Proceedings of the Hamburg International Conference of Logistics (HICL) – 29

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Published in: Data science and innovation in supply chain management
Wolfgang Kersten, Thorsten Blecker and Christian M. Ringle (Eds.)
ISBN: 978-3-753123-46-2 , September 2020, epubli

A Holistic Digitalization KPI Framework for the Aerospace Industry

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Purpose: The aerospace supply chain is characterized by a high degree of small and medium-sized suppliers. To stay competitive, suppliers are facing high pressures to digitalize their business but have limited resources available. Furthermore, aerospace suppliers lack a framework to measure their current state of digitalization. Therefore, this paper provides a holistic digitalization KPI framework for manufacturing aerospace companies.

Methodology: The framework is based on a top-down and bottom-up development approach. Within the top-down approach, 42 digitalization maturity models are being analyzed to identify relevant dimensions. To reveal digitalization indicators, a comprehensive literature review is being used as a bottom-up approach. Indicators are then assigned to the sub-dimension. Finally, indicators are grouped to similar indicators and merged to digitalization KPI.

Findings: The developed KPI framework encompasses 89 digitalization KPI among nine dimensions: Strategy and Organizational Leadership, Governance and Transformation Management, Digital Skills/Human Capital, Smart Product, Customer Focus, Smart Process/Operations, Digital Technology, Financial Focus, and Network and Security.

Originality: The presented digitalization KPI framework provides a scientific foundation for measuring the digitalization maturity level of aerospace companies. Therefore, maturity models and benchmarking tools can incorporate the developed (sub-) dimensions and KPI to measure and compare the digital readiness of aerospace companies as well as to derive guidance for areas of improvement.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

In recent years, the global aerospace industry was characterized by strong market growth, mainly due to the increased demand in the Asian markets (Esposito, et al., 2019, p. 1). Therefore, it is not surprising that the German aerospace industry is one of the high-selling branches achieving annual growth rates of 5% and above (Initiative Supply Chain Excellence, 2017, p. 10). Concurrently, increasing global competition forces aerospace companies to transform and optimize their business processes to reduce costs and to stay competitive (Esposito, et al., 2019, p. 2). Moreover, the coronavirus pandemic in the first half of 2020 has significantly weakened the economic situation of almost all aerospace suppliers. 63 % of all suppliers expect an extensive impact, 26 % even fear an existence-threatening impact (Santo and Wenzel, 2020, pp. 7–8). Normalization of the previous production volume is expected earliest 2023 which will cause challenges in price fights due to over capacities (Santo and Wenzel, 2020, p. 23).
The German aerospace supplier landscape is highly dominated by small and medium-sized enterprises (SMEs). According to a study by Initiative Supply Chain Excellence (2017, p. 9), 76% of German aerospace suppliers are classified as SMEs. Often, these suppliers are highly specialized, focusing on assembly tasks, and mainly act as Tier-2 and Tier-3 suppliers within the supply chain Initiative Supply Chain Excellence, 2017, pp. 9-10, p. 13). Currently, aerospace original equipment manufacturers (OEMs) aim to reduce their total number of suppliers by consolidating their supplier base drastically and re-insource strategic components (Roland Berger, 2018, pp. 10–13; Santo, et al., 2019, p. 10). In the future, a small number of Tier-1 suppliers will receive more comprehensive work packages and will manage

their sub-supply chains individually (Initiative Supply Chain Excellence, 2017, p. 12; Santo, et al., 2019, p. 10). Hence, many Tier-2 and Tier-3 suppliers aim to develop themselves upstream among the value chain (Initiative Supply Chain Excellence, 2017, p. 15).

To be considered as a potential aerospace supplier in the future and to cope with changing requirements of OEMs, SMEs need to adopt modern, flexible, and agile production processes as well as to increase their digital maturity (Initiative Supply Chain Excellence, 2017, p. 27). Compared to the automotive industry, manufacturing in the aerospace industry is characterized by small batch sizes (up to batch size 1) and a lower degree of automation (Guffarth, 2015, p. 130; Hansen, 2016). Hence, companies need to utilize new (Industry 4.0) technologies and digitalize their business on the one hand but have limited resources and knowledge of business digitalization on the other hand. Even though 71 % of the aerospace suppliers have developed a general digital awareness, only 37 % have started to digitalize their processes and functions (Santo, et al., 2019, p. 21). For the successful digitalization of the supply chain, aerospace suppliers agree that costs for SMEs need to stay bearable (Stegkemper, 2016, p. 11).

Thus, especially in the current economic situation, it is more important than ever that SME classified aerospace suppliers can determine their digital maturity on a sound basis. The evaluation of digital maturity allows a purposeful prioritization of the next steps and the related investments. To assess digital maturity, a standardized and structured digitalization Key Performance Indicator (KPI) framework is needed (HAMBURG AVIATION e.V., 2020).

Therefore, this paper aims to answer the following research questions (RQ):
RQ1: *Which dimensions and sub-dimensions should a digitalization KPI framework for aerospace companies comprise?*
Based on the framework developed, measurable indicators for evaluating digital maturity are required. Thus, the second RQ is:
RQ2:*What are applicable KPI for developing a digitalization maturity model?*
The paper is structured as follows: First, definitions for the digital transformation of supply chains and KPI measurement systems are presented. Subsequently, the paper describes the KPI framework development approach in the methodology chapter. The developed digitalization KPI framework is shown in the results. Finally, we conclude by stating implications and limitations as well as providing an outline for further research.

2 Theoretical background

For developing a digitalization KPI framework for aerospace companies, a general understanding of digitalization and the digital transformation of supply chains is required. Therefore, a short definition of these terms is given before defining KPI and KPI frameworks.

2.1 Digitalization and digital transformation of supply chains

The upcoming term ‘Digitalization’ is not a new phenomenon. However, the term is often equated with the term ‘Digitization’ and therefore needs to be differentiated. Digitization describes the transforming of analog data into digital data (Bitkom, 2016, p. 7; Wolf and Strohschen, 2018, p. 58). Thus, from a technical perspective, analog data, e.g. temperature, conditions, voice, or written text, is gathered and transferred into digital data which can be used by computers or devices for digital signal processing (Wolf and Strohschen, 2018, p. 58). However, digitalization in a business context does not only describe data transformation but comprises the change of value creation processes at a company level by refining existing and implementing new digital technologies (Kersten, Schröder and Indorf, 2017, p. 51). Furthermore, this development requires adjustments of company strategies based on new digital business models as well as the acquisition of required competencies and qualifications (Kersten, Schröder and Indorf, 2017, p. 51).

Next to the company level, digitalization has a significant impact on the transformation of production as well as on the supply and value chain of goods (Baum, 2013, p. 38; Kersten, Schröder and Indorf, 2017, p. 51). The digital transformation aims to increase flexibility, productivity, and transparency of all supply chain partners accompanied by focusing on changing customer needs for digital products and services (Kersten, Schröder and Indorf, 2017, p. 48, p. 51). A digitized supply chain is realized by implementing cyber-physical systems (CPS) that embed software and electronics (e.g. sensors and actuators) into items and link them via the internet (Hausladen, 2016, p. 77). Thus, single machines as well as production systems can interact with their environment linking the physical with the virtual world.

As previously mentioned, aerospace companies that are aiming to implement digitalization tools need to determine their digital maturity. Therefore, a standardized digitalization KPI framework is required. Hence, before presenting the developed framework, a short definition of KPI and KPI frameworks will be provided.

2.2 KPI and KPI frameworks

According to Parmenter (2015, pp. 7–8), “Key Performance Indicators (KPI) are those indicators that focus on the aspects of organizational performance that are the most critical for the current and future success of the organization.” Indicators provide three basic functions, namely control, communication and improvement (Franceschini, Galetto and Maisano, 2019, p. 9). Thus, KPI can be utilized to control and communicate the company’s performance to internal and external stakeholders as well as to identify potential gaps between actual performance and targets to derive improvements.

By nature, KPI are measured frequently and have a major impact on the critical success factors of an organization (Parmenter, 2019, p. 15). Therefore, an organization needs to determine whether the indicator is considered as a key performance indicator according to the individual corporate strategy and its targets. Indicators that are measured on a less frequent basis (e.g. monthly, quarterly, or bi-annually) and are not crucial to the business are defined as performance indicators (PI) (Parmenter, 2019, p. 13). PI support and complement KPI and are therefore important to the business.
The selection of relevant indicators for companies and the determination of an indicator being a PI or a KPI is complex and highly individual to the applying company (Franceschini, Galetto and Maisano, 2019, p. 85). Hence, this paper does not distinguish between PI and KPI but provides a full set of indicators (in the further course denoted as KPI). The final selection of the relevant (Key) Performance Indicators is up to future respective users. However, in this paper, we propose an indicator subset based on the rated importance of aerospace companies which may be considered as KPI from aerospace companies.
For evaluating the overall performance of an area of activity, a business unit, or an organization, a set of KPI, respectively a KPI framework is needed. In literature, KPI frameworks are often referred to as ‘performance measurement systems’ which are defined as a “set of metrics used to quantify both the efficiency and effectiveness of actions” (Neely, Gregory and Platts, 1995, pp. 80–81).

3 Methodology

The KPI framework developed is based on a top-down and bottom-up approach (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The top down-approach aims to identify relevant dimensions and sub-dimensions forming the structure of the KPI framework. This approach applies a literature review based on scientific literature, international standards and guidelines as well as industry reports and documents revealing 42 KPI frameworks/maturity models. The KPI frameworks identified are then analyzed according to their applicability in determining the digital maturity of an aerospace company resulting in the selection of 19 relevant KPI frameworks. Analyzing the frameworks for key subjects results in 9 main dimensions and 30 underlying sub-dimensions.

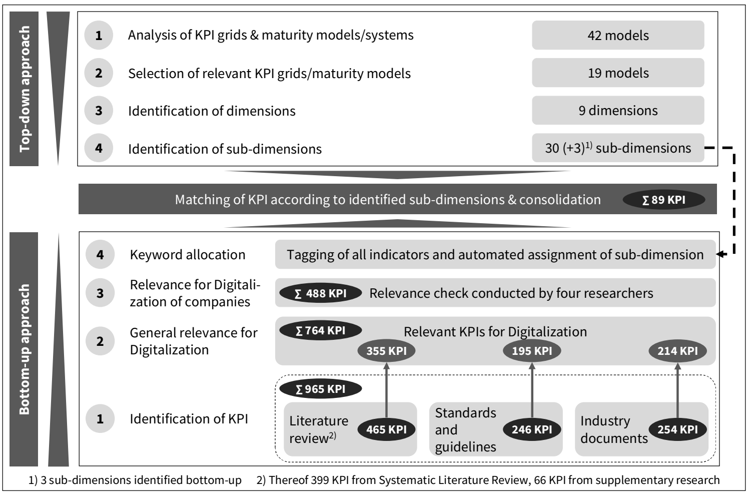

Figure 1: Development Approach of the Digitalization KPI Framework

The bottom-up approach aims to identify relevant KPI for measuring the current state of digitalization. The method deploys a systematic literature review (SLR) based on Fink (2014) revealing 399 KPI as well as a supplementary literature research (snowball method) revealing 66 KPI. In total, 465 KPI are derived from the scientific literature review. For the search string of the SLR as well as the databases used, see Figure 2. The detailed procedure of the SLR can be inferred from Figure 3. Next to scientific literature, standards and guidelines (e.g. international norms) as well as industry documents (e.g. white papers from management consultancies) are included in the body of literature. The analysis of these documents results in 246 KPI from standards and guidelines as well as 254 KPI from industry reports and documents. Thus, 965 KPI are identified in total (cf. Figure 1). Within the next step, the KPI are analyzed according to their general relevance to digitalization resulting in the exclusion of 201 KPI. Subsequently, a relevance check for the remaining 764 KPI is conducted by four researchers individually. Every indicator is scrutinized based on the question: "Is the indicator relevant for the digital transformation of the aerospace industry?" An indicator is included in the framework when a consensus from at least three researchers is achieved. Remaining indicators without a consensus are the basis for discussion within two researcher's workshops. Following, 488 KPI are included in the final set for developing the KPI framework. Furthermore, the bottom-up approach reveals three additional sub-dimensions that are not covered by the 19 KPI grids/maturity models analyzed. Therefore, these sub-dimensions are added to the 30 sub-dimensions (see Figure 5).

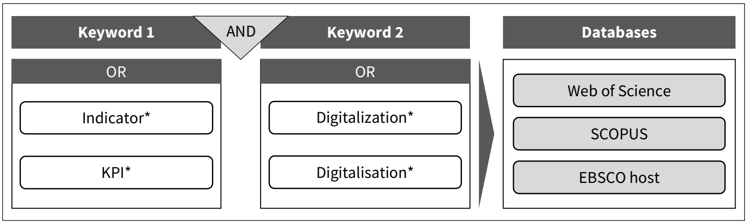

Figure 2: Search String and Sources of Systematic Literature Review

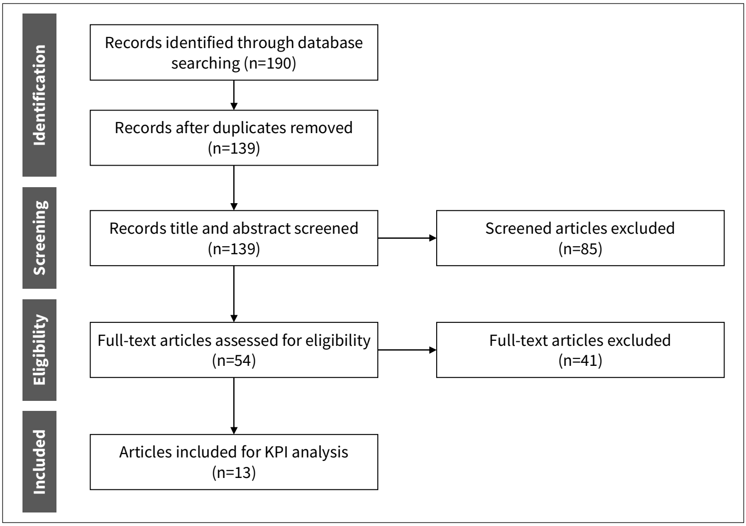

Figure 3: Flowchart of Systematic Literature Review

To link the bottom-up approach with the top-down approach, a keyword assignment procedure is applied (see Figure 4). All 488 KPI are assigned with three keywords based on the KPI text. Concurrently, all 33 sub-dimensions are classified with keywords according to their definitions within a

keyword assignment matrix. With an Excel-based macro, the KPI are automatically assigned to a sub-dimension according to their keywords. Based on this approach, 446 KPI can be classified automatically whereas 42 KPI need a manual classification. Afterward, all assigned sub-dimensions are reviewed independently and, if required, refined by two researchers. Finally, synonymous KPI within each sub-dimension are grouped and summarized to 89 meaningful and measurable KPI, whereof 58 KPI are qualitative and 31 KPI are quantitative.
To identify the most important KPI for the aerospace industry from the KPI framework, a workshop with 18 experts from aerospace companies was

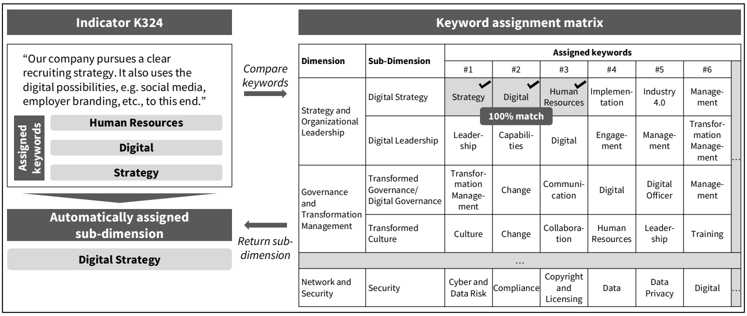

Figure 4: Keyword assignment approach (example for indicator K324)

conducted. Experts were individually asked to select 30 out of 89 KPI which are "most important for the successful digital transformation of aerospace companies". The most important KPI are derived by summing up the total votes for every KPI. Due to several draws in the number of votes, the shortlisted KPI framework comprises 33 KPI.

4 Results

This paper aims to develop a structured digitalization KPI framework for aerospace companies as well as the corresponding (sub-) dimensions. First, according to RQ 1, a basic framework of dimensions and sub-dimensions is required for developing a holistic digitalization KPI framework. Thus, answering RQ 1, the framework developed is presented in Figure 5 showing the dimensions and sub-dimensions as well as the number of KPI per (sub-) dimension. Furthermore, this chapter provides a short definition of each dimension and sub-dimension. Following, applicable KPI need to be developed. Thus, answering RQ 2, the corresponding digitalization KPI and their assigned (sub-) dimensions are presented in Table 1 (see appendix).

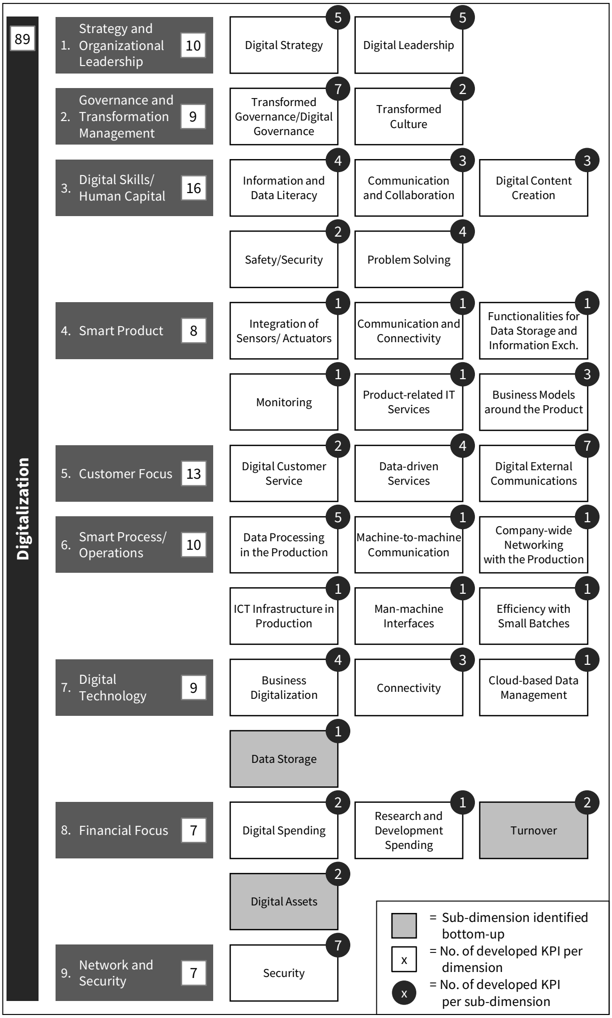

Figure 5: Structure of the Digitalization KPI Framework

Dimension 1: Strategy and Organizational Leadership

The dimension 'Strategy and Organizational Leadership' describes a company's ability to develop and implement new business models to strategically align the company for upcoming challenges related with the company's digitalization (Lichtblau, et al., 2015, p. 29; Berghaus, Back and Kaltenrieder, 2017, p. 29). Therefore, the efficient provision of the right digital competences and resources is of high importance.

Sub-dimension 1.1: Digital Strategy

A digital strategy links information systems with management strategies and business models to cope with disruptive technological developments and changes in customer behavior (Azhari, et al., 2014, p. 39; Deloitte, 2018, p. 10; Waspodo, Ratnawati and Halifi, 2018, p. 1). Therefore, a digital strategy needs to be transparent, easily understandable and clearly communicated across the entire organization (Azhari, et al., 2014, p. 39; KPMG, 2016). Digital strategies aim to utilize new digital technologies to generate sustainable increases in performance and higher competitiveness (BSP Business School Berlin, 2016, p. 8; Berghaus, Back and Kaltenrieder, 2017, p. 27).

Sub-dimension 1.2: Digital Leadership

Digital leadership integrates the digital change into existing leadership concepts (Buhse, 2014, p. 230). The middle and top management need to learn how to deal with new technologies and promote a company culture that encourages employees to generate new ideas, innovation and organizational development (EFQM, 2012, p. 6; Azhari, et al., 2014, p. 39). To convince employees from the need for digital change, the management has to act as a role model for its value and ethics (EFQM, 2012, p. 6; BSP Business School Berlin, 2016, p. 7).

Dimension 2: Governance and Transformation Management

The dimension 'Governance and Transformation Management' encompasses success criteria for implementing the digital strategy by motivating and incorporating all employees into the change process (Strategy & Transformation Consulting; KPMG, 2016, p. 2). Consistent, supportive change management, as well as professional project management is essential for effective transformation management aiming a high value-added through digital processes (Strategy & Transformation Consulting; Jodlbauer and Schagerl, 2016, p. 1478).

Sub-dimension 2.1: Transformed Governance/Digital Governance

Transformed governance, resp. digital governance is a comprehensive, top-down driven process for the digital transformation of an organization (Fitzgerald, et al., 2013, p. 40; Azhari, et al., 2014, p. 49; Kompetenzzentrum Öffentliche IT, 2016; Berghaus, Back and Kaltenrieder, 2017, p. 39). The top management needs to lead the digital transformation by supporting and training employees to develop a common vision and to establish new ways of working (Fitzgerald, et al., 2013, pp. 53–54; Geissbauer, Vedso and Schrauf, 2016, p. 9; Berghaus, Back and Kaltenrieder, 2017, p. 39).

Sub-dimension 2.2: Transformed Culture

The transformed culture acts as a basis for an agile innovative and entrepreneurial environment by creating openness and appreciation for digital technologies (Fitzgerald, et al., 2013, p. 49; Azhari, et al., 2014, p. 39; BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 3; Berghaus, Back and Kaltenrieder, 2017, p. 37). Furthermore, the transformed culture comprises decentralized decision-making processes and transparent communication processes that facilitate change within short reaction times (Azhari, et al., 2014, p. 39, p. 47; BSP Business School Berlin, 2016, p. 7).

Dimension 3: Digital Skills/Human Capital

Digital skills and human capital are a central component for the success of the company's digital transformation (BSP Business School Berlin, 2016, p. 7; Geissbauer, Vedso and Schrauf, 2016, p. 9). Therefore, employees need to have relevant information and communication technology (ICT) skills but also a willingness for lifelong learning, openness to new technology and interdisciplinary thinking (Lichtblau, et al., 2015, p. 52; BSP Business School Berlin, 2016, p. 7; Schumacher, Erol and Sihn, 2016, p. 164; Kotarba, 2017, p. 127; European Commission, 2019). Organizations need to offer appropriate training, education and autonomy to recruit, retain, develop and utilize their employees (Azhari, et al., 2014, p. 39; Lichtblau, et al., 2015, p. 52; Geissbauer, Vedso and Schrauf, 2016, p. 9; KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164).

Sub-dimension 3.1: Information and Data Literacy

Information and data literacy comprises skills to retrieve and analyze digital data, information, and content (Carretero, Vuorikari and Punie, 2017, p. 19). Thus, these skills encompass the basic IT skills for working in a digitized environment, e.g. internet user skills (European Commission, 2019).

Sub-dimension 3.2: Communication and Collaboration

Communication and collaboration skills encompass the ability to communicate and collaborate through digital technologies (IBF Intranet Benchmarking Forum, 2010, p. 11; Berghaus, Back and Kaltenrieder, 2017, p. 33; Carretero, Vuorikari and Punie, 2017). These skills support flexible forms of working, seeking knowledge and sharing ideas with other employees as well as throughout the entire value chain (Nabitz, Klazinga and Walburg, 2000, p. 13; IBF Intranet Benchmarking Forum, 2010, p. 11; Berghaus, Back and Kaltenrieder, 2017, p. 33).

Sub-dimension 3.3: Digital Content Creation

Digital content creation skills are required to create, edit, and integrate digital information and content into business processes (Carretero, Vuorikari and Punie, 2017). These skills also comprise to create value from data by applying data analytics technology (Lichtblau, et al., 2015, p. 54; Geissbauer, Vedso and Schrauf, 2016, p. 17).

Sub-dimension 3.4: Safety/Security

Safety and security skills in a digitized human resource context relate to the protection of the physical and psychological health of employees in the transformed working environment (Nabitz, Klazinga and Walburg, 2000, p. 13; Carretero, Vuorikari and Punie, 2017). Employees need to be aware of the impact of digital technologies on social well-being and must respect and support a culture of mutual support and diversity.

Sub-dimension 3.5: Problem-solving

Problem-solving skills allow employees to resolve problems in a digital environment independently (Carretero, Vuorikari and Punie, 2017). Next to technical knowledge, these skills also comprise systems thinking and process understanding (Lichtblau, et al., 2015, p. 54). For developing problem-solving skills and keeping up-to-date, continued education and training are required (Carretero, Vuorikari and Punie, 2017).

Dimension 4: Smart Product

Smart products are digitized products equipped with ICT, e.g. sensor or RFID technology which facilitates the collection of data from manufacturing and usage phase as well as recording the own status (IHK München und Oberbayern, 2015a; Lichtblau, et al., 2015, p. 11, p. 44, p. 68; Schumacher, Erol and Sihn, 2016, p. 164). Smart products can be either expansion of existing products or new digitized products providing fully integrated solutions (Geissbauer, Vedso and Schrauf, 2016, p. 6). By offering smart products, companies can provide further data-driven-services like predictive maintenance (Lichtblau, et al., 2015, p. 44).

Sub-dimension 4.1: Integration of Sensors/Actuators

Smart products contain sensors or actuators which provide computing capacities to measure and control the current state of technical systems and the environment (IHK München und Oberbayern, 2015a; VDMA, 2016, p. 14). Products can evaluate and react to data generated from sensors autonomously, e.g. by requesting service offerings or triggering purchase orders automatically (IHK München und Oberbayern, 2015b).

Sub-dimension 4.2: Communication and Connectivity

By equipping smart products with communication interfaces, resp. connectivity functionality, machines, systems, and processes can communicate with each other (IHK München und Oberbayern, 2015a; VDMA, 2016, p. 14). The connectivity is realized by field bus, ethernet, or internet interfaces and can also be upgraded to existing machines without internet access (IHK München und Oberbayern, 2015a).

Sub-dimension 4.3: Functionalities for Data Storage and Information Exchange

Products provide the functionality to store and exchange data, e.g. by using barcodes and rewritable data storage. Therefore, units can receive and share information autonomously and store data within their own data storage (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14).

Sub-dimension 4.4: Monitoring

Monitoring enables products to self-detect failures as well as to record their status (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). Therefore, products can perform diagnoses autonomously as well as determining their own functional and operational capabilities independently.

Sub-dimension 4.5: Product-related IT Services

Product-related IT services can either be coupled or decoupled from the physical product (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). Decoupled services can be online portals, e.g. for ordering spare and consumables, whereas coupled services are embedded into the product and the IT infrastructure (IHK München und Oberbayern, 2015b). Thus, products can access services (e.g. condition-based maintenance services) independently (VDMA, 2016, p. 14).

Sub-dimension 4.6: Business models around the product

Technological innovations enable companies to develop new business models providing further business and revenue opportunities (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). The sources of additional revenues encompass consulting services, individualization of products, product-related services as well as flexible pay-per-use solutions (IHK München und Oberbayern, 2015b).

Dimension 5: Customer Focus

The dimension 'Customer Focus' describes the company's ability to understand the needs and requirements of their digital customers (EFQM, 2012, p. 4; Berghaus, Back and Kaltenrieder, 2017, p. 23). Therefore, companies adjust their on- and offline interaction with customers as well as the customer experience based on their customers (Berghaus, Back and Kaltenrieder, 2017, p. 23; Deloitte, 2018). Customers benefit from higher service levels enabling them to achieve higher value propositions and better competitiveness (EFQM, 2012, p. 4; Jahn and Pfeiffer, 2014, pp. 84–85).

Sub-dimension 5.1: Digital Customer Service

Digital customer service is the fulfillment of customer needs through digital omni-channels such as e-mails, chats, self-service portals, and social media (Dimmel, 2016; Geissbauer, Vedso and Schrauf, 2016, p. 29). Companies, therefore, need to apply a digital customer relationship management for anticipating customer requirements and for individualizing sales and marketing activities (Jahn and Pfeiffer, 2014, p. 90; BSP Business School Berlin, 2016, p. 7; Geissbauer, Vedso and Schrauf, 2016, p. 29).

Sub-dimension 5.2: Data-driven Services

Data-driven services drive the after-sales and service business by incorporating and analyzing product data generated during the usage phase (Lichtblau, et al., 2015, p. 13). Thus, companies can generate additional revenue by combining product and services into an integrated platform solution (e.g. selling machines with a maintenance contract guaranteeing a system availability through predictive maintenance) (Lichtblau, et al., 2015, p. 47; Geissbauer, Vedso and Schrauf, 2016, p. 6).

Sub-dimension 5.3: Digital External Communications

Effective digital external communication is realized through tools such as communication and interaction platforms, co-creation and self-customization platforms, feedback instruments as well as data analytics (Jahn and Pfeiffer, 2014, pp. 84–85). Thus, customers can be incorporated closer to operations by including personal customer data into product improvement and development (Geissbauer, Vedso and Schrauf, 2016, p. 16).

Dimension 6: Smart Processes/Operations

Smart processes/operations are the requirements for the interconnectedness of the horizontal and vertical supply chain (Lichtblau, et al., 2015, p. 39, p. 68). Processes should be automated, decentralized and designed end-to-end integrating all systems and regarding components (EFQM, 2012, p. 16; Lichtblau, et al., 2015, p. 39, pp. 66–67; Schumacher, Erol and Sihn, 2016, p. 164; Berghaus, Back and Kaltenrieder, 2017, p. 31). Therefore, it is crucial to connect processes not only within the own company but along the whole value chain from suppliers to the customers (Lichtblau, et al., 2015, p. 39).

Sub-dimension 6.1: Data Processing in the Production

Data processing in the production is required to connect the physical production equipment of the factory with the virtual world (Lichtblau, et al., 2015, p. 13). Data from production is gathered, stored and processed for autonomous production process planning and steering (IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 13; VDMA, 2016, p. 16).

Sub-dimension 6.2: Machine-to-machine Communication (M2M)

Machine-to-machine communication is enabled through data interfaces, e.g. field bus, ethernet, and web interfaces, which facilitate autonomous information exchange (VDMA, 2016, p. 16). Thus, information and location can be separated allowing to establish production compounds between companies in the value chain (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16).

Sub-dimension 6.3: Company-wide Networking with the Production

For developing efficient and standardized workflows, networking and data exchange is not only required within the production but also between production and other company units (VDMA, 2016, p. 16). By using consistent file formats and unified IT solutions, business units like procurement or sales can link production data to their information and data (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16).

Sub-dimension 6.4: ICT Infrastructure in Production

Exchanging production data between partners within the value chain requires reliable and consistent information and telecommunication infrastructure in production (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16). ICT infrastructure in production is a central requirement for implementing applications targeting technical and organizational process improvements (VDMA, 2016, p. 16).

Sub-dimension 6.5: Man-machine Interfaces

Innovative man-machine interfaces enable employees to receive the relevant information of the production units at the right time at the right place (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16). Therefore, companies need to provide mobile terminals such as tablets or data glasses simplifying operational processes and enhancing production efficiency (IHK München und Oberbayern, 2015b).

Sub-dimension 6.6: Efficiency with Small Batches

The customer requirement for highly individualized goods results in small batch sizes implying higher complexity of production processes (VDMA, 2016, p. 16). Thus, high efficiency with small batches becomes crucial for the competitiveness of manufacturing companies. The production process, therefore, needs to be designed flexible and modular closely linking production planning with order planning and processing (IHK München und Oberbayern, 2015b).

Dimension 7: Digital Technology

Digital transformation requires the identification, evaluation, and implementation of digital technologies (BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 4; Lipsmeier, et al., 2018, p. 32). Therefore, companies need to own applicable IT competencies and infrastructures (BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164; Lipsmeier, et al., 2018, p. 32). To support employees and enable flexible forms of working, IT infrastructure needs to be kept up to date and adjusted regularly (KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164; Berghaus, Back and Kaltenrieder, 2017, p. 33).

Sub-dimension 7.1: Business Digitalization

The digitization of companies is realized through networked digital technologies which can increase the efficiency of the company and reduce costs (IHK München und Oberbayern, 2015b; Kotarba, 2017, p. 128). Furthermore, higher service levels and improved communication with customers can be obtained (Geissbauer, Vedso and Schrauf, 2016, p. 19; Kotarba, 2017, p. 128). Business digitization is supported by technologies such as data analytics, cloud technologies, agile IT systems, and the use of sales platform (IHK München und Oberbayern, 2015b; Geissbauer, Vedso and Schrauf, 2016, p. 19, p. 30; Kotarba, 2017, p. 128; European Commission, 2019).

Sub-dimension 7.2: Connectivity

Internet-based interconnectedness of an enterprise requires a certain quality of the fixed and mobile connection (Kotarba, 2017, p. 127; European Commission, 2018a, p. 1; 2018b, p. 3). A high-performance connection ensures competitiveness and networking of all relevant units, employees, and customers of the company (IHK München und Oberbayern, 2015b; Kotarba, 2017, p. 127).

Sub-dimension 7.3: Cloud-based Data Management

Cloud-based data management is facilitated through an internet-based infrastructure to provide data storage, computing power, or software (IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 43). It enables the scalability of computing power, data storage space, and access at any time from anywhere (Shi, et al., 2010, pp. 47–48; IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 43). Therefore, it is an important instrument for managing the increasing volume of data (Lichtblau, et al., 2015, p. 44).

Sub-dimension 7.4: Data Storage

Next to physical inhouse servers, data can be also stored on virtual cloud solutions enabling more flexible disk space (Lichtblau, et al., 2015, p. 43). To fulfill legal and security requirements, virtual data storage solutions need to meet a defined set of the company's requirements for being trustworthy.

Dimension 8: Financial Focus

The dimension financial focus examines the financial management associated with capital-intensive digitalization and Industry 4.0 projects (Lichtblau, et al., 2015, p. 62). Therefore, the financial strategy needs to support the overall digitalization strategy of the company by providing the required resources and investments enabling long-range planning (EFQM, 2012, p. 14).

Sub-dimension 8.1: Digital Spending

Digitalization requires significant investments into hardware and software (e.g. manufacturing execution software) as well as into the ICT infrastructure (Geissbauer, Vedso and Schrauf, 2016, p. 9; Kotarba, 2017, pp. 132-

133). The majority of companies expect a positive return of these investments within two years (Geissbauer, Vedso and Schrauf, 2016, p. 9).

Sub-dimension 8.2: Research and Development Spending

The success and therefore the impact of new products shows a significant positive correlation to the research and development (R&D) spending (Robert G. Cooper and Elko J. Kleinschmidt, 2007, p. 63, p. 65). Therefore, the company's R&D spending on digital technologies strongly drives the success of the digitized company.

Sub-dimension 8.3: Turnover

Digitalization provides various opportunities to increase turnover through the use of new technologies (Lichtblau, et al., 2015, p. 18). Increased turnover can be obtained from higher product value for customers or new digital sales channels higher (VDMA, 2016, p. 12). Higher product margins can be generated through individualized products as well as additional services derived from data analytic insights (Lichtblau, et al., 2015, p. 18; Geissbauer, Vedso and Schrauf, 2016, p. 14).

Sub-dimension 8.4: Digital Assets

Digital assets refer to the monetary value of the digital asset stock (Kotarba, 2017, p. 132). This contains hardware assets (e.g. the value of computers and servers) and software assets (e.g. purchased software licenses).

Dimension 9: Network and Security

Trust in the security of digital ecosystems is the main prerequisite for a successful digital transformation of a company (Geissbauer, Vedso and Schrauf, 2016, p. 5). Trust is based on transparency, legitimacy, and effectiveness and is related to the confidence in the security of internal and external data storage, communication and data exchange (Lichtblau, et al., 2015, p. 43; Geissbauer, Vedso and Schrauf, 2016, p. 5, p. 20).

Sub-dimension 9.1: Security

Organizations need to undertake measures to protect data and communication channels against manipulation and unauthorized access (Lichtblau, et al., 2015, p. 43; Geissbauer, Vedso and Schrauf, 2016, p. 20; Jodlbauer and Schagerl, 2016, p. 1477). These measures should not only target the internal IT but also external channels and mobile devices (Lichtblau, et al., 2015, p. 43).

5 Conclusion

Concluding the paper, we will present implications from our research. Furthermore, we state limitations accompanied by our research design and provide an outline for further research opportunities and potential advancements of the digitalization KPI framework.

5.1 Implications

This paper presents a holistic, scientific digitalization KPI framework, applicable for all partners across aerospace supply chains. We contribute to existing theory by providing a cross-departmental digitalization framework covering technological, safety- and strategy-related as well as organizational and human-related aspects. Thus, we provide a future basis for researchers and managers to evaluate the digital maturity of companies. Therefore, the KPI framework can be incorporated into existing or new maturity models expanding them by digitalization aspects. Maturity models can be utilized for a standardized benchmarking process. Hence, managers can evaluate the digital maturity of their own company but might also compare the results with peer groups. Especially in the light of the ongoing consolidation of aerospace supply chains and the increasing pressure on Tier-2 and Tier-3 suppliers, a distinct digital maturity might become an important selection criterion for aerospace OEMs and therefore a competitive advantage for SMEs in future.

5.2 Limitations and further research

Even though we highly adhered to the defined methodology, this paper comes along with some limitations. First, due to the actuality and novelty of digitalization KPI, scientific literature available is currently still limited. To develop a comprehensive digitalization KPI framework, it was highly necessary to include grey literature such as company reports and industry guidelines. However, we assume that combining scientific with grey literature will increase the quality of the KPI framework and ensure higher applicability for prospective users. Second, the full list of 89 KPI was shortlisted by 18 aerospace experts within a three-part workshop. A higher number of participants may have generated more resilient results. Furthermore, it must be noted that due to practicability and segmentation into dimensions, the amount of KPI among each part of the workshop was not equally distributed which might distort the shortlisted result. Third, the developed KPI framework was neither verified nor validated in practice. Thus, we cannot make a point on the applicability or practical measurability of the developed KPI. Fourth, in this paper we assumed all indicators being KPI. As stated in the theoretical background, some indicators might also be considered as PI which is, however, highly individual to the user. Last, this paper presents a holistic digitalization KPI framework. Thus, (sub-) dimensions may not be distinct but might overlap in their meaning.

The presented digitalization KPI grid provides a scientific basis for developing a digitalization maturity model for aerospace companies. Based on a single KPI or a subset of KPI, different digital maturity levels might be developed, e.g. in cooperation with aerospace experts. Therefore, workshops or focus groups may be a suitable methodology. Furthermore, discussions during the conducted shortlisting workshop have shown a different perception of importance regarding the different dimensions. Hence, we suggest

determining a weighting vector/approach when developing a future maturity model, e.g. based on a pairwise comparison of each (sub-) dimension. Another research opportunity is the re-examination of the perceived importance of KPI, e.g. in a quantitative large-scale study with aerospace experts. Next to a higher validity of rated importance, this study could also provide evidence on indicators being KPI or PI.
Finally, since our findings are solely based on literature, we suggest discussing and, if necessary, refining the developed digitalization KPI together with aerospace experts to ensure better practical applicability and measurability.

Financial Disclosure

The presented framework is part of the German-Canadian research project DIMLA (Digitalization and Internationalization Maturity Level in Aerospace). We gratefully thank the Federal Ministry of Education and Research (BMBF) and Project Management Jülich (PtJ) for the project funding.

Appendix

ID	SL[1]	Key Performance Indicator (KPI)	Sources
1. Strategy and Organizational Leadership			
1.1. Digital Strategy			
D1.1.1	X	Is your digital strategy documented, regularly updated, and communicated transparently to all employees?	[1]; [2]
D1.1.2	X	Is a strategic roadmap/strategy process for digital transformation included in the corporate strategy?	[1]; [2]; [3]; [4]
D1.1.3	X	Is the implementation status of your digital strategy measured and tracked regularly (e.g. through indicators)?	[1]; [5]; [6]
D1.1.4	X	Does your company have sufficient resources (e.g. financial resources, human resources) and a clear recruiting strategy to implement your digital strategy?	[1]; [7]; [8]
D1.1.5	X	Does your employee development strategy consider digital expertise as a central component?	[1]; [3]
1.2. Digital Leadership			
D1.2.1	X	Does your company have the capability to identify & solve digital competence gaps in your company?	[2]; [9]; workshop
D1.2.2		Does your company apply a cross-channel operational leadership with external stakeholders?	[3]; [10]
D1.2.3		Does your company continuously develop the leadership culture as well as document and communicate efforts in your company?	[1]; [7]; workshop

1 Shortlist (SL) determined from expert workshop

ID	SL1	Key Performance Indicator (KPI)	Sources
D1.2.4		Does your senior/top management improve the company's management system and performance and manage change effectively?	[3]; [10]; [11]
D1.2.5		Does your middle management develop the Mission, Vision, Values, and Ethics and act as a role model?	[3]; [4]; [10]
2. Governance & Transformation Management			
2.1. Transformed Governance/Digital governance			
D2.1.1		Does your company have defined quality criteria and targets for your digital activities which are evaluated regularly?	[1]; [3]
D2.1.2		Does your internal IT department proactively ensure the use of the digital technologies relevant to your company to meet changing requirements?	[3]; [4]
D2.1.3		Do your executives take risks for potential improvements of your core competencies by using innovative digital solutions?	[3]
D2.1.4		Percentage of jobs that include digitized processes (incl. back-office and front-office processes)	[2]; [4]
D2.1.5	X	Do you apply the latest digital methods to automate your routine and core processes?	[1]; [3]
D2.1.6	X	Do you have defined internal experts (e.g. a Chief Digital Officer) for the implementation of digital transformation?	[1]; [3]; [12]
D2.1.7		Does your organizational flexibility enable a decentralized decision-making process?	[1]; [2]; [3]
2.2. Transformed Culture			
D2.2.1		Does your company's culture promote consistent change, creativity, and exchange between employees, e.g. by new forms of work?	[1]; [3]; [4]; [7]

ID	SL1	Key Performance Indicator (KPI)	Sources
D2.2.2	X	Do you evaluate and proactively communicate errors and lessons learned from failed digital projects within the company?	[3]
3. Digital Skills/Human Capital			
3.1. Information and Data Literacy			
D3.1.1		Percentage of employees using computers at work (incl. tablets and smartphones)	[2]; [5]; [8]; [13]; [14]; [15]; workshop
D3.1.2		Percentage of individuals in the company using the internet	[2]; [5]; [16]; [17]; [18]
D3.1.3		Percentage of employees with basic digital skills (e.g. internet usage, copying files and folders, browsing, evaluating, and searching data, using formulas in spreadsheets)	[2]; [5]; [9]; [19]; [20]; [21];
D3.1.4		Percentage of employees in the ICT sector (incl. software, hardware, telecommunication, services)	[22]
3.2. Communication and Collaboration			
D3.2.1	X	Percentage of employees collaborating through digital technologies, e.g. by interacting and sharing on digital collaboration platforms?	[3]; [4]; [9]; [23]
D3.2.2		Percentage of employees using digital communication tools, e.g. video calls and social networks?	[2]; [4]
D3.2.3		Percentage of employees using the internet for communication uses, e.g. for sending/receiving emails, video calls, messaging services, social networks?	[19]; workshop

ID	SL1	Key Performance Indicator (KPI)	Sources
3.3. Digital Content Creation			
D3.3.1		Percentage of employees applying tools for analyzing and developing digital content to support the day-to-day business?	[1]; [2]; [9]
D3.3.2	X	Percentage of employees with special digital expertise (e.g. ICT specialists, STEM graduates, programmer)	[1]; [2]; [3]; [4]; [9]; [20]; [24]
D3.3.3	X	Percentage of employees capable of creating value from data, e.g. by integrating and re-elaborating digital content?	[9]; [11]
3.4. Safety/Security			
D3.4.1	X	Are your employees aware of important rules regarding IT security (e.g. protecting personal data and privacy, managing digital identity, netiquette) and monitored regularly (e.g. through external audits)?	[3]; [9]; [11]
D3.4.2		Does your company have defined rules and guidelines to protect the health and well-being of employees?	[9]
3.5. Problem Solving			
D3.5.1		Percentage of employees taking online courses and use the internet for training and education?	[2]; [19]; [25]
D3.5.2	X	Does your company offer continuous training for your employees in digital competence development?	[1]; [7]; [17]
D3.5.3	X	Percentage of employees taking industry-based training for digital requirements (e.g. IT infrastructure, Automation technology, Data analytics, Data security/communications security, Development or application of assistance systems, Collaboration software, process understanding)	[1]; [6]; [14]
D3.5.4		Percentage of employees with ICT problem-solving skills (e.g. connecting and installing new ICT devices)?	[9]; [19]

ID	SL1	Key Performance Indicator (KPI)	Sources
4. Smart Product			
4.1. Integration of Sensors/Actuators			
D4.1.1		Are your company's products equipped with sensors and actuators?	[7]; [26]
4.2. Communication and Connectivity			
D4.2.1	X	Are your company's products equipped with communication interfaces that enable connections to other systems?	[7]; [26]
4.3. Functionalities for Data Storage and Information Exchange			
D4.3.1		Are your company's products equipped with data storage and information exchange functionalities?	[7]; [26]
4.4. Monitoring			
D4.4.1	X	Are your company's products equipped with IT-supported condition monitoring (e.g. self-reporting, automatic identification, assistance systems)?	[6]; [7]; [26]
4.5. Product-related IT Services			
D4.5.1		Does your company provide new or additional product-related IT services next to its products?	[7]; [26]
4.6. Business Models around the Product			
D4.6.1	X	Does your company use and analyze data from digitized products (customer data, product, or machine-generated data) for your business model, e.g. for modifying products and services using prototypes?	[3]; [11]; [12]; [17]
D4.6.2	X	Does your company actively integrate ideas from employees, customers, and partners into the development of new digital innovations?	[3]; [23]

ID	SL1	Key Performance Indicator (KPI)	Sources
D4.6.3	X	Does your company actively evaluate new technologies and changes in customer behavior to identify and promote digital innovations?	[1]; [2]; [3]; [14]; [17]; [24]; [27]
5. Customer Focus			
5.1. Digital Customer Service			
D5.1.1		Does your company actively include your customers to deliver a consistent best-in-class experience on digital and non-digital channels?	[2]; [3]; [23]
D5.1.2		Does your company apply digital technologies to offer digital customer service and post-sale service?	[2]; [4]; [7]; [27]; [28]
5.2. Data-driven Services			
D5.2.1		Does your company collect and analyze customer data from the product usage phase to increase customer insight (e.g. for personalized offers, for design & engineering)?	[6]; [11]
D5.2.2		Does your IT & data architecture enable your company to gather, aggregate, and interpret real-time manufacturing, product, and sales data?	[7]; [11]; [25]
D5.2.3		Does your company apply analytics for data evaluation to provide a real-time customer experience?	[3]; [23]
D5.2.4		Does your company apply customer and interaction data for marketing, sales, and communication activities?	[3]; [28]
5.3. Digital External Communications			
D5.3.1		Does your company perform online activities and consume online content?	[21]
D5.3.2		Does your company actively use social media to inform on current topics?	[2]; [4]; [17]; [18]; [29]; [30]

ID	SL1	Key Performance Indicator (KPI)	Sources
D5.3.3		Does your company personalize digital external communication with customers and suppliers?	[3]; [18]; [28]
D5.3.4	X	Does your company institutionalize collaboration on digital topics with external partners (e.g. academia, industry, suppliers, and customers)?	[2]; [3]; [11]
D5.3.5	X	Does your company apply standardized and efficient processes within the collaboration with external partners (e.g. external contractors, start-ups, or research institutes)?	[3]
D5.3.6		Does your company consolidate, analyze, and integrate customer and interaction data from multiple digital channels (e.g. website, blogs, forums, social media platforms) into your communications and service processes?	[2]; [3]; [4]; [11]
D5.3.7		Does your company communicate to customers the use of their personal data?	[3]
6. Smart Process/Operations			
6.1. Data Processing in the Production			
D6.1.1	X	Does your company use insights from the data and information generated during the production?	[3]; [4]; [6]; [7]; [26]; [28]
D6.1.2		Do production processes in your company respond automatically in real-time or have a fast response time?	[6]; [7]
D6.1.3		Do you have use cases in the production of products in which a workpiece guides itself autonomously?	[6]
D6.1.4		Does the purchasing in your company base on the high-quality master data?	[7]

ID	SL1	Key Performance Indicator (KPI)	Sources
D6.1.5		Does your company ensure the consistency and control of all material master data?	[7]
6.2. Machine-to-machine Communication (M2M)			
D6.2.1		Does your company describe machine-to-machine (M2M) communication in the production environment?	[6]; [7]; [26]
6.3. Companywide Networking with the Production			
D6.3.1	X	Does your production share information with other business units or central units?	[6]; [7]; [26]; workshop
6.4. ICT Infrastructure in Production			
D6.4.1		How advanced is the ICT infrastructure for your production equipment?	[2]; [3]; [4]; [7]; [26]
6.5. Man-machine Interfaces			
D6.5.1		Does your company describe man-machine interaction in the production environment?	[7]; [26]; [28]
6.6. Efficiency with Small Batches			
D6.6.1		Does your company use flexible production systems to efficiently produce even small batch sizes?	[7]; [26]
7. Digital Technology			
7.1. Business Digitalization			
D7.1.1	X	Percentage of businesses using digital technologies (such as e.g. sensor technology, RFID, real-time location systems, e-invoices, cloud technologies, electronic information sharing, embedded IT systems, M2M communications)	[2]; [6]; [11]; [13]; [16]; [17]; [18]; [22]; [24]; [28]; [29]; [31]; [32]

ID	SL1	Key Performance Indicator (KPI)	Sources
D7.1.2	X	Percentage of businesses using software systems (such as CAD, CAM, PLM, CMSS, ERP, MES, PDM, PPS, PDA, MDC, SCM and internet platforms) to improve internal processes and ensure continuous data and information exchange	[2]; [3]; [6]; [7]; [11]; [16]; [20]; [29]; workshop
D7.1.3	X	What is the degree of digitalization of your vertical and horizontal value chain?	[1]; [2]; [11]; [12]; [13]
D7.1.4	X	Does your company evaluate the current as well as the future use of digital technologies?	[17]; [31]
7.2. Connectivity			
D7.2.1		Percentage of businesses with internet access (including fixed broadband, mobile broadband)	[2]; [5]; [7]; [13]; [15]; [17]; [18]; [21]; [25]
D7.2.2		Percentage of business with an extranet	[5]
D7.2.3		Are your company's networks easy to access and use?	[2]; [5]; [8]; [17]; [25]
7.3. Cloud-based Data Management			
D7.3.1		Does your company use cloud-based services (such as cloud-based software for data storage and analysis)?	[6]; [7]; [20]; [29]
7.4. Data Storage			
D7.4.1		Are trusted data storage and processing available in your company?	[2]; [8]
8. Financial Focus			
8.1. Digital Spending			
D8.1.1		Total investment in e-commerce	[5]; [6]; [15]

ID	SL1	Key Performance Indicator (KPI)	Sources
D8.1.2	X	Total investment in Information and Communication Technologies (ICT), incl. Software (e.g. ERP systems), hardware (e.g. broadband access, data storage) and IT services spending (e.g. IT consulting)	[2]; [3]; [5]; [19]; [23]; [25]
8.2. Research and Development Spending			
D8.2.1	X	Relative investment in Research and development (R&D) in Information and Communication Technologies (ICT)	[2]; [6]; [22]; workshop
8.3. Turnover			
D8.3.1	X	Relative revenue generated from digital products and services	[1]; [2]; workshop
D8.3.2		Relative revenue generated from selling online/e-commerce	[15]; [20]; [29]; workshop
8.4. Digital Assets			
D8.4.1		Total monetary value of hardware assets, e.g., computers and servers	[2]
D8.4.2		Total monetary value of software assets, e.g., purchased software licenses	[2]
9. Network & Security			
9.1. Security			
D9.1.1	X	To which extent are your IT systems secured (e.g., IT security for production, secured internal data storage, secured cloud storage, secured internal and external data exchange) in your company?	[3]; [4]; [6]; [11]; [18]; [28]
D9.1.2		Total number of ICT patents in your company	[9]; [22]
D9.1.3		Software piracy rate in your company	[17]; [18]
D9.1.4		Total number of security loopholes identified in your company (e.g., number of issues on client data protection, cybercrimes)	[2]; [15]; [33]

ID	SL1	Key Performance Indicator (KPI)	Sources
D9.1.5		Total number of electronic privacy issues identified in your company	[8]; [30]
D9.1.6	X	Does your company implement a security strategy to avoid employees' and contractors' carelessness, cybercrime, terrorist organizational hackers' attacks, and state-organized attacks?	[7]
D9.1.7		Does your company have defined rules and guidelines to protect devices?	[9]

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