimenez, Sanz Valle and Hernandez-Espallardo, (2008). The managerial risk-taking and IRM were measured by three and one items, respectively, which were adapted from previous research studies by Covin and Slevin (1986) and García-Granero et al. (2015), whereas IRM was adopted from the study of (Wu and Wu, 2014). We only control firm age (number of years since the company's creation); Firm age was measured in two separate categories:" lower than 20 years$= 1$ and more than 20 years activity$= 2$".

4.3 Data Analysis and Results

Verifying the adequacy of the data check is essential before performing factor analysis. The KMO index and Bartlett's test were both used to look for the appropriateness of sample adequacy. Thus, KMO in a factorial analysis was 0.896, and thus, the sampling adequacy for this approach is significantly above the threshold value of 0.7(Bilgin and Danis, 2016).The significance level of Bartlett's test (x2 = 873.474; df= 78, p= 0.000) is smaller than 5 percent strengthened its adequacy. Finally, the results verified that the executed dataset in this paper was ideal for exploratory factor evaluation procedures.

4.4 Measurement Model

The authors used Smart PLS software V.2.3.7 (Ringle, Wende and Becker, 2015) to analyze the measurement and structural models (Hair et al., 2017, 2016). We examined the measurement model, through Convergent and discriminant validity. Assessment of the convergent validity includes factor loadings > 0.7, composite reliability (CR) > 0.7 and average variance extracted (AVE) > 0.5 and Cronbach alpha > 0.7 (Hair et al., 2013).

Table 2: Measurement model

First-order constructs	Second-order constructs	Item	Loadings	t-value	AVE	CR	a
Managerial Risk-taking (MR)		MR1	0/7065	7/32***	0/64	0/84	0/71
		MR2	0/9078	49/45			
		MR3	0/7803	10/42			
IRM		IRM	1/0000	——	1/0	1/0	1/0
Product innovation		product_1	0/9044	38/40	0/76	0/90	0/84
		product_2	0/8970	51/48			
	Innovation	product_3	0/8236	20/04			
Process innovation		process_1	0/7397	12/14	0/70	0/87	0/79
		process_2	0/8905	41/63			
		process_3	0/8872	36/41			
Administrative innovation		Admin_1	0/8714	23/60	0/80	0/92	0/87
		Admin_2	0/9312	63/76			
		Admin_3	0/8854	32/04			

Notes: AVE = average variance extracted; CR = Composite reliability; a= Cronbach's alpha * for two-tailed tests: ***2.57 (1% significance level)

Table 3: Discriminant validity – Fornell- Larcker criterion

Construct	IRM	MR	Administrative	Process	Product
IRM	**1/0000**				
MR	0/4597	**0/8025**			
Administrative	0/6369	0/3419	**0/8964**		
Process	0/5707	0/5207	0/6464	**0/8421**	
Product	0/5982	0/5107	0/6163	0/6921	**0/8758**

Note: The bold values in the above matrix are the squared correlations between the latent constructs, and the diagonal values are AVEs

Table 2 shows that the results of the measurement model exceeded the recommended values, thus indicating sufficient convergent validity. In addition to Table 3, Table 4, and Table 5 shows the Discriminant validity. In this regard, the square root of the AVE in table 3, is higher than its highest correlation with any other construct (Fornell and Larcker, 1981; Hair et al., 2017, 2016).

The comparison of cross-loadings in Table 4 indicates that an indicator's loadings are higher than other loadings for its construction in the same column and same row. The Heterotrait- the Monotrait ratio of correlations (HTMT), is another Discriminant validity.

HTMT values shown in Table 5 imply that all values are below the threshold of 0.9 (Hair et al., 2017). Thus, the discriminant validity is established between the latent constructs and, overall, the reflective constructs are reliable and valid.

4.5 Structural Equation Modeling

As mentioned in the previous section SmartPLS 3.2.7 was used to test the structural model and hypotheses (Ringle, Wende and Becker, 2015). The primary criterion for spiritual model evolution is R2, which represents the amount of explained variance of each endogenous latent variable (Hair et al., 2016). Table 6 shows that the R2 for the entire model is 0/5276, which presents a reasonable explanation of the model. In addition, the effects of control variable (CV) on innovation was tested by adding Firm age as a CV to the model. By adding firm age to the model, the R2 of innovation has change from0/526 to 0/539. Using effect

Table 4: Cross-Loadings

	Managerial risk-taking	IRM	Product	Process	Administrative
Mr1	*0/7065*	0/2769	0/3747	0/3351	0/1975
Mr2	*0/9078*	0/4104	0/4527	0/4906	0/3599
Mr3	*0/7803*	0/4085	0/4002	0/4123	0/2437
IRM1	0/4597	*1/0000*	0/5982	0/5707	0/6369
product_1	0/4931	0/5259	*0/9044*	0/6298	0/5531
product_2	0/4565	0/5399	*0/8970*	0/6745	0/6149
product_3	0/3858	0/5065	*0/8236*	0/4989	0/4357
process_1	0/3844	0/2794	0/3904	*0/7397*	0/4570
process_2	0/4012	0/6154	0/6901	*0/8905*	0/6071
process_3	0/5285	0/5015	0/6284	*0/8872*	0/5562
Admin_1	0/2167	0/5057	0/4914	0/5308	*0/8714*
Admin_2	0/2863	0/5647	0/5732	0/6037	*0/9312*
Admin_3	0/4094	0/6376	0/5879	0/6000	*0/8854*

Notes: Italic values are loadings for each item that is above the recommended value of 0.5; an item's loadings on its variable are higher than all of its cross-loadings with other variable

Table 5: Discriminant validity– Heterotrait- the Monotrait ratio of correlations (HTMT)

Construct	IRM	MR	Administrative	Process
MR	0/5384			
Administrative	0/6783	0/4170		
Process	0/6212	0/6821	0/7681	
Product	0/6500	0/6527	0/7059	0/8183

Note: The criterion for HTMT is 0.90 (Hair et al., 2017)

Table 6: Results of R2 and Q2 value*

Endogenous latent variables	R Square	Q2-value
Innovation	0/539	0/284

Notes: *Q2 value = effect size: 0.02 = small; 0.15 = medium; 0.35 = large

size suggested by Chin, Marcolin, and Newsted, (2003):f2=R2included – R2 excluded/1-R2included, The effect size 0/026 was obtained, which shows small effect. Thus, the result illustrates that firm age does not have a significant effect.

When blindfolding is run for all endogenous latent constructs in the model, they all have Q2 values considerably above zero. Table 6 shows that all Q2 values are providing support for predictive relevance (Hair et al., 2017). Table 6 shows the results of R2 and Q2 values. The result of R2 value based on Table 6, indicates that 53 percent of the variance, adjusted R2, in Innovation is explained By IRM and risk-taking with firm age as CV.

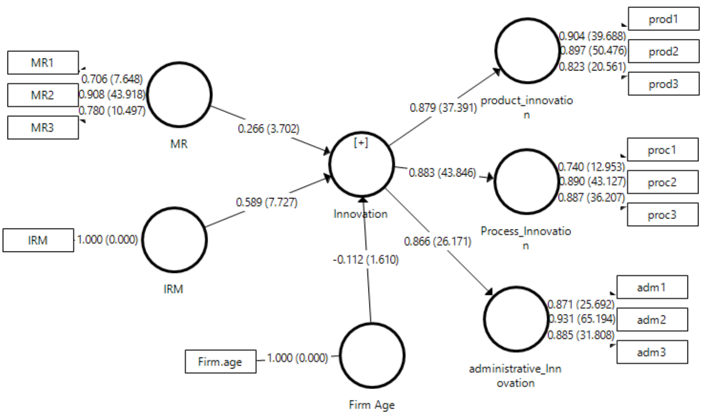

Figure 2: Structural Model Test result

Table 7: Structural results and hypothesis testing

Hypothesis	Path direction	Path coefficient Without CV	With CV	T-value Without CV	With CV	Decision
H1	MR->Innovation	0/2582	0/266	3/52	3/701	Supported
H2	IRM->Innovation	0/5705	0/589	6/97	7/27	Supported

Table 7 and Figure 2 show the structural model analysis. The results showed that the relationships between Managerial risk-taking and innovation (Path coefficient = 0/266, t-value = 3/701 with a p-value<0.01). Thus, H1 is supported and predicted that managerial risk-taking positively affects innovation in the insurance industry. Furthermore, as Table 7 shows, the relationship between IRM and innovation is significant (Path coefficient = 0/589, t-value = 7/27 and with a p-value<0.01). Thus, the H2 is supported as well.

5 Conclusion

The main aim of our study has been the study of risk management, both integrated risk management (IRM) and managerial risk-taking (MR). To the best of our knowledge, it is a new line of study, which is still fragmented and with little empirical evidence. Given this gap, our study presents, after a theoretical review of the variables, an empirical model which was tested on a sample of 109 managers from Iran's' insurance companies in different types of positions.

The results of this paper suggest that both IRM and Managerial risk-taking (MRT) enable the Company's development through innovation in any types. Results show that the risk arises from a variety of sources and most importantly, innovation has a high probability of failure at several stages of organizational development; that is, all types of innovation involve risk, and all risk includes the possibility of failure.

This study offers two important implications. First, it confirms previous research findings and shows that how insurance company as a business enterprise can, to a large extent, bring success in innovation through integrated risk management.

Hence, a firm which adopts an IRM approach may gain more and useful insight about the affection of RM on the firm value and developing innovation activities because these companies have this opportunity to identify all innovation barriers through a systematic IRM framework.

On the other hand, the study predicts that managers who take risks are more inclined to develop innovative products, services, and processes.

If a manager has a low-tolerance for innovative and creative ideas, then it is unlikely to bring new product/process on a regular basis. Thus, managers with the risk appetite ability not only have a higher level of tolerance to innovation uncertainty but also have more assurance in completing innovation projects (Simon and Houghton, 2003).

The second implication of the study is that, even though the company's age did not have a significant effect on innovation; it seems that the company's age can strengthen the effect of managers' risk-taking and integrated risk on innovation. In other words, as the years of activity of insurance companies, more opportunities to innovate and use Risk Management Experience. Therefore, the nature of risk management can be associated with the company's age.

Additionally, We found that IRM was positively related to innovation. In addition, both managerial risk-taking and IRM have a significant indirect effect on product/process and administrative innovation. Thus, these risk management procedures help the companies to improve their organizational performance. This paper contributes to the literature on innovation in the insurance industry through the studying the role of IRM and Managerial risk-taking.

This study offers tremendous managerial implications. First, the hypothesized relationships are supported through the data. This contemporary model has validated to significantly explain both managerial risk-taking and IRM to acquire innovation within the insurance industry. Innovation risks in the insurance industry are among the issues that demand considerable attention. Risk management in insurance has an undeniable role in the improvement and effectiveness of insurance services and economic domains and consequently develops insurance approaches at the micro and macro levels. Thus, innovation in the insurance industry. Since Iranian insurance companies, as a business enterprise, are subject to large fluctuations including operational, national, and political fields, dealing with all risks associated with these areas in the innovation process requires the use of national leadership. This indicates the high status of IRM in an insurance company in Iran.

Consequently, the current study could assist both insurance managers and CEO's to alter better guidelines and strategies to promote the outstanding risk framework throughout the entire company.

Second, our findings provide new insights concerning the role of IRM and managers' risk-taking in facilitating innovation consequences. The results of our study challenge the existing studies that propose the complementary effects of IRM and managerial risk-appetite for innovation. Third, insurance managers ought to consider the efforts and rewards cautiously, when adopting the IRM framework. More particularly, insurance companies will reap an excessive level of revenue and overall performance and will gain more perception about every risk across innovation procedure. Therefore, insurance companies' should construct an effective IRM system that oversees many systematic and strategic risks through organizational innovation. Fourth, insurance managers, need to be conscious that managers' risk-taking will inspire employees to be creative and could proportion their new thoughts freely in their organizational development.

This study has certain limitations regarding the study's sample and setting. First, data were collected in the insurance sector as one of the leading financial instructions, in Iran; therefore, the generalization of the study' results to other financial institutions or other industries and countries with different risk cultures might be rather. Thus, further studies in other areas and sectors to test the model are highly recommended. Second, there is not a specific scale to measure IRM. Therefore, the IRM scale in this study may not be the best measurement scale.

Third, we examined the only effect of managerial risk-taking and IRM on innovation. Future research is needed to examine the effect of other variables on innovation such as innovation culture or adding some control variables such as organizational risk climate or company's size.

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Enhanced FMEA for Supply Chain Risk Identification

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Supply chain risk identification is fundamental for supply chain risk management. Its main purpose is to find critical risk factors for further attention. The failure mode effect analysis (FMEA) is well adopted in supply chain risk identification for its simplicity. It relies on domain experts' opinions in giving rankings to risk factors regarding three decision factors, e.g. occurrence frequency, detectability, and severity equally. However, it may suffer from subjective bias of domain experts and inaccuracy caused by treating three decision factors as equal. In this study, we propose a methodology to improve the traditional FMEA using fuzzy theory and grey system theory. Through fuzzy theory, we design semantic items, which can cover a range of numerical ranking scores assessed by experts. Thus, different scores may actually represent the same semantic item in different degrees determined by membership functions. In this way, the bias of expert judgement can be reduced. Furthermore, in order to build an appropriate membership function, experts are required to think thoroughly to provide three parameters. As the results, they are enabled to give more reliable judgement. Finally, we improve the ranking accuracy by differentiating the relative importance of decision factors. Grey system theory is proposed to find the appropriate weights for those decision factors through identifying the internal relationship among them represented by grey correlation coefficients. The results of the case study show the improved FMEA does produce different rankings from the traditional FMEA. This is meaningful for identifying really critical risk factors for further management.

Keywords: supply chain risk identification; FMEA; grey system theory; fuzzy set theory

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1 Introduction

Risk identification involving both risk classification and risk ranking can be seen as a fundamental work for risks assessment. It identifies critical risks that need further assessment and treatment (Berman and Putu, 2012). Generally, researchers categorize risks into several groups for systematically risk identification. In our study, risks are classified into three levels—the macro level, the company level and the industry level. Risks on the macro level may influence the whole supply chain's operation; risks on the company level are from operation activities of a company; risks on the industry level are from the development of industry (Zhou et al., 2012).

Subsequently, we still need to identify most relevant risk factors so that only those relevant and important ones are studied further. As a large number of risk factors that may be involved, the easiest way is through risk ranking so that a company can effectively mitigate them (Chopra and Sodhi, 2004). A comparison of nine risk ranking techniques is shown in Table 1, where techniques are compared in five attributes—complexity of application, risk consequence analysis, risk probability analysis, quantified output, and objectivity.

Table 1: Comparison of different techniques

Techniques	Complexity of application	Risk consequence analysis	Risk probability analysis	Quantitative output	Objectivity
Structured "What-if"(SWIFT)	Low	A	A	No	Low
Fault tree analysis	Medium	NA	A	Yes	High
Cause and consequence analysis	High	A	A	Yes	High
Cause and effect analysis	Medium	A	NA	No	Medium
Decision tree	High	A	A	Yes	Medium
FMEA	Medium	A	A	Yes	Medium
Hazard analysis and critical control points	Medium	A	NA	No	Medium
Analysis hierarchy process	Medium	NA	NA	Yes	High
Bayesian statistics and Bayes nets	High	A	NA	Yes	High

According to the above table, risk ranking techniques can be classified into four big categories. The first category is a supporting method, which can only give a general analysis about the risks. For example, SWIFT uses a series of “What if” questions to identify the deviations from normal conditions with the help of a predefined checklist. The second category uses scenario analysis, which is good at analyzing the causes of risks. Fault tree analysis, cause and consequence analysis, cause and effect analysis, and decision tree belong to this category (Dakas et al., 2009, Hauptmanns, 2010, Hichem and Pepijn, 2007). The third category is function analysis method including FMEA, hazard analysis, and critical control points. They focus on analyzing the effects of risks. The final category is the statistical method, which applies the statistical knowledge into the analysis process. AHP and BBN belong to this category.

FMEA has been adopted widely as it can produce quantitative output, which is desirable for risk ranking. However, it may be biased as the opinions of domain experts can be subjective. The target of the current study is to improve FMEA for its objectivity using fuzzy set theory and grey system theory.

The structure of the paper is as follows. The next section describes the traditional FMEA; section 3 presents the enhanced FMEA. A case study is provided in section 4. Finally, conclusions are made in section 5.

2 The Traditional FMEA

FMEA identifies failure modes and mechanisms as well as their effects. There are several types of FMEA, e.g. design FMEA, system FMEA, process FMEA, service FMEA, software FMEA, etc. The current study adopts the FMEA methodology. In the study, the system means the supply chain while the failure mode refers to the potential supply chain risk. For each risk, experts give three scores between one and ten regarding the risk’s occurrence frequency (OF), detectability and severity. Then the risk priority number (RPN) can be calculated through multiplying these three score and represents the risk impact of the risk factor. The higher is the RPN, the more critical is the risk.

Table 2: Scores marked by experts

Risk	Experts	OF	Detectability	Severity
Risk 1	B1	4	5	9
	B2	5	1	5
	B3	2	2	8
	Average	3.7	2.7	7.3
Risk 2	B1	9	3	4
	B2	6	2	2
	B3	8	3	5
	Average	7.7	2.7	3.7

2.1 An Example

We assume that there are three domain experts—B1, B2 and B3, who give ranks regarding the risk impacts of two risk factors: risk 1 and risk 2 in a scale of 1 to 10. The greatest rank, 10, refers to the greatest risk impact. The summary of scores marked by experts is shown in Table 2.

Then, using the average numbers of three experts' rankings, RPNs for risks 1 and 2 can be calculated as RPN_1=3.7*2.7*7.3=7.3 and RPN_2=7.7*2.7*3.7=7.7, respectively. Since RPN_2 is greater than RPN_1, risk 2 is more risky than risk 1 according to those three experts.

2.2 Limitations of Traditional FMEA

Through the above example, three limitations of the traditional FMEA can be recognized. Firstly, there may be ranking differences among experts, which can lead to the inaccuracy of outcomes. For example, for the same degree of risk impact, expert B1 may score 9 while expert B2 scores 7. Secondly, the approach depends on the experience and knowledge of experts to a large degree and the outcome can be very subjective. Finally, the RPN formula above does not consider the relative importance of three decision factors. The severity of a risk factor could be more important than OF or detectability while in the current approach, three decision factors are treated as equal. As a result, the above RPN may not be able to give accurate risk rankings.

3 Improved FMEA

To reduce the limitations of the traditional FMEA, we propose to improve it using fuzzy set theory and grey relation analysis. The primary procedure of the improved FMEA is as follows.

- Identify the relevant risk factors (regarding the risk categories) and domain experts.
- Reduce the expert bias using Fuzzy Set theory.
- Experts reach consensus for each risk.
- Improve assessment precision through Grey Correlation Analysis.
- Ranking risk factors.

Specially, we use Fuzzy Set theory in step 2 to reduce experts' ranking difference and Grey Correlation Analysis in step 4 to improve assessment precision through applying appropriate weightages to decision factors.

3.1 Fuzzy Set

In the classical discrete sets, an element either belongs to a set or it does not. But for fuzzy sets, their elements have degrees of membership according to certain membership functions (Abdelgawad and Fayek, 2011). There are many types of membership functions based on the graphs, e.g. triangular, trapezoidal, Gaussian, generalized bell, sigmoid, and others. We choose the triangular membership function to improve the traditional FMEA. A triangular membership function is specified by three parameters, a, b, and c in formula (1):

$$M(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{x-a}{b-a}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \tag{1}$$

where M refers to the membership of score x. The value of the membership ranges from 0 to 1. The value of 1 represents the full membership.

3.2 Grey Relation Analysis

Grey system theory was first developed in 1982 (Deng, 1982). A grey system generally refers to a system lacking certain information, e.g. structure message, operation mechanism, or behavior document. The aims of the grey system theory are to provide theory, techniques, notions and ideas for resolving latent and intricate systems (Deng, 1982). This study adopts the grey relation analysis, which describes the relationships between one main factor and all the other factors in a given system. The degree of correlation among different factors is measured by their grey correlation coefficient. The greater is the value of coefficient, the closer relationship is between the two factors.

4 Case Study

In this section, we use a case study to improve the traditional FMEA through the proposed methodology. Assuming there are three risk factor, e.g. raw material shortage, labour availability, and natural disaster as well as three experts, e.g. B1, B2, B3, the ranking process follows the five steps illustrated in sections 4.1 to 4.5.

4.1 Identify the Relevant Risks List and Experts

Table 3 summarizes the risk factors and experts, which are identified for the ranking process.

Risks identified are raw material shortage (R1), labor availability (R2), and natural disaster (R3) while three experts, B1, B2 and B3 are from supply chain, operation, and R&D departments, respectively.

Table 3: Risks and experts identified

Potential Risks	Experts	Department
Raw material shortage (R1)	B1	Supply chain department
Labor availability (R2)	B2	Operation department
Natural disaster (R3)	B3	R&D department

4.2 Reduce Experts Bias Using Fuzzy Set Theory

The process of reducing expert bias (ranking difference) includes 1) setting up the fuzzy semantic assessment set, 2) determining membership functions for fuzzy semantic items, and 3) calculating specific numbers for fuzzy semantic items through defuzzification.

4.2.1 Set up the fuzzy semantic assessment set (Faisal and Sarah, 2015)

In the study, the fuzzy semantic assessment set is designed to include the sematic items of "very high", "high", "medium", "low", and "very low". The implications of the five semantic items in terms of three decision factors, occurrence frequency, detectability, and severity are illustrated in Table 4.

The definitions of semantic items can guide experts to score a risk factor. In the above table, the semantic item "very high" means "occurs in high frequency" for occurrence frequency, "very hard to detect" for detectability, and "lead to failure of whole supply chain" for severity.

The purpose of the fuzzy sematic assessment set is to provide a few number of semantic items like "very high", "high", etc. to reflect experts' numerical rankings from 1-10. For example, given the same level of risk impact, different experts may give different numerical scores of "7" or "9". But in terms of semantic items, these scores can be translated to either "high" or "very high" with certain degrees of membership. In this way, the ranking difference, e.g. the bias of experts can be reduced.

Table 4: Implication of semantic items

Semantic items	Occurrence frequency	Detectability	Severity
Very high	Occurs in high frequency	Very hard to detect	Lead to failure of whole supply chain
High	Occurs frequently	Hard to detect	Lead to the failure of critical parts of supply chain
Medium	Occurs occasionally	Can be detected occasionally	Lead to the failure of non-essential parts of supply chain
Low	Occurs in less times relatively	Easy to detect	A little influence on the supply chain
Very Low	Unlikely to occur	Very easy to detect	Mainly no influence on the supply chain

4.2.2 Determine membership functions of fuzzy semantic items

The membership functions for the five semantic items, “very low (VL)”, “low (L)”, “medium (M)”, “high (H)”, and “very high (VH)” are given in Figure 1 regarding equation (1).

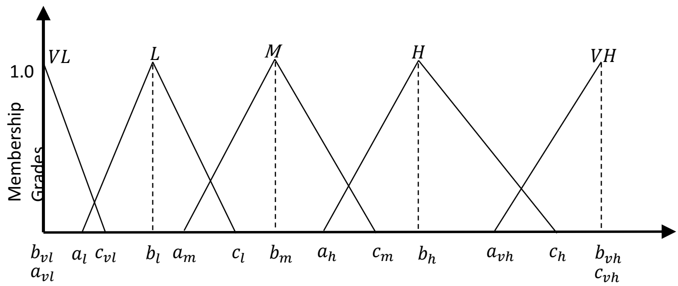

Figure 1: The structure of membership functions

Each membership function is determined by three parameters describing the range of membership. For example, risk factors with scores from a_l to c_l can be generally considered as low risk factors. Score b_l represents full “low risky” membership. For risk factors with scores close to a_l become less “low” but more “very low” risky. Similarly, those with scores close to c_l become less “low” but more “medium” risk. Three parameters determining a membership function are important and need domain experts’ inputs to find out their values.

Thus, instead of giving only one number representing absolute “low” risk, an expert should think over and give a range of numbers which can also be considered as “low” risk but with different degrees. In this way, experts are enabled to think thoroughly and give more feasible ranks of risks. Table 5 collects the inputs of three parameters for each semantic item from three experts (B1, B2, and B3). The last row is the average of three scores.

Subsequently, we have three parameters for each membership function through Table 5:

— For semantic item “very low”: $a_{vl} = 0, b_{vl} = 0, c_{vl} = 2.6$;

Table 5: Experts' inputs regarding three parameters

Expert	Very low	Low	Medium	High	Very high
B1	0, 0, 2.8	1.6, 3.3, 4.8	3.8, 5.8, 7.8	6.8, 8.3, 9.8	8.8, 10,10
B2	0, 0, 2.6	1.2, 3.4, 5.8	3.5, 5.5, 7.6	6.1, 7.8, 9.8	8.6, 10, 10
B3	0, 0, 2.4	1.4, 3.5, 5.1	3.5, 5.5, 8.0	6.6, 8.6, 9.8	8.5, 10, 10
Average	0, 0, 2.6	1.4, 3.4, 5.2	3.6, 5.6, 7.8	6.5, 8.2, 9.8	8.6, 10, 10

— For semantic item "low": $a_l = 1.4, b_l = 3.4, c_l = 5.2$;

— For semantic item "medium": $a_m = 3.6, b_m = 5.6, c_m = 7.8$;

— For semantic item "high": $a_h = 6.5, b_h = 8.2, c_h = 9.8$;

— For semantic item "very high": $a_{vh} = 8.6, b_{vh} = 10, c_{vh} = 10$.

4.2.3 Calculate the specific number of fuzzy semantic item

The aim of the current step is to obtain the specific number, representing a semantic item in one number. Defuzzification is introduced to transfer the values of three parameters into one specific number and the formula (2) adopted is as follow(Chen, 2010).

$$I = \frac{a + ab + c}{4} \tag{2}$$

We then have the specific number of each semantic item as follows.

— For semantic item "very low": $I_{vl} = 0.65$;

— For semantic item "low": $I_l = 3.4$;

— For semantic item "medium": $I_m = 5.7$;

— For semantic item "high": $I_h = 8.2$;

— For semantic item "very high": $I_{vh} = 9.7$;

In summary, the target of the current step is to reduce bias from experts in two aspects. On the one hand, we establish a judgment standard using a fuzzy semantic assessment set so that we can have the same semantic item (very low, low, medium, high, and very high) from the ranges of scores given by experts. On the other hand, in order to establish membership functions, each expert should give three numbers for each fuzzy semantic item describing the extension of membership. This enables them to think thoroughly and subsequently reduces subjectivity of judgment.

4.3 Establish the Judgment Matrix

Now, experts can rank risks R1 to R3 using semantic items ("very low", "low", "medium", "high", and "very high") in terms of their occurrence frequency, detectability and severity. The outcomes of experts' rankings are given in Table 6.

$$x = \begin{bmatrix} x_{o1} & x_{o2} & x_{o3} & x_{o4} & x_{o5} \\ x_{d1} & x_{d2} & x_{d3} & x_{d4} & x_{d5} \\ x_{s1} & x_{s2} & x_{s3} & x_{s4} & x_{s5} \end{bmatrix} \tag{3}$$

Where "o", "d", and "s" represent decision factors "occurrence frequency", "detectability", and "severity", respectively. The first row represents an expert's rankings of "occurrence frequency" in terms of five semantic items "very high", "high", "medium", "low", and "very low", respectively. Similarly, the second and third rows are the experts' rankings of "detectability" and "severity".

Thus, according to Table 6, we can summarize three experts' judgements on three risks regarding three decision factors in tables 8-10. Each entry records the total counts/percentage of same judgement from experts. For example, in Table 7, 3 out 3 (100%) experts think that the "occurrence frequency" of Risk 1 is "very high"; only 1 out 3 (33%) of them think that the "severity" of Risk 1 is "high".

Table 6: Judgment of experts

Expert	Risk	Occurrence frequency	Detectability	Severity
B1	R1	M	L	VH
	R2	H	L	M
	R3	L	M	H
B2	R1	M	M	VH
	R2	M	M	M
	R3	M	L	VH
B3	R1	M	L	H
	R2	H	M	M
	R3	M	L	H

Table 7: Three experts' average judgment for risk 1

	VH	H	M	L	VL
Occurrence frequency	0	0	3 (100%)	0	0
Detectability	0	0	1(33%)	2(67%)	0
Severity	2(67%)	1(33%)	0	0	0

Table 8: Three experts' average judgment for risk 2

	VH	H	M	L	VL
Occurrence frequency	0	2(67%)	1(33%)	0	0
Detectability	0	0	2(67%)	1(33%)	0
Severity	0	0	3(100%)	0	0

Table 9: Three experts' average judgment for risk 3

	VH	H	M	L	VL
Occurrence frequency	0	0	2(67%)	1(33%)	0
Detectability	0	0	1(33%)	2(67%)	0
Severity	1(33%)	2(67%)	0	0	0

$$x^1 = \begin{bmatrix} x^1_{o1}\, x^1_{o2}\, x^1_{o3}\, x^1_{o4}\, x^1_{o5} \\ x^1_{d1}\, x^1_{d2}\, x^1_{d3}\, x^1_{d4}\, x^1_{d5} \\ x^1_{s1}\, x^1_{s2}\, x^1_{s3}\, x^1_{s4}\, x^1_{s5} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0.33 & 0.67 & 0 \\ 0.67 & 0.33 & 0 & 0 & 0 \end{bmatrix} \quad (4)$$

$$x^2 = \begin{bmatrix} x^2_{o1}\, x^2_{o2}\, x^2_{o3}\, x^2_{o4}\, x^2_{o5} \\ x^2_{d1}\, x^2_{d2}\, x^2_{d3}\, x^2_{d4}\, x^2_{d5} \\ x^2_{s1}\, x^2_{s2}\, x^2_{s3}\, x^2_{s4}\, x^2_{s5} \end{bmatrix} = \begin{bmatrix} 0 & 0.67 & 0.33 & 0 & 0 \\ 0 & 0 & 0.67 & 0.33 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (5)$$

$$x^3 = \begin{bmatrix} x^3_{o1}\, x^3_{o2}\, x^3_{o3}\, x^3_{o4}\, x^3_{o5} \\ x^3_{d1}\, x^3_{d2}\, x^3_{d3}\, x^3_{d4}\, x^3_{d5} \\ x^3_{s1}\, x^3_{s2}\, x^3_{s3}\, x^3_{s4}\, x^3_{s5} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0.67 & 0.33 & 0 \\ 0 & 0 & 0.33 & 0.67 & 0 \\ 0.33 & 0.67 & 0 & 0 & 0 \end{bmatrix} \quad (6)$$

Subsequently, the judgment matrices for risks 1, 2 and 3 are listed in matrices of (4) (5) and (6). They represent the rankings from three experts given in terms of five semantic items.

4.4 Improve Precision through Grey System Theory

In the current section, we firstly establish an assessment matrix based on step 3 and then a reference matrix using the most risky semantic item. Subsequently, the degree of relevancy is measured through the grey correlation coefficient. Finally, we apply weights to decision factors (occurrence frequency, detectability, and severity) to differentiate their relevant importance.

4.4.1 Establishment of assessment matrix and reference matrix

The assessment matrix is built based on the judgment matrices of (4) (5) and (6) and specific numbers of sematic items. The assessment matrix for three risks are formed as follow:

$$R = \begin{bmatrix} r_{1o} & r_{1d} & r_{1s} \\ r_{2o} & r_{2d} & r_{2s} \\ r_{3o} & r_{3d} & r_{3s} \end{bmatrix} \tag{7}$$

Where

$r_{io} = I_{vh} \times x^i_{o1} + I_h \times x^i_{o2} + I_m \times x^i_{o3} + I_l \times x^i_{o4} + I_{vl} \times x^i_{o5}$ is the score of "occurrence frequency" for risk i.

$r_{id} = I_{vh} \times x^i_{d1} + I_h \times x^i_{d2} + I_m \times x^i_{d3} + I_l \times x^i_{d4} + I_{vl} \times x^i_{d5}$ is the score of "detectability" for risk i.

$r_{is} = I_{vh} \times x^i_{s1} + I_h \times x^i_{s2} + I_m \times x^i_{s3} + I_l \times x^i_{s4} + I_{vl} \times x^i_{s5}$ is the score of "severity" for risk i.

With specific numbers for five sematic items, e.g. $I_{vl} = 0.65, I_l = 3.4, I_m = 5.7$, $I_h = 8.2$, and $I_{vh} = 9.7$, we have:

- For risk 1, $r_{1o} = 5.7, r_{1d} = 4.2, r_{1s} = 8.9$;
- For risk 2, $r_{2o} = 7.4, r_{2d} = 4.9, r_{2s} = 5.7$;
- For risk 3, $r_{3o} = 4.9, r_{3d} = 4.2, r_{3s} = 8.7$;

Then, we have the assessment matrix in (8).

$$R = \begin{bmatrix} r_{1o} & r_{1d} & r_{1s} \\ r_{2o} & r_{2d} & r_{2s} \\ r_{3o} & r_{3d} & r_{3s} \end{bmatrix} = \begin{bmatrix} 5.7 & 4.2 & 8.9 \\ 7.4 & 4.9 & 5.7 \\ 4.9 & 4.2 & 8.7 \end{bmatrix} \tag{8}$$

Furthermore, we use the specific number of semantic item "very high", e.g. 9.7 to establish the reference matrix in (9).

$$R_f = \begin{bmatrix} r_{fo} & r_{fd} & r_{fs} \end{bmatrix} = \begin{bmatrix} 9.7 & 9.7 & 9.7 \end{bmatrix} \tag{9}$$

This reference matrix represents a very risky situation of a risk factor where the "occurrence frequency", "detectability", and "severity" are all "very high" (Table 4).

4.4.2 Calculating the grey correlation coefficient

Now with the assessment matrix R in (8) and the reference matrix R_f in (9), we can calculate the grey correlation coefficient between them using the grey correlation coefficient function (10) (Du et al., 2011):

$$\lambda(x_{fj}, x_{ij}) = \frac{\underset{i}{\min}|x_{fj} - x_{ij}| + v\underset{i}{\max}|x_{fj} - x_{ij}|}{|x_{fj} - x_{ij}| + v\underset{i}{\max}|x_{fj} - x_{ij}|} \qquad (10)$$

Where

i refers to risk i;

j refers to decision factor j;

f refers to the reference matrix entry;

$\lambda(x_{fj}, x_{ij})$ refers to the grey correlation coefficient of entries x_{fj} and x_{ij};

v is the distinguishing coefficient; its value is within [0,1] and normally $v = 0.5$.

Table 10 presents the results of all $|x_{fj} - x_{ij}|$ and the minimal and maximal values are $\underset{i}{\min}|x_f - x_i| = 0.8$ and $\underset{i}{\max}|x_f - x_i| = 5.5$.

Thus, we have

$$\lambda_{1o} = \frac{\underset{i}{\min}|x_{fj} - x_{ij}| + 0.5\underset{i}{\max}|x_{fj} - x_{ij}|}{|x_{fj} - x_{ij}| + 0.5\underset{i}{\max}|x_{fj} - x_{ij}|} = \frac{0.8 + 0.5 \times 5.5}{4 + 0.5 \times 5.5} = 0.52 \qquad (11)$$

Table 10: Results of all $|x_{fj} - x_{ij}|$

No.	Occurrence frequency	Detectability	Severity
$\Delta_{1j} = \lvert x_{fj} - x_{1j} \rvert$	$\lvert x_{fo} - x_{1o} \rvert = 4$	$\lvert x_{fd} - x_{1d} \rvert = 5.5$	$\lvert x_{fs} - x_{1s} \rvert = 0.8$
$\Delta_{2j} = \lvert x_{fj} - x_{2j} \rvert$	$\lvert x_{fo} - x_{2o} \rvert = 2.3$	$\lvert x_{fd} - x_{2d} \rvert = 4.8$	$\lvert x_{fs} - x_{2s} \rvert = 4$
$\Delta_{3j} = \lvert x_{fj} - x_{3j} \rvert$	$\lvert x_{fo} - x_{3o} \rvert = 4.8$	$\lvert x_{fd} - x_{3d} \rvert = 5.5$	$\lvert x_{fs} - x_{3s} \rvert = 1$

Similarly, we can get the grey correlation coefficient matrix (12).

$$\lambda = \begin{bmatrix} \lambda_{1o} & \lambda_{1d} & \lambda_{1s} \\ \lambda_{2o} & \lambda_{2d} & \lambda_{2s} \\ \lambda_{3o} & \lambda_{3d} & \lambda_{3s} \end{bmatrix} = \begin{bmatrix} 0.52 & 0.43 & 1 \\ 0.7 & 0.47 & 0.52 \\ 0.47 & 0.43 & 0.95 \end{bmatrix} \tag{12}$$

Furthermore, assuming the weights of decision factors are given in matrix (13).

$$\omega = \begin{bmatrix} 0.3 & 0.2 & 0.5 \end{bmatrix} \tag{13}$$

Where ω_o is the weight of Occurrence frequency, ω_d the weight of detectability, and ω_s the weight of severity.

We have

$$G = \begin{bmatrix} \omega_o \lambda_{1o} + \omega_d \lambda_{1d} + \omega_s \lambda_{1s} \\ \omega_o \lambda_{2o} + \omega_d \lambda_{2d} + \omega_s \lambda_{2s} \\ \omega_o \lambda_{3o} + \omega_d \lambda_{3d} + \omega_s \lambda_{3s} \end{bmatrix} = \begin{bmatrix} 0.742 \\ 0.564 \\ 0.702 \end{bmatrix} \tag{14}$$

Matrix G is the final rankings of three risks regarding three decision factors considering three experts' judgement. The final scores of risks 1, 2, and 3 are 0.742, 0.564, and 0.702, respectively. As the 0.742 is the greatest, R1 is the most risky one while R3 is the second and R2, the third. In summary, from the highest to the lowest in term of risk impacts, the ranking of studied risks is R1>R3>R2.

4.5 Compare the Traditional and the Improved FMEA

For the assessment matrix R (8), the RPN applying the traditional FMEA is as follows.

$$RPN = \begin{bmatrix} r_{1o} \times r_{1d} \times r_{1s} \\ r_{2o} \times r_{2d} \times r_{2s} \\ r_{3o} \times r_{3d} \times r_{3s} \end{bmatrix} = \begin{bmatrix} 5.7 \times 4.2 \times 8.9 \\ 7.4 \times 4.9 \times 5.7 \\ 4.9 \times 4.2 \times 8.7 \end{bmatrix} = \begin{bmatrix} 213 \\ 206 \\ 179 \end{bmatrix} \tag{15}$$

Thus, the ranking of risks is R1>R2>R3, which is different from the outcome of the improved FMEA in matrix (14). The reason is that the improved FMEA considers weights (matrix (13)) for three decision factors.

Furthermore, if we directly include those weights into the assessment matrix (8) without applying the grey correlation coefficient. The result is as follows.

$$RPN^1 = \begin{bmatrix} 5.7 \times 0.3 \times 4.2 \times 0.2 \times 8.9 \times 0.5 \\ 7.4 \times 0.3 \times 4.9 \times 0.2 \times 5.7 \times 0.5 \\ 4.9 \times 0.3 \times 4.2 \times 0.2 \times 8.7 \times 0.5 \end{bmatrix} = \begin{bmatrix} 6.39 \\ 6.18 \\ 5.37 \end{bmatrix} \tag{16}$$

The new ranking becomes the same as the one from the traditional FMEA, e.g. R1>R2>R3, but different from the improved FMEA. This emphasizes the importance of including the grey correlation coefficient in allocating appropriate weightages to decision factors.

5 Conclusion

In this study, the methodology to improve FMEA for supply chain risk identification is proposed in order to reduce the bias from domain experts and improve the ranking accuracy.

First of all, the subjective bias in ranking from experts can be reduced through establishing semantic items, which are linked to numerical scores through fuzzy membership functions. In this way, even though experts give difference scores for the same level of risk impact, those scores can still represent the same semantic meaning, perhaps in different degrees. In this way, the bias from experts can be reduced.

Furthermore, in order to build a membership function, three parameters are requested to represent the coverage of a semantic item in terms of numerical scores. This enables experts to think thoroughly and further improves the reliability of their judgement.

Finally, in the traditional FMEA, decision factors are treated equally in their roles to determine the impact of a risk. This may not rational. In the improved FMEA, we differentiate the importance of decision factors in ranking risk impacts. The grey correlation coefficient is adopted to extract appropriate weights for decision factors. This further improves the accuracy of the ranking.

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