Abstract

Purpose – This paper aims to show that current Industry 4.0 maturity models primarily focus on manufacturing processes. Until now, research has been lacking with regard to outbound logistics, that is, the delivery process. This paper develops such a model.

Design/methodology/approach – Methodologically, this paper is grounded in design science research (DSR) and rigorously follows the model development guidelines presented by De Bruin et al. (2005). This work builds on current maturity models and original empirical research to populate and test the model.

Findings – The model appears to be applicable to describing the status quo of the digitization efforts in outbound logistics, developing a corporate vision for delivery logistics excellence and providing guidance on the development path.

Research limitations/implications – Thus far, the model has been applied only for a development stakeholder. For further validation, the authors are currently working on additional case studies to demonstrate the model’s applicability.

Practical implications – The developed model provides guidance for the digitization of an important value-adding activity in supply chain management: the delivery process.

Originality/value – To the authors’ knowledge, the proposed model is the first to explicitly consider the delivery process; therefore, it complements available approaches that focus on the manufacturing process. Moreover, the results show that the widely used Supply Chain Operations Reference model can serve as the basis for additional process maturity models.

Keywords Logistics, Supply chain management, Value chain

Paper type Research paper

1. Introduction

The term supply chain management (SCM) was first coined by Oliver and Webber (1982) in a Booz Allen and Hamilton publication 35 years ago. Within their contribution, these authors broach the issue of a material flow instead of a functional silo perspective:

[... ] it views the supply chain as a single entity rather than relegating fragmented responsibility for various segments in the supply chain to functional areas such as purchasing, manufacturing, distribution, and sales.

Since then, many researchers have investigated the concept of SCM, thereby establishing the current theoretical and operational bases. Stock and Boyer (2009) attempted to develop a uniform agreed-upon definition within a qualitative study. Their main motivation was to provide common ground among researchers and practitioners to advance theory and practice. Accordingly, these authors define SCM as:

The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production...
facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction (Stock and Boyer, 2009, p. 706).

The task of achieving efficiency and customer satisfaction in a value-adding network of interdependent institutions is facilitated by information and communication technology (ICT) (Masteika and Cepinskis, 2015). Two recent advances in the field of ICT are of specific importance for SCM: the Internet of Things (IoT) and cyber-physical systems (CPS).

The IoT is a dynamic network infrastructure with self-configuring capabilities where both physical and virtual things have identities with intelligent interfaces that are seamlessly integrated in the information network. The IoT is the technological basis that enables the networking of and with things. The exchanged data can be analyzed and new insights can be gained. CPS merge informational and electronic components to form embedded intelligent systems that control themselves autonomously. Therefore, CPS may be defined “[…] as transformative technologies for managing interconnected systems between its physical assets and computational capabilities” (Lee et al., 2015, p. 18). Both the IoT and CPS are radically transforming business models and their resulting supply chains in a unique, unprecedented way, thereby triggering a fourth industrial revolution. This phenomenon is referred to as Industry 4.0. The unique characteristic of Industry 4.0 is its set of automated self-configuration, self-adjustment and self-optimization capabilities that allow for more agile and cost-efficient processes. Furthermore, increased customer satisfaction is obtained via smart connected products that pave the way for new data-driven value-adding services. Strong empirical and econometrical evidence links ICT capabilities (Brynjolfsson and Hitt, 2000; Bharadwaj, 2000) and supply chain maturity (McCormack et al., 2008) to business performance. Therefore, we stress the argument that current trends in the form of IoT and CPS will further increase productivity and commercial success.

Acknowledging these changes in the business environment, the demand for management concepts that reflect the emerging challenges and opportunities of the digital age ahead of us has increased. Therefore, the concept of SCM must become SCM 4.0. Hence, the tools and best practice processes that have been developed over the past 35 years need to be re-evaluated and refined. Adequate tools to identify and then build SCM 4.0 capabilities are maturity models. In general, maturity models describe typical patterns in the development of resources. All models are built on the hypothesis that organizational evolution follows a predictable stage-by-stage pattern (Isoherranen et al., 2015). Herein, each stage represents a certain level of maturity and later stages are superior to the earlier ones, with the highest level denoting excellence (Rao et al., 2003). Those maturity stages can be applied to various domains, e.g. business units or specific processes, which can be regarded as model dimensions (Fraser et al., 2002). Model dimensions represent a specific field of application. Knowing the maturity stage in the respective field of application is essential to identifying improvement potentials and stimulating a continuous improvement process (Isoherranen et al., 2015). Consequently, maturity models enhance organizational excellence and help firms to address increasing market dynamics.

In this context, this work aims to develop a theoretically grounded model for the delivery process of manufacturing companies, which has so far been neglected in the available literature despite its particular relevance. According to McCormack et al. (2008), the delivery process has a greater impact on business performance than other supply chain processes. Politis et al. (2014) highlighted the effect of logistics service quality on customer satisfaction in manufacturing companies’ supply chains. Because competitive advantage “[…] rests on a firm’s idiosyncratic and difficult-to-imitate resources […]” (Teece et al., 1997, p. 513), the
developed maturity model will provide not only a collection of best practices but also a flexible, customizable modeling architecture that is capable of taking into account the specific characteristics and peculiarities of an organization.

This study provides three key contributions. First, it reviews available maturity models with a specific Industry 4.0/SCM 4.0 perspective. Second, the developed model complements the available ones by focusing on the delivery process, which can be defined as all activities that are necessary to fulfill a customer order. Third, this work will thoroughly document both the scientific development process and the final maturity model (please refer to the digital Appendix of this article). Most previous publications have focused on model development but lack full documentation, which limits the transferability of their results into practice. Providing such transparency may increase the vulnerability of the model to potential critiques. Nonetheless, we believe that comprehensibility and reproducibility are of greater importance.

The remainder of this article is structured as follows. Section 2 provides the theoretical background, reviews Industry 4.0 maturity models and highlights the research gap that this paper addresses. Section 3 describes the applied methodology and documents the model’s development. Finally, Section 4 provides a summary, discusses limitations, and offers suggestions for future research.

2. Theoretical background and literature review
The theoretical foundations of maturity models include the resource-based view (RBV) of the firm in combination with dynamic capability theory (DCT). The RBV considers organizations as collections of resources. To create competitive advantage, resources must be valuable, rare, non-imitable and non-substitutable (Penrose, 1959; Barney, 1986). Resources can be either assets or capabilities. Tangible (e.g. buildings, machines) and intangible (e.g. brand reputation, organizational learning) assets are used and controlled by an organization. In this context, capabilities represent a set of skills exercised through organizational routines (Galbreath, 2005). DCT complements the RBV by acknowledging that market dynamics are constantly changing the requirements to achieve competitive advantages (Teece et al., 1997). Consequently, organizations require competences that respond to shifts in the business environment to maintain performance in the long run. In this regard, DCT distinguishes between ordinary and dynamic capabilities (Winter, 2003). Ordinary capabilities provide firms with considerable success in the present and near future. Although such ordinary capabilities are fundamental in performing organizational tasks on a daily basis, they do not guarantee a sustainable competitive advantage. In contrast, dynamic capabilities enable organizations to realign, reconfigure and renew ordinary capabilities that continuously support the ability to evolve through innovation and change. According to Teece (2014, p. 332), the purpose of dynamic capabilities is the “[…] (1) identification, development, co-development, and assessment of technological opportunities in relationship to customer needs (sensing); (2) mobilization of resources to address needs and opportunities and to capture value from doing so (seizing); and (3) continued renewal (transforming).” Maturity models are tools that contribute to these purposes.

The first manifestations of maturity models date back to the 1970s and are rooted in software engineering (Nolan, 1973; Van Ioooy et al., 2013). Since then, the concept of maturity has evolved into an important tool in business practice. The concept of maturity can be used for descriptive, prescriptive and/or comparative purposes (Röglinger et al., 2012). It serves a descriptive purpose if applied for as-is assessments, a prescriptive purpose if used to establish a desirable path of development and a comparative purpose if used for internal or external benchmarking. Thus, maturity models are adequate tools for:
- documenting the status quo;
- developing a corporate vision for process excellence and providing guidance on that development path; and
- comparing capabilities between business units and organizations.

Because of the broad range of potential applications, maturity models have gained popularity both in management and science. Over the past decade, the number of scientific contributions has increased considerably (Wendler, 2012). Recently, Tarhan et al. (2016) performed a comprehensive systematic literature review. This paper does not intend to replicate the efforts of these researchers; rather, it complements this previous review with a detailed search and analysis of Industry 4.0/SCM 4.0 maturity models.

Tarhan et al. (2016) considered studies that were published between 1990 and 2014 in academic journals, conference proceedings and books. Their review is conducted in a general “all-inclusive manner” with no specific focus on a certain domain or aspect of business process management. Based on their search of digital libraries, they initially retrieved 2,899 references, with 61 of those considered relevant for further analysis. They report that most previous publications establish a maturity model, show the application of a model or compare different models. A key finding is the lack of empirical works on the development of maturity models. In addition, Tarhan et al. (2016) call for more prescriptive rather than descriptive models. This call has also been made by other authors (Van Iiooy et al., 2013; Isoherranen et al., 2015). Descriptive models provide little guidance for the specific actions necessary to make it to the next maturity level. Tarhan et al. (2016) argued that a major prerequisite for the fulfillment of its prescriptive purpose is extensive documentation that lays out specific process areas, goals, best practices and achievement measures. Furthermore, these authors also emphasize that extensive models might deter decision makers because the models demand greater efforts for adoption.

Because the review process ended in October 2014, none of the 61 analyzed references considered the recent Industry 4.0 developments. Therefore, this paper aims to complement the previous review with the inclusion of more recent publications. The literature search was performed in common digital libraries such as EBSCOhost, Emerald Insight, ScienceDirect, Wiley and Google Scholar. The search terms covered “Industry 4.0,” “Industrial Internet,” “I 4.0,” “Internet of Things,” “IoT,” “Cyber-Physical Systems” and “CPS” in combination with “maturity model” and “capability model.” To ensure academic rigor, only publications from peer-reviewed journals and conference proceedings were considered. First, the abstracts of all identified references were analyzed with regard to their relevance. A publication was considered relevant if it presented a full model that included maturity stages and dimensions. The digital library research was complemented by the backtracking of footnotes and the search for citations of the identified relevant articles. Ultimately, ten studies were chosen for further analysis.

A comparison of the models reveals three publication streams (Table I). The first group of authors concentrates on IT architecture and/or capabilities, specifically with regard to the IoT (Katsma et al., 2011; Weber et al., 2017; Jæger and Halse, 2017). The second group that consists of only one contribution (Westermann et al., 2016) focuses specifically on CPS. The third group pursues a broader perspective. The authors align their models to the Industry 4.0 phenomenon and acknowledge that digitization radically affects current business models in a unique and unprecedented way – especially the models of manufacturing companies (Leyh et al., 2016; Ganzarain and Errasti, 2016; Schumacher et al., 2016; Gökalg et al., 2017; Klötzer and Pflaum, 2017; De Carolis et al., 2017). The third group of maturity models is also the largest and raises the most interest among researchers, which is not surprising because
Industry 4.0 conceptually integrates the IoT and CPS perspectives and represents the current state of the art.

To classify the maturity models in terms of content, the Supply Chain Operations Reference (SCOR) framework is used. SCOR was first presented in 1996 and has been constantly updated by the endorsing Supply Chain Council and now the American Production and Inventory Control Society. The most recent version is from 2017. The SCOR framework follows a hierarchical three-level structure that builds on the assumption that every supply chain can be described by using a set of predefined processes. The top level contains six basic process types that can be further subdivided into more detailed process categories and process elements (SCOR, 2017).

(1) **Plan**: The process balances resources with market requirements. It includes the gathering of requirements, the collection of data from available resources, the balancing of requirements and resources to determine planned capabilities, the identification of gaps in demand or resources and the planning of actions that correct these gaps. The process plays a superordinate strategic role.

(2) **Source**: The process includes all procurement activities concerning the ordering and receipt of goods and services from suppliers. It involves issuing purchase orders, scheduling deliveries and receiving, validating and storing goods.

(3) **Make**: The process describes all activities associated with the transformation of materials or the performance of services, which includes assembly, chemical processing, maintenance, repair, overhaul, recycling, refurbishment and remanufacturing.

<table>
<thead>
<tr>
<th>Model</th>
<th>Focus</th>
<th>Stages/dimensions</th>
<th>Supported SCOR top-level processes (plan, source, make, deliver, return, enable)</th>
<th>Model documentation (attributes/characteristics for each maturity stage and dimension)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katsma et al. (2011)</td>
<td>IT architecture/capabilities/IoT</td>
<td>4/4</td>
<td>Enable</td>
<td>Full documentation</td>
</tr>
<tr>
<td>Leyh et al. (2016)</td>
<td>Industry 4.0</td>
<td>5/4</td>
<td>Plan, enable</td>
<td>Full documentation</td>
</tr>
<tr>
<td>Ganzarain and Errasti (2016)</td>
<td>Industry 4.0</td>
<td>5/3</td>
<td>Plan, make, enable</td>
<td>Partial documentation</td>
</tr>
<tr>
<td>Schumacher et al. (2016)</td>
<td>Industry 4.0</td>
<td>5/9</td>
<td>Enable</td>
<td>Missing documentation</td>
</tr>
<tr>
<td>Westermann et al. (2016)</td>
<td>CPS</td>
<td>Layer 1: 5/1, Layer 2: 4/5-15</td>
<td>Enable</td>
<td>Partial documentation</td>
</tr>
<tr>
<td>Gokalp et al. (2017)</td>
<td>Industry 4.0</td>
<td>6/5</td>
<td>Enable</td>
<td>Missing documentation</td>
</tr>
<tr>
<td>Klotzer and Pflaum (2017)</td>
<td>Industry 4.0</td>
<td>5/18</td>
<td>Make, enable</td>
<td>Full documentation</td>
</tr>
<tr>
<td>Weber et al. (2017)</td>
<td>IT architecture/capabilities/IoT</td>
<td>5/1</td>
<td>Enable</td>
<td>Missing documentation</td>
</tr>
<tr>
<td>De Carolis et al. (2017)</td>
<td>Industry 4.0</td>
<td>5/4</td>
<td>Make, enable</td>
<td>Missing documentation</td>
</tr>
<tr>
<td>Jæger and Halse (2017)</td>
<td>IT architecture/capabilities/IoT</td>
<td>8/1</td>
<td>Enable</td>
<td>Missing documentation</td>
</tr>
</tbody>
</table>
Deliver: The process includes all activities associated with the fulfillment of customer orders and consists of receiving, picking, packing, shipping and invoicing customer orders.

Return: The process considers reverse flows of materials and goods and includes organizing the return shipment and deciding on the disposition option.

Enable: The process establishes the fundamental requirements that are necessary for value creation within the supply chain and includes resource management, data management, facilities management, contract management, supply chain network management, compliance and risk management and performance management.

By applying this classification scheme to the ten models mentioned above, we conclude that several approaches support the plan, make and enable processes. However, a research gap is observed in the sourcing, delivery and return processes. To fully benefit from the Industry 4.0 concept, all value-adding processes must be considered via a holistic, integrated approach, which is particularly true because McCormack et al. (2008) found that the thus far neglected maturity of the delivery process has a greater impact on business performance than other SCOR processes.

Finally, the documentation of the previous models is mostly unsatisfactory, which seems to be a general problem with maturity models (Albliwi et al., 2014). From our point of view, none of the models can be fully applied using the given published information. Some do not even provide a full description of the maturity stages (Schumacher et al., 2016). Other models provide at least partial information and briefly describe the characteristics for each maturity stage and dimension (Westermann et al., 2016; Klötzer and Pflaum, 2017).

To summarize, the review shows that there is a lack of state-of-the-art Industry 4.0 maturity models with a comprehensive documentation that focus on the sourcing, delivery and return processes. Based on that, a model for the delivery process is developed in the following paragraph. The overall goal is to complement previous publications that focus on the manufacturing process. This model will allow decision makers to document the status quo, develop a vision for and provide guidance toward process excellence and compare capabilities between business units and organizations in outbound logistics as an important value-adding process (Rutner and Langley, 2000).

3. Development of the Industry 4.0 maturity model for delivery processes

Methodologically, this study is grounded in design science research (DSR). According to Van Aken (2005, p. 22):

DSR […] is solution-oriented, using the results of description-oriented research from supporting (explanatory) disciplines as well as from its own efforts, but the ultimate objective of academic research in these disciplines is to produce knowledge that can be used in designing solutions to field problems.

We believe that the current Industry 4.0 development is a pertinent field problem that requires new capabilities to remain competitive; therefore, we consider DSR to represent an appropriate foundation. DSR focuses on the development and application of artifacts. In general, artifacts can be any type of construct, model or method (Hevner et al., 2004). In this paper, the artifact is the Industry 4.0 maturity model for the delivery processes in supply chains. According to Österle et al. (2010), a typical DSR project consists of four phases: analysis, design, evaluation and diffusion. This paper focuses on the design and evaluation
steps by thoroughly describing the model’s development and evaluation. Hevner et al. (2004) presented seven guidelines for DSR and highlight the importance of applying rigorous methods in the construction and evaluation of artifacts. Therefore, we build on the often-cited generic six phases of maturity model development presented by De Bruin et al. (2005) as described in the next paragraph.

3.1 Design principles: model development methodology
In their seminal work, De Bruin et al. (2005) presented six relevant phases: scope, design, populate, test, deploy and maintain. This study concentrates on the first five phases, which are further explained in the following sections because the sixth phase would require a longitudinal study.

3.1.1 Scope. The first phase defines the scope of the model, which can be either general or domain-specific. General models can be applied to different domains (e.g. quality management), whereas domain-specific models are coupled to a certain field of application (e.g. software development). Moreover, stakeholders that can assist in model development or benefit from the application of the model must be identified. These stakeholders may be from academia, industry, government or a combination.

3.1.2 Design. The second phase determines the architecture of the model based on five sub-criteria: audience, method of application, driver of application, respondents and application. It is important to define the target audience to meet their needs. This is especially relevant for the level of detail because a trade-off is observed between accuracy and simplicity.

With regard to the structural elements of a maturity model, De Bruin et al. (2005, p. 4) note that “[…] the number of stages may vary from model to model, but what is important is that the final stages are distinct and well-defined, and that there is a logical progression through stages.” They also stress the need to provide “[…] a summary of the major requirements and measures of the stages, especially those aspects that are new to the stage and not included as elements of lower stages” (p. 4). These stages are applied to the model’s dimensions. The inclusion of several dimensions allows for the modeling of complex domains. Each dimension may represent a different maturity stage, which facilitates detailed analyses and the identification of specific opportunities to make improvements.

3.1.3 Populate. The third phase broaches the issue of the specific content of the model by defining model components and subcomponents. A component denotes what needs to be measured. According to De Bruin et al. (2005), components can be defined by a review of the literature or the use of empirical approaches such as stakeholder interviews, surveys, focus groups and case studies.

3.1.4 Test. The fourth phase tests the validity and reliability of the model to strengthen the populated model’s relevance and rigor. The model’s validity guarantees that the model measures what it intends to measure, whereas reliability refers to whether the results are exact and repeatable. De Bruin et al. (2005) suggested several methods to ensure the model’s validity and reliability, such as case studies, surveys, and literature reviews. They conclude that “[…] the manner in which testing is undertaken can vary between models […]” (p. 5).

3.1.5 Deploy. The fifth phase combines the model’s distribution within business practice for the purpose of determining its generalizability. De Bruin et al. (2005) proposed a two-step procedure to ensure the general acceptance of the model: applying the model to one of the involved stakeholders and applying the model to organizations that did not participate in the model’s development and testing.
3.2 Model development: scope, design, populate and test

The framework of De Bruin et al. (2005) serves as the methodological foundation for further procedures. The first four steps (scope, design, populate and test) that represent the development in a narrower sense will be described in detail. To highlight the focus on the delivery process in conjunction with Industry 4.0, the model is named the Delivery Process Maturity Model (DPMM 4.0).

3.2.1 Maturity model scope. The model’s scope is designed for manufacturing firms and is thus domain-specific. These firms can be distinguished based on their production strategy. Possible strategies are make-to-stock, make-to-order and engineer-to-order. Because most organizations either follow a make-to-stock or make-to-order approach, the model focuses on these two. Moreover, two types of stakeholders are considered relevant for model development: academia and industry. Therefore, the development process builds on available publications and original empirical work to adequately represent the practitioners.

3.2.2 Maturity model design. The targeted audience is internal executives and management (because they are responsible for developing and maintaining Industry 4.0 capabilities) as well as external auditors and consultants (because they are often engaged in guiding organizational change). The major drivers of the model’s application are market dynamics that force organizations to rethink their business models. The respondents are management executives and mid-level staff, as they possess the expertise to assess their current Industry 4.0 capabilities. The model can be applied to multiple entities (e.g. production sites) in multiple regions. DPMM 4.0 can be used on an self- or guided assessment basis. After clarifying why and how the model is applied, the stages and dimensions must be defined. For this step, we refer to previous Industry 4.0 and maturity model literature.

3.2.2.1 Maturity stages of DPMM 4.0. Maturity stages represent a certain level of maturity and enable the improvement of the selected domain in a targeted way (Fraser et al., 2002). Each stage requires an appropriate denotation and a general description. Despite being a relatively new research domain, the literature review found six maturity models that have already been published (Leyh et al., 2016; Ganzarain and Errasti, 2016; Schumacher et al., 2016; Gokalp et al., 2017; Klötzer and Pflaum, 2017; De Carolis et al., 2017). Consequently, information is available on the criteria for maturity and the methods of measuring maturity. Beyond the six identified Industry 4.0 maturity models, the contribution of Leyh et al. (2016) stands out. Compared with the other models, the System Integration Maturity Model Industry 4.0 (SIMMI 4.0) is based on two of the most established and widely employed maturity models: Capability Maturity Model Integration (CMMI) and the Service-Oriented Architecture Maturity Model (SOAMM). Moreover, SIMMI 4.0 stands out based on its comprehensive documentation. Consequently, the maturity stages of DPMM 4.0 are based on those of SIMMI 4.0 and adopted for the delivery process. Table II summarizes the maturity stages and provides a detailed description.

3.2.2.2 Model dimensions of DPMM 4.0. The model’s dimensions add specific content to the previously defined maturity stages (Fraser et al., 2002). Each dimension consists of elements or activities that allow a detailed understanding of the described phenomenon (Fraser et al., 2002). Methodologically, an appropriate denotation and a general definition of each element are required (De Bruin et al., 2005).

The frequently used SCOR framework subdivides the top-level Delivery process (sD) into four categories based on the respective production strategy: deliver make-to-stock (sD1), deliver make-to-order (sD2), deliver engineer-to-order (sD3) and deliver retail product (sD4). Because this maturity model is designed for manufacturers with make-to-stock or make-to-order production strategies, only sD1 and sD2 are taken into further consideration. A comparison between these two categories reveals considerable consistency, with both
including 15 elements and exhibiting only two minor differences. First, sD2.2 allows for the customer-specific configuration of a product based on the standardized available parts or other offered options which is not included in sD2.1. Second, the title of sD1.11 (load vehicle and generate shipping docs) differs from that of sD2.11 (load product and generate shipping docs). However, this deviation is only semantic and can be neglected with regard to model development because the definitions of the given elements match. Moreover, several of the activities serve a similar purpose, thereby providing the basis for three process groups: order processing, warehousing and shipping. Table III provides the relevant process elements and their assignment to the process groups. For the detailed element descriptions, refer to the SCOR (2017) framework.

To summarize, DPMM 4.0 consists of five maturity stages (basic digitization, cross-department digitization, horizontal and vertical digitization, full digitization and optimized full digitization) that are applied to three dimensions (order processing, warehousing and shipping). Each dimension has three to seven elements. The high level of detail enables rich analyses of the maturity results and improves the ability to derive a supply chain-specific development path. After conceptually determining the design, the subsequent paragraph focuses on the model’s content.
3.2.3 Maturity model population. Several publications present successful Industry 4.0 approaches that are summarized and described in Table IV. The identified approaches are not mutually exclusive and include various overlaps. However, these similarities are not considered critical because this stage of the model’s development is focused on comprehensiveness rather than on the segregation of concepts.

To verify the relevance and test the comprehensiveness of the identified approaches, a complementary empirical study is conducted. With the support of a stakeholder, a leading Industry 4.0 corporation from the manufacturing industry that wishes to remain anonymous, and additional searches on professional social networks (LinkedIn, Xing), 207 experts were identified and invited to participate in an online survey. The questionnaire consisted of three parts. The first part collected data concerning the respondents’ Industry 4.0 experience. The second part aimed to ensure the maturity model’s exhaustiveness. Therefore, participants were asked to rate the relevance of the identified Industry 4.0 approaches for each of the DPMM 4.0 dimensions (order processing, warehousing and shipping) on a four-tiered Likert scale (not relevant, marginally relevant, fairly relevant and highly relevant). The respondents were allowed to choose “not sure” in the case of missing expertise. Moreover, they were invited to name and describe additional Industry 4.0 approaches that have not been queried, but appear to be relevant in the respective dimension. Finally, the third part contained general demographic questions (e.g. age and sex). Before going live, five experts that represented both academia and industry pre-tested the questionnaire and their suggestions regarding question sequence and wording were considered in the final version of the questionnaire.

The field phase occurred in late May and June 2017. In total, 43 experts finished the survey, which equals a response rate of 20.6 per cent. The participants indicated that they were from upper organizational hierarchy levels with the majority from top management (25 per cent) or middle management (37 per cent). Five experts were from academia to complement the industry-dominated sample. Most of the participants (86 per cent) worked for large corporations with over 250 employees. On average, the respondents were 40.7 years old. Because top-level jobs are primarily held by men (Dezso et al., 2013), the participants were also pre-dominantly male (86 per cent). Despite the novelty of the concept, over half of the respondents (58 per cent) indicated that they had been working on Industry 4.0 approaches for more than two years. Therefore, we are confident that the sample reflects the necessary expertise to contribute to the population of the model.

<table>
<thead>
<tr>
<th>ID (sD1/sD2) – SCOR process element</th>
<th>Process element group</th>
</tr>
</thead>
<tbody>
<tr>
<td>sD1.1/sD2.1 – Process inquiry and quote</td>
<td>Order processing</td>
</tr>
<tr>
<td>sD1.2/sD2.2 – Receive (configure), enter and validate order</td>
<td>Order processing</td>
</tr>
<tr>
<td>sD1.3/sD2.3 – Reserve inventory and determine delivery date</td>
<td>Order processing</td>
</tr>
<tr>
<td>sD1.4/sD2.4 – Consolidate orders</td>
<td>Order processing</td>
</tr>
<tr>
<td>sD1.5/sD2.5 – Build loads</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.6/sD2.6 – Route shipments</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.7/sD2.7 – Select carriers and rate shipments</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.8/sD2.8 – Receive product from source or make</td>
<td>Warehousing</td>
</tr>
<tr>
<td>sD1.9/sD2.9 – Pick product</td>
<td>Warehousing</td>
</tr>
<tr>
<td>sD1.10/sD2.10 – Pack product</td>
<td>Warehousing</td>
</tr>
<tr>
<td>sD1.11/sD2.11 – Load vehicle/product and generate shipping docs</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.12/sD2.12 – Ship product</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.13/sD2.13 – Receive and verify product by customer</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.14/sD2.14 – Install product</td>
<td>Shipping</td>
</tr>
<tr>
<td>sD1.15/sD2.15 – Invoice</td>
<td>Order processing</td>
</tr>
</tbody>
</table>

Table III. Overview of the relevant process elements in supply chains
After the field phase, the collected data were analyzed with regard to the response behavior and no anomalies were found. Overall, all of the cited Industry 4.0 approaches seem relevant for the delivery process with averages varying from 2.83 to 3.81 (Table V). A one-way ANOVA found that the following elements presented significant differences between the three queried process groups: integrated database, integrated interfaces, digital mapping and user/product interfaces.

To assess the groups that differ from each other post hoc Tukey tests were performed. The results show that an integrated database is less important for warehousing than it is for order processing ($p = 0.001, \frac{\text{CI}}{0.46}, 95\% = \text{CI}\left[0.75, 0.17\right]$) and shipping ($p = 0.012, \frac{\text{CI}}{0.36}, 95\% = \text{CI}\left[0.65, 0.07\right]$) processes. Moreover, integrated interfaces are significantly less important for warehousing than for order processing ($p < 0.001, \frac{\text{CI}}{0.49}, 95\% = \text{CI}\left[0.78, 0.07\right]$).

### Table IV.

<table>
<thead>
<tr>
<th>Industry 4.0 approach</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated database</td>
<td>The company uses a single consistent database that integrates disparate sources of data from different departments</td>
<td>Zhou et al. (2015, p. 2148), Shrouf et al. (2014, p. 698)</td>
</tr>
<tr>
<td>Integrated interfaces</td>
<td>The organization provides shared and integrated interfaces to avoid media discontinuities; this refers to interfaces between organizations, human-machine-interfaces and user/product interfaces</td>
<td>Zhou et al. (2015, p. 2148), Hermann et al. (2016, p. 3932), Shrouf et al. (2014, p. 698), Han and Chi (2016, p. 109), Butzer et al. (2016, p. 5), Biahmou et al. (2016, p. 673)</td>
</tr>
<tr>
<td>Consistent data/information flow</td>
<td>An end-to-end data/information flow is built from multiple sources to enable real-time analytics</td>
<td>Gilchrist (2016, p. 206 and 208), Varghese and Tandur (2014, p. 634), Kagermann (2015, p. 30)</td>
</tr>
<tr>
<td>Mobile devices</td>
<td>Employees can access, edit and add information everywhere through mobile devices that use cloud services</td>
<td>Varghese and Tandur (2014, p. 634), Zhou et al. (2015, p. 2149), Shrouf et al. (2014, p. 698)</td>
</tr>
<tr>
<td>Digital mapping</td>
<td>Data on the physical reality are compiled and formatted into a virtual image to create a digital twin. The digital twins create simulation models for the purpose of monitoring, diagnostics and prognostics</td>
<td>Gilchrist (2016, p. 207), Zhou et al. (2015, p. 2148), Hermann et al. (2016, p. 3929)</td>
</tr>
<tr>
<td>Automated monitoring</td>
<td>Full tracking and traceability of all processes and associated goods with seamless real-time feedback regarding their status is provided</td>
<td>Gilchrist (2016, p. 208), Kagermann (2015, p. 30)</td>
</tr>
<tr>
<td>Machine learning</td>
<td>Systems are provided with algorithms that can learn from existing data without being explicitly programmed</td>
<td>Shrouf et al. (2014, p. 699), Hermann et al. (2016, p. 3934), Han and Chi (2016, p. 111)</td>
</tr>
<tr>
<td>Self-optimization</td>
<td>Providing decentralized systems with the ability to react autonomously to changing external conditions and providing optimal solutions by adapting objectives as well as the resulting behavior</td>
<td>Shrouf et al. (2014, p. 699), Kagermann (2015, p. 30), Gölzer et al. (2015, p. 2), Butzer et al. (2016, p. 2)</td>
</tr>
<tr>
<td>Partner integration</td>
<td>Customers, suppliers and other external partners are integrated with the ultimate goal of creating distinct industrial digital ecosystems</td>
<td>Kiel et al. (2016, p. 689), Biahmou et al. (2016, p. 673), Arnold et al. (2016, p. 1640015-6)</td>
</tr>
</tbody>
</table>
Integrated database: The ANOVA results show that there is a significant difference between warehousing and shipping ($p < 0.001$, $95\% \text{ CI} [-0.73, -0.15]$).

Integrated interfaces: Similarly, there is a significant difference between warehousing and shipping ($p = 0.044$, $95\% \text{ CI} [-0.87, -0.01]$).

Consistent data/information flow: No significant difference was observed between warehousing and shipping ($p = 0.282$).

Mobile devices: There is a significant difference between warehousing and shipping ($p < 0.001$, $95\% \text{ CI} [-0.66, 0.28]$).

Digital mapping: A significant difference was observed between warehousing and shipping ($p = 0.046$).

Automated monitoring: No significant difference was observed between warehousing and shipping ($p = 0.210$).

Machine learning: No significant difference was observed between warehousing and shipping ($p = 0.338$).

Self-optimization: No significant difference was observed between warehousing and shipping ($p = 0.246$).

Partner integration: A significant difference was observed between warehousing and shipping ($p < 0.001$, $95\% \text{ CI} [-1.05, -0.28]$).

Overall, the results show that while all queried Industry 4.0 approaches seem to be highly relevant for order processing and shipping, the approaches are not as relevant for warehousing. In fact, the collected data imply that digitization in warehousing is generally less relevant, which can be attributed to the changing role of warehousing. Industry 4.0 supply chains require fewer inventories because of shorter cycle/lead times, better planning and more sophisticated forecasting capabilities. The mantra is: “less storage, more flow” (Harrington, 2004). Although the number of warehouses might decrease in the future, they will most likely not disappear as a relic of outdated business models. Inventory will still provide flexibility and act as the facilitator of last resort between supply and demand. The highest potential for digitization likely occur in the support of accurate warehouse/distribution functions and the provision of tracking and traceability (Harrington, 2004), which require a consistent data flow and automated process monitoring, the two highest-rated approaches.

The few answers provided to the open questions indicate the comprehensiveness of the surveyed Industry 4.0 approaches. Several participants noted a specific need to consider simulations for warehousing and shipping processes and the utilization of autonomous vehicles, robotics and RFID containers for warehousing processes.

When processing the gathered information, a top-down approach was chosen. The previous Industry 4.0 literature in combination with survey results was used to develop an Industry 4.0 vision for the delivery process. This vision populates the model for each DPMM 4.0 model element on the highest maturity stage: “Stage 5 – Optimized full digitization”. Subsequently, the content of the remaining four stages was gradually derived following three guidelines. Starting from the Industry 4.0 vision, each lower maturity stage was characterized by:

- more human interventions;
- lower inter- and intra-organizational integration; and
- less automatized data and information flows.

### Table V.

Results of the survey concerning Industry 4.0 approaches
3.2.4 Maturity model testing. After populating the model, it had to be tested for validity and reliability (De Bruin et al., 2005). For this development stage, the paper refers to Becker et al. (1995), who suggested principles for good model development, and Mettler (2010), who presented criteria to characterize the quality of a maturity model. The criteria taken into account included comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detailedness, conceptual reliability and applicability. These criteria were applied to the Industry 4.0 vision for the delivery process, that is, Stage 5 of the DPMM 4.0. Table VI provides a detailed description.

To assess the model, another online survey was initiated that consisted of two parts. First, experts were asked to assess the eight quality criteria for the three dimensions (order processing, warehousing and shipping). A four-tiered Likert scale (strongly disagree, fairly disagree, fairly agree and strongly agree) was used for this purpose. The participants were advised to select “not sure” if they lacked expertise. Additionally, open questions provided participants the opportunity to name important issues that have not been considered in the presented Industry 4.0 vision. Second, the respondents were asked for demographic information. Before data collection, the questionnaire was pre-tested by five experts from both industry and academia in terms of wording and design.

The 207 identified Industry 4.0 experts were invited to participate in July 2017. In total, 37 participants completed the survey, which equals a response rate of 19.8 per cent. Almost half of the respondents (43 per cent) had already shared their expertise during the first survey. Again, most of the participants indicated that they were from upper organizational hierarchy levels that included top (43 per cent) or middle (21 per cent) management. The majority of the respondents (78 per cent) worked for large corporations with over 250 employees. The only major differences between the first and the second survey were in terms of age and sex: the respondents were noticeably older (49.1 years old), and the proportion of men was even higher (94.6 per cent) in the second survey. Anomalies concerning response behavior were not found.

For all the queried quality criteria, the averages showed satisfactory values between 2.97 and 3.73 (Table VII). A one-way ANOVA showed only one significant difference between the three process groups: relevance. The post hoc Tukey test indicated that the populated Industry 4.0 vision is considered less relevant for order processing than for shipping processes ($p = 0.014, -0.44, 95\%\textnormal{-CI}[−0.81, −0.08]$). This finding in conjunction with the comparatively low value for detailedness led to a critical reflection of the respective model component. At this point, we are still confident that the model reflects

<table>
<thead>
<tr>
<th>Quality criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensibility</td>
<td>The Industry 4.0 vision is easy to understand</td>
</tr>
<tr>
<td>Comprehensiveness</td>
<td>The Industry 4.0 vision considers all relevant parameters</td>
</tr>
<tr>
<td>Relevance</td>
<td>The Industry 4.0 vision contains only elements that are important and consistent with the purpose of the maturity model</td>
</tr>
<tr>
<td>Consistency</td>
<td>The Industry 4.0 vision is inherently conclusive</td>
</tr>
<tr>
<td>Systematic structure</td>
<td>The Industry 4.0 vision displays a logical composition</td>
</tr>
<tr>
<td>Detailedness</td>
<td>The Industry 4.0 vision is ideal for a model with regard to the level of detail</td>
</tr>
<tr>
<td>Conceptual reliability</td>
<td>The Industry 4.0 vision fulfills the conception of Industry 4.0</td>
</tr>
<tr>
<td>Applicability</td>
<td>The Industry 4.0 vision supports the implementation of Industry 4.0</td>
</tr>
</tbody>
</table>
the relevant Industry 4.0 approaches and that an appropriate level of detail was applied. However, special attention will be paid to this specific model part during future implementations, and if necessary, changes will be made. The few answers to the open questions indicated the comprehensiveness of the surveyed Industry 4.0 vision. Several participants suggested the inclusion of the following aspects: suppliers’ delivery capacity, product surveillance during storage, considering customer requests despite the Frozen Zone and decision-making regarding the replacement of an initial product, the provision of spare parts or an appointment with service technicians when critical product conditions are reached.

3.3 Presentation of the final maturity model and initial deployment

Figure 1 provides an overview of the final model. The full version that includes the detailed description at the element level is available as a digital Appendix to this article. Compared with other approaches, DPMM 4.0 recognizes that every organization has a unique structure. Therefore, companies that use the model must examine their delivery process first to determine the relevant sD1 or sD2 SCOR process elements. Only these elements will be considered during the maturity assessment procedure.

The assessment begins with general information about the participating company (the number of employees, annual turnover and industry) to prepare potential internal or external benchmarking and to identify the production strategy in place. The participants are required to review the SCOR process elements for \( i = \{1, 2, 3\} \) model dimensions, including order processing \( \text{DIM}_1 = \{\text{sD1.1/sD2.1}, \text{sD1.2/sD2.2}, \text{sD1.3/sD2.3}, \text{sD1.4/sD2.4}, \text{sD1.15/sD2.15}\} \), warehousing \( \text{DIM}_2 = \{\text{sD1.8/sD2.8}, \text{sD1.9/sD2.9}, \text{sD1.10/sD2.10}\} \) and shipping \( \text{DIM}_3 = \{\text{sD1.5/sD2.5}, \text{sD1.6/sD2.6}, \text{sD1.7/sD2.7}, \text{sD1.11/sD2.11}, \text{sD1.12/sD2.12}, \text{sD1.13/sD2.13}, \text{sD1.14/sD2.14}\} \) and select the relevant ones, that is, \( R\text{DIM}_1 \subseteq \text{DIM}_1 \), \( R\text{DIM}_2 \subseteq \text{DIM}_2 \) and \( R\text{DIM}_3 \subseteq \text{DIM}_3 \). If the organization already uses the SCOR framework, then it may rely on available flow charts for this task. The chosen elements in dimension \( i \) are assigned to the consecutive index \( j(i) = \{1, \ldots, J(i)\} \). For each element DPMM 4.0 provides \( k(j(i)) = \{1, \ldots, K(j(i))\} \) statements that are evaluated on a four-tiered scale (0 = “not implemented”, 1 = “partly implemented”, 2 = “for the most part implemented” and 3 = “fully implemented”). The assessments \( a_{sD(i),k(j(i))} \) are converted to percentage scores for each model element (1), dimension (2) and the entire process (3) following these formulas:

<table>
<thead>
<tr>
<th>Quality criteria</th>
<th>Order processing Avg. (SD)</th>
<th>Warehousing Avg. (SD)</th>
<th>Shipping Avg. (SD)</th>
<th>F(df between groups, df within groups)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensibility</td>
<td>3.62 (0.49)</td>
<td>3.63 (0.49)</td>
<td>3.51 (0.51)</td>
<td>F(2, 106) = 0.62, p = 0.541</td>
</tr>
<tr>
<td>Comprehensiveness</td>
<td>3.12 (0.65)</td>
<td>3.24 (0.55)</td>
<td>3.27 (0.52)</td>
<td>F(2, 107) = 0.62, p = 0.540</td>
</tr>
<tr>
<td>Relevance</td>
<td>2.97 (0.62)</td>
<td>3.30 (0.64)</td>
<td>3.41 (0.66)</td>
<td>F(2, 99) = 4.48, p = 0.014</td>
</tr>
<tr>
<td>Consistency</td>
<td>3.50 (0.56)</td>
<td>3.50 (0.56)</td>
<td>3.56 (0.50)</td>
<td>F(2, 106) = 0.13, p = 0.882</td>
</tr>
<tr>
<td>Systematic structure</td>
<td>3.59 (0.55)</td>
<td>3.53 (0.56)</td>
<td>3.73 (0.45)</td>
<td>F(2, 106) = 1.37, p = 0.259</td>
</tr>
<tr>
<td>Detailedness</td>
<td>3.07 (0.74)</td>
<td>3.34 (0.70)</td>
<td>3.39 (0.61)</td>
<td>F(2, 92) = 2.06, p = 0.134</td>
</tr>
<tr>
<td>Conceptual reliability</td>
<td>3.26 (0.66)</td>
<td>3.40 (0.55)</td>
<td>3.42 (0.60)</td>
<td>F(2, 103) = 0.74, p = 0.481</td>
</tr>
<tr>
<td>Applicability</td>
<td>3.31 (0.71)</td>
<td>3.35 (0.54)</td>
<td>3.42 (0.55)</td>
<td>F(2, 103) = 0.30, p = 0.740</td>
</tr>
</tbody>
</table>

Table VII. Survey results regarding quality criteria
| Stage 1 – Basic digitization | Order processing is not digitized; manual exchange of data/information between order processing and other departments; the employed system supports only order-processing (department-specific) | Warehousing is not digitized; manual exchange of data/information between warehousing and other departments; the employed system supports only warehousing (department-specific) | Shipping is not digitized; manual exchange of data/information between shipping and other departments; the employed system supports only shipping (department-specific) |
| Stage 2 – Cross-department digitization | Order processing is digitally supported; electronic exchange of data/information between order processing and other departments; department-wide integration of order processing into enterprise systems | Warehousing is digitally supported; electronic exchange of data/information between warehousing and other departments; department-wide integration of warehousing into enterprise systems | Shipping is digitally supported; electronic exchange of data/information between shipping and other departments; department-wide integration of shipping into enterprise systems |
| Stage 3 – Horizontal and vertical digitization | Order processing is continuously digitally supported; automated flow of data/information within the company (e.g. order confirmation); shared, integrated interfaces (e.g. receipt of orders); recourse to company-specific data for order processing (e.g. determination of delivery date); company-wide integration of order processing into cloud-based IoT operating system; access to order processing information through mobile device | Warehousing is continuously digitally supported; automated flow of data/information within the company (e.g. planning picking waves); recourse to company-specific data for warehousing (e.g. product storage); company-wide integration of warehousing into cloud-based IoT operating system; access to warehousing information through mobile device | Shipping is continuously digitally supported; automated flow of data/information within the company (e.g. planning transportation mode); recourse to company-specific data for shipping process (e.g. delivery date); automated monitoring for full traceability; company-wide integration of shipping into cloud-based IoT operating system; access to shipping information through mobile device |
| Stage 4 – Full digitization | Automated real-time order processing is continuously digitally supported; automated real-time flow of data/information; recourse to customer-specific data as well as business partner data for comprehensive order processing (e.g. carrier’s capacity); supply chain-wide integration of order processing into cloud-based IoT operating system | Automated real-time warehousing is continuously digitally supported; automated real-time flow of data/information; recourse to customer-specific data for comprehensive warehousing (e.g. customized packaging); supply chain-wide integration of warehousing into cloud-based IoT operating system | Automated real-time shipping is continuously digitally supported; automated real-time flow of data/information; recourse to customer-specific data as well as business partner data for comprehensive shipping (e.g. customer’s preferred routes); supply chain-wide integration of shipping into cloud-based IoT operating system |
| Stage 5 – Optimized full digitization | Automated real-time order processing is continuously digitally supported within the supply chain; real-time simulation for decision making (e.g. order confirmation); real-time optimization (e.g. determination of delivery date); self-learning abilities from solved cases; supply chain-wide integration of order processing into self-optimizing cloud-based IoT operating system | Automated real-time warehousing is continuously digitally supported within the supply chain; real-time simulation for decision making (e.g. cost-effective packaging); real-time optimization (e.g. routes of autonomously acting transportation system); real-time self-adjustment to changing environment; self-learning abilities from solved cases; supply chain-wide integration of warehousing into self-optimization cloud-based IoT operating system | Automated real-time shipping is continuously digitally supported within the supply chain; real-time simulation for decision making (e.g. efficient grouping of orders); real-time optimization (e.g. shipping routes); real-time self-adjustment to changing environment; self-learning abilities from solved cases; supply chain-wide integration of shipping into self-optimization cloud-based IoT operating system |

Figure 1. Overview of the DPMM 4.0
• The potential element score $PES_{i,j(i)}$, the achieved element score $AES_{i,j(i)}$, and the relative element score $RES_{i,j(i)}$:

$$PES_{i,j(i)} = K(j(i)) \times 3 \quad \forall i, j(i)$$

$$AES_{i,j(i)} = \sum_{k(j(i))=1}^{K(j(i))} \text{as}_{i,j(i),k(j(i))} \quad \forall i, j(i)$$

$$RES_{i,j(i)} = \frac{AES_{i,j(i)}}{PES_{i,j(i)}} \times 100\% \quad \forall i, j(i)$$

• The relative dimension score $RDS_i$:

$$RDS_i = \frac{\sum_{j(i)=1}^{f(i)} AES_{i,j(i)}}{\sum_{j(i)=1}^{f(i)} PES_{i,j(i)}} \times 100\% \quad \forall i$$

• The total relative process score $TRPS$:

$$TRPS = \frac{\sum_{i=1}^{3} \sum_{j(i)=1}^{f(i)} AES_{i,j(i)}}{\sum_{i=1}^{3} \sum_{j(i)=1}^{f(i)} PES_{i,j(i)}} \times 100\%$$

Finally, the relative score is converted into a maturity stage. With the five stages describing a path towards excellence, the scale is evenly distributed. That is, the first stage corresponds to a score between 0 and 20 per cent, the second stage to a score between 20 and 40 per cent, the third stage to a score between 40 and 60 per cent, the fourth stage to a score between 60 and 80 per cent, and the fifth stage to a score between 80 and 100 per cent.

The cascading structure allows for a brief initial overview of the delivery process’s maturity, which serves a descriptive purpose. For the prescriptive purpose, the process elements with the lowest scores must be identified since they present the greatest digitization deficits. Because those elements are a bottleneck to the entire process, these areas must be addressed first. A case-specific development path can be derived by reviewing the detailed description of the next maturity level and the respective assessment statements to determine the requirements for ascending the maturity ladder. However, applicants should not automatically strive for the highest level. Rather, critical reflection is required to determine whether a specific measure makes sense economically. Thus, a cost-benefit analysis must be performed, and whether the measures fit the organizational and supply chain-specific objectives must be determined.
The final DPMM 4.0 has been successfully deployed at a company that supported the development as a stakeholder. The management of the multinational firm was highly interested in a tool that complements their already used maturity model for manufacturing processes. DPMM 4.0 has been used to assess, benchmark and compare two sites with what finally led to the derivation of a roadmap toward excellence in the company’s delivery processes. The corresponding detailed case study has been published in a separate article (Felch et al., 2018).

4. Summary, limitations and outlook
Our initial literature review shows that previous maturity models in the Industry 4.0 context have focused on the production processes in manufacturing firms. Nevertheless, the Industry 4.0 idea also influences the upstream and downstream stages of value creation in industrial companies. In the long run, the exclusive consideration of production processes will be insufficient when the involvement of other value creation stages (e.g. sourcing or logistics) is disregarded. Without the expansion of the Industry 4.0 idea to the entire industrial value chain, the capabilities of Industry 4.0 cannot be completely exploited, and the accruing competitive advantages cannot be deployed.

Against this background, this paper closes a research gap by providing a theoretically grounded, methodologically rigorous development of a maturity model for the delivery processes of manufacturing firms. The value of the presented model resides in the combination of scientific rigor, practical relevance, and direct applicability. Röglinger et al. (2012, p. 328) called for more “[…] elaborate support by means of ready-to-use and adaptable instruments for maturity assessment and improvement.” DPMM 4.0 is both ready-to-use and adaptable. The tool is directly applicable because of its extensive documentation. Despite the limited space in peer-reviewed articles, this paper describes the model’s scope, purpose of use, structure (maturity stages, dimensions and elements), target groups, potential assessment methods and the maturity score calculations. The adaptability is derived from the model’s reference to the SCOR framework. Because SCOR is successfully and widely used in business practice, we believe that it is the ideal basis for process maturity models. Therefore, from a theoretical perspective, our approach might serve as the blueprint for maturity models of other value-adding processes that have also received limited consideration until now (e.g. the sourcing process). The modularized structure makes DPMM 4.0 generic as well as customizable.

With regard to business practice, this work provides detailed knowledge on how to digitize outbound logistics, which could become a critical bottleneck on the path toward a connected and smart supply chain. The developed model is a good starting point for practitioners who seek to ensure the competitiveness of their distribution processes in the digital age ahead. In short, DPMM 4.0 allows an organization to determine its current maturity level in each delivery sub-process, to compare its current maturity level with other sites, business units and/or companies, to develop a corporate vision for delivery logistics excellence, to identify potential improvement measures and to provide guidance on the development path.

There are also limitations to this study. First, maturity models have generally been subject to criticism (Albliwi et al., 2014) with certain authors arguing that these models oversimplify reality and that their fundamental stage hypothesis lacks an empirical foundation (Benbasat et al., 1984). However, several case studies have shown the benefits of maturity models (Isoherranen et al., 2015). These models have been successfully applied in business practice and represent a popular tool for developing operational excellence to strengthen corporate and supply chain competitiveness. Second, although the development process has been supported by both previous publications and empirical work, these expert opinions and judgments still contain a certain degree of subjectivity. Moreover, the model
population and evaluation process was mostly based on experts from German industrial companies, which imposes a potential regional bias. Therefore, further research should consider a more international perspective.

Moreover, although the concept of Industry 4.0 may have reached a degree of maturity, it is still an evolving concept. Therefore, critical assessments are required to determine whether the highest maturity stage continues to reflect the current technological state-of-the-art. With the further emergence of digitization aspects, the model will have to be reviewed. In this regard, the model might benefit from its reference to the SCOR model, which is further developed on an ongoing basis. Relevant structural changes in the delivery process would be considered in the SCOR framework. Therefore, future versions should be compared with the current SCOR 12 and potential changes regarding the delivery process elements should trigger a subsequent revision of DPMM 4.0 elements. Additionally, the development of new delivery process technologies might necessitate additional assessment statements or further maturity levels for drastic changes.

Tarhan et al. (2016, p. 130) highlight that “[...] the attention in research has been at the development and release of models, while empirical works on the validation of these models are few and far between.” Notwithstanding the successful application of the model at a multinational company from the electronics industry (Felch et al., 2018), this criticism also applies to this paper. The authors are currently working on providing further case studies that demonstrate the model’s applicability. However, because additional empirical verifications are always warranted, future research should aim to further exemplify the generalizability of DPMM 4.0.

Despite these limitations, we are confident that our work is suitable for providing structured insights in the digitization of outbound logistics, an important value-adding activity in SCM. Herein, this study adds another piece to the puzzle for the purpose of supporting today’s manufacturing firms and their supply chains in the development of tomorrow’s digital equivalents.

References


Appendix. DPMM 4.0 – model documentation

Content

- Process inquiry and quote (sD1.1/sD2.1)
- Receive (configure), enter and validate order (sD1.2/sD2.2)
- Reserve inventory and determine delivery date (sD1.3/sD2.3)
- Consolidate orders (sD1.4/sD2.4)
- Build loads (sD1.5/sD2.5)
- Route shipments (sD1.6/sD2.6)
- Select carriers and rate shipments (sD1.7/sD2.7)
- Receive product from source or make (sD1.8/sD2.8)
- Pick product (sD1.9/sD2.9)
- Pack product (sD1.10/sD2.10)
- Load vehicle/product and generate shipping docs (sD1.11/sD2.11)
- Ship product (sD1.12/sD2.12)
- Receive and verify product by customer (sD1.13/sD2.13)
- Install product (sD1.14/sD2.14)
- Invoice (sD1.15/sD2.15)
Process inquiry and quote (sD1.1/sD2.1)
“Receive and respond to general customer inquiries and requests for quotes.”  (SCOR, 2017, p. 2.5.6 and p. 2.5.26)

Stage 1 – Basic digitization
- Electronic receipt of customer inquiries and request for quotes via phone, fax or e-mail;
- Manual data entry in the company’s order processing system;
- Manual procurement and analysis of relevant information (e.g. production and delivery data); and
- Manual response to customer inquiries and request for quotes via phone, fax or e-mail.

Stage 2 – Cross-department digitization
- Electronic receipt of customer inquiries and request for quotes via standardized interface;
- Manual verification of transmission, correction and addition of data;
- Electronic assembly of relevant information in a one-page format; and
- Electronic response to customer inquiries and request for quotes via standardized interface.

Stage 3 – Horizontal and vertical digitization
- Automatic receipt of customer inquiries and request for quotes via standardized interface;
- Guarantee of correct filling due to stored metadata;
- In cases of failure: color-marking of the respective fields, notification of the responsible parties and manual correction of data;
- Recourse to company-specific data (e.g. production and delivery data) when creating response;
- Automatic response to customer inquiries and request for quotes via standardized interface; and
- Access to order processing information through mobile devices.

Stage 4 – Full digitization
- Automated real-time receipt of customer inquiries and request for quotes;
- Recourse to customer-specific data if the business partner already exists in the system;
- Recourse to carrier data or experience; and
- Automated real-time response to customer inquiries and request for quotes.

Stage 5 – Optimized full digitization
- Real-time simulation for decision-making;
- Automated analysis of customer inquiries, request for quotes or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Receive (, configure), enter and validate order (sD1.2/sD2.2)
“Receive orders from the customer and enter them into a company’s order processing system. Orders can be received through phone, fax, or electronic media. (Configure your product to the customer’s specific needs, based on standard available parts or options.) Technically’ examine orders to ensure an orderable configuration and provide accurate price. Check the customer’s credit. Optionally accept payment.”  (SCOR, 2017, p. 2.5.7 and p. 2.5.27)
Stage 1 – Basic digitization

- Electronic receipt of customer order via phone, fax or e-mail;
- Manual data entry in the company’s order processing system;
- Manual procurement and analysis of relevant information from various IT systems;
- Manual verification for orderable configuration and calculation of accurate price;
- Manual check of customers’ credit;
- (Manual configuration of product to the customer’s need or request based on standard available parts or other offered options);
- Electronic order confirmation via phone, fax or e-mail;
- Electronic transmission of order modifications via phone, fax or e-mail;
- Manual verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Manual revision of cost situation and calculation of price adjustments; and
- Electronic message to inform the customer about decision on approval or rejection.

Stage 2 – Cross-department digitization

- Electronic receipt of order via standardized interface;
- Manual verification of transmission, correction and addition of data;
- Electronic assembly of relevant data in one-page format;
- Electronically supported verification for orderable configuration and calculation of accurate price;
- Electronically supported check of customers’ credit;
- (Electronically supported configuration of product to the customer’s need or request based on standard available parts or other offered options);
- Electronic order confirmation via standardized interface;
- Electronic transmission of order modifications via standardized interface;
- Electronically supported verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Electronically supported revision of cost situation and calculation of price adjustments; and
- Automated message to inform the customer about decision on approval or rejection.

Stage 3 – Horizontal and vertical digitization

- Automatic transmission of order via standardized interface;
- Guarantee of correct filling due to stored metadata;
- In cases of failure: colored marking of the respective fields, notification of the responsible parties and manual correction of data;
- Automated procurement of missing data;
- Recourse to company-specific information (e.g. current and future production and delivery utilization, electronically stored flow charts) for analyzing order status;
- Automated verification for orderable configuration and calculation of accurate price;
- Automated check of customer’s credit;
- (Automated configuration of product to the customer’s need or request based on standard available parts or other offered options);
Stage 4 – Full digitization

- Automated real-time transmission of order into order processing system;
- Automated real-time procurement of missing data;
- Automated linkage of order and existing customer information;
- Recourse to business partner information when analyzing order status (e.g. real-time order status of carrier, delivery capability of suppliers and of factories from production networks, material flow tracking);
- Automated real-time verification for orderable configuration and calculation of accurate price;
- Automated real-time check of customer’s credit;
- (Automated real-time configuration of product to the customer’s need or request based on standard available parts or other offered options);
- Automated real-time transmission of order confirmation;
- Automated real-time transmission of order modifications;
- Automated verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Automated revision of the cost situation and calculation of price adjustments;
- Automated message to inform the customer and responsible parties about decision on approval or rejection; and
- Business partner access to all the order data and real-time traceability (e.g. order status, location, delivery date, free possibilities for change, change of the delivery date, progress monitoring) via database of IoT operating system.

Stage 5 – Optimized full digitization

- Automated real-time verification of modifications based on 3D-simulation (e.g. feasibility analysis, availability check of material, capacity check);
- Automated real-time revision of cost situation and calculation of price adjustments;
- Automated analysis of new order status (e.g. postponement of the delivery date);
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of data transmission, verification of orderable configuration, cost calculation or verification of order modifications in case of failure; and
- Self-learning abilities from solved cases of failure.

Reserved inventory and determine delivery date (sD1.3/sD2.3)

“Inventory (both on hand and scheduled) is identified and reserved for specific orders and a delivery date is committed and scheduled.” (SCOR, 2017, p. 2.5.8 and p. 2.5.28)
Stage 1 – Basic digitization

- Manual identification and reservation of inventory (on hand or scheduled) in company’s order processing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. availability of capacities and resources, production capacity);
- Manual scheduling of delivery date;
- Confirmation of delivery date to customer and carrier via phone, fax or e-mail; and
- Manual rescheduling of delivery date and confirmation in case of rejection by customer.

Stage 2 – Cross-department digitization

- Electronically supported identification and reservation of inventory (on hand or scheduled) in company’s system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported scheduling of delivery date;
- Electronic confirmation of delivery date to customer and carrier via standardized interface; and
- Electronically supported rescheduling of delivery date and confirmation in case of rejection by customer.

Stage 3 – Horizontal and vertical digitization

- Automated identification and reservation of inventory (on hand or scheduled) in cloud-based IoT operating system;
- Automated scheduling of delivery date;
- Recourse to company-specific parameters (e.g. availability of resources, production capacity, average delivery time, electronically stored flow charts, country-specific requirements);
- Automated transmission of delivery date to customer and carrier via standardized interface;
- Automated rescheduling of delivery date and confirmation in case of rejection by customer; and
- Access to information for reservation of inventory and determination of delivery date through mobile devices.

Stage 4 – Full digitization

- Automated real-time identification and reservation of inventory (on hand or scheduled) in cloud-based IoT operating system;
- Automated real-time scheduling of delivery date;
- Recourse to carrier experience for scheduling (e.g. average transportation time, carrier availability and free capacity);
- Recourse to customer-specific data or requests (e.g. opening hours of receiving department, country-specific holidays, preferred delivery date, precautions for delivery)
- Automated real-time transmission of delivery date to customer and carrier via standardized interface;
- Automated real-time rescheduling of delivery date and confirmation in case of rejection by customer;
Within Frozen Zone: no consideration of further customer requests due to status of shipment; and
Postponement of delivery date by customer via access to cloud-based IoT operating system.

**Stage 5 – Optimized full digitization**

- Automated real-time rescheduling of delivery date in case of short-term changes (e.g. delays of sourcing, production, carrier);
- Autonomous real-time confirmation to customer and notification of responsible parties;
- Automated analysis of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of inventory reservation, scheduling of delivery date or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

**Consolidate orders (sD1.4/sD2.4)**

“The process of analyzing orders to determine the groupings that result in least cost/best service fulfillment and transportation.” *(SCOR, 2017, p. 2.5.9 and p. 2.5.29)*

**Stage 1 – Basic digitization**

- Manual analysis of orders (same customer) in company’s order processing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision making for an ideal order bundling; and
- Response to customer about most favorable variant via phone, fax or e-mail.

**Stage 2 – Cross-department digitization**

- Electronically supported analysis of orders (same customer) in company’s system.
- Electronic assembly of relevant information in a one-page format.
- Electronically supported comparison of data and decision making for an ideal order bundling.
- Electronic response to customer about most favorable variant via standardized interface.

**Stage 3 – Horizontal and vertical digitization**

- Automated analysis of orders (same customer) in cloud-based IoT operating system;
- Recourse to order-specific data and parameters (e.g. transportation criteria, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
- Automated comparison of data, forecasting and decision making for an ideal order bundling;
- Automated response to customer about most favorable variant via standardized interface; and
- Access to information for order bundling through mobile devices.

**Stage 4 – Full digitization**

- Automated real-time analysis of orders (same customer) in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability and free capacity, dimensions of transport space);
Stage 5 – Optimized full digitization

- Automated real-time adaptation of bundles in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of bundles based on different criteria (e.g. cost savings, service fulfillment, customer satisfaction, recourse to parameters, carrier information, customer requests);
- Automated analysis of bundles or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Build loads (sD1.5/sD2.5)
“Transportation modes are selected and efficient loads are built.” (SCOR, 2017, p. 2.5.10 and p. 2.5.30)

Stage 1 – Basic digitization

- Manual selection of transportation modes (types: overland transport (e.g. road, rail, pipeline), maritime transportation (e.g. inland waterways, ocean), air transportation, combined or intermodal transportation) in company’s shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, costs of transportation mode, efficiency, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision-making concerning transportation modes;
- Manual analysis of orders or order bundles (various customers) in company’s shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, special requirements (e.g. hazmat, cross-border transportation, transport volume));
- Manual comparison of data and decision making for an ideal order bundling; and
- Response to customer about most favorable variant (transportation mode, efficient load) via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported selection of transportation modes in company’s system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making concerning transportation modes;
• Electronically supported analysis of orders or order bundles (various customers) in company's system;
• Electronic assembly of relevant information in a one-page format;
• Electronically supported comparison of data and decision making for an ideal order bundling; and
• Electronic response to customer about most favorable variant (transportation mode, efficient load) via standardized interface.

Stage 3 – Horizontal and vertical digitization

• Automated selection of transportation modes in cloud-based IoT operating system;
• Recourse to order-specific data and parameters (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, costs of transportation mode, efficiency, special requirements [e.g. hazmat, cross-border transportation, status of shipment, reliability of transportation modes]);
• Automated comparison of data and decision making concerning transportation modes;
• Automated analysis of orders or order bundles (various customers) in cloud-based IoT operating system;
• Recourse to order-specific data and parameters (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
• Automated comparison of data, forecasting as well as decision-making for an ideal order bundling;
• Automated response to customer about most favorable variant (transportation mode, efficient load) via standardized interface; and
• Access to information of transportation mode and efficient load through mobile devices.

Stage 4 – Full digitization

• Automated real-time selection of transportation modes in cloud-based IoT operating system;
• Recourse to carrier information (e.g. real-time carrier availability and free capacity);
• Recourse to customer requests (e.g. preferred transportation modes) via access to cloud-based IoT operating system;
• Within Frozen Zone: no consideration of further customer requests due to status of shipment;
• Automated real-time analysis of orders or order bundles (various customers) in cloud-based IoT operating system;
• Recourse to carrier information (e.g. real-time carrier free capacity, dimensions of transport space);
• Recourse to customer requests (e.g. preferred delivery date) via access to cloud-based IoT operating system; and
• Automated real-time response to customer about most favorable variant (transportation mode, efficient load).

Stage 5 – Optimized full digitization

• Automated real-time adaptation of bundles or transportation mode in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria);
• Automated real-time response to customer and notification of responsible parties;
Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
Automated analysis of bundles as well as transportation mode based on different criteria (e.g. cost savings, service fulfillment, customer satisfaction, recourse to parameters, carrier information, customer requests);
Automated analysis of bundles, transportation mode or data transmission in case of failure; and
Self-learning abilities from solved cases of failure.

Route shipments (sD1.6/sD2.6)
“Loads are consolidated and routed by mode, lane and location.” (SCOR, 2017, p. 2.5.11 and p. 2.5.31)

Stage 1 – Basic digitization
- Manual route planning in company’s shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. grouping of orders, transportation mode and criteria, product destination, delivery date, costs, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision making concerning route planning; and
- Response to customer about most favorable route via phone, fax or e-mail.

Stage 2 – Cross-department digitization
- Electronically supported route planning in company’s system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making concerning route planning; and
- Electronic response to customer about most favorable route via standardized interface.

Stage 3 – Horizontal and vertical digitization
- Automated route planning in cloud-based IoT operating system;
- Recourse to order-specific data and parameters (e.g. grouping of orders, transportation mode and criteria, product destination, delivery date, costs, special requirements [e.g. hazmat, cross-border transportation, route safety]);
- Automated comparison of data and decision-making concerning route planning;
- Automated response to customer about most favorable route via standardized interface; and
- Access to information for route planning through mobile devices.

Stage 4 – Full digitization
- Automated real-time route planning in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability);
- Recourse to customer requests (e.g. preferred routes) via access to cloud-based IoT operating system;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment; and
- Automated real-time response to customer about most favorable route via standardized interface.
Stage 5 – Optimized full digitization

- Automated real-time rescheduling of routes in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria, delay of carrier);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of planned routes based on different criteria (e.g. service fulfillment, customer satisfaction, recourse to parameters, carrier information and customer requests);
- Automated analysis of planned routes or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Select carriers and rate shipments (S1D1.7/S2D.7)

“Specific carriers are selected by lowest cost per route and shipments are rated and tendered.” (SCOR, 2017, p. 2.5.12 and p. 2.5.32)

Stage 1 – Basic digitization

- Manual carrier selection in company’s shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. grouping of orders, transportation modes, route planning, transport criteria, mode of shipment, product destination, price, priority of distribution);
- Manual comparison of data and decision-making concerning carrier selection;
- Manual commissioning of carrier (informing about decision on approval or rejection) via phone, fax or e-mail; and
- Manual transmission of necessary product data, documents and company-specific transport specifications to the carrier via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported carrier selection in company’s system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making concerning carrier selection;
- Electronically supported commissioning of carrier (informing about decision on approval or rejection) via standardized interface; and
- Electronic transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated carrier selection in cloud-based IoT operating system;
- Recourse to different parameters (e.g. groupings of orders, priority of distribution, transport criteria, mode of shipment, product destination, price, technical facilities for product monitoring, route practicability (shortest, fastest, resource-saving route), availability of integrated status measurement devices (e.g. monitoring of the mechanical load, moisture, GPS tracking, carrier reliability, product-specific transportation criteria, routing, means of transport and implementation of company-specific guidelines);
- Automated comparison of data and decision making concerning carrier selection;
• Automated commissioning of carrier (informing about decision on approval or rejection) via standardized interface;
• Automated transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface; and
• Access to information for carrier selection through mobile devices.

Stage 4 – Full digitization

• Automated real-time carrier selection in cloud-based IoT operating system;
• Recourse to carrier information (e.g. real-time carrier availability and free capacity, company-specific Incoterms);
• Recourse to customer requests (e.g. mode of shipment) via access to cloud-based IoT operating system;
• Within Frozen Zone: no consideration of further customer requests due to status of shipment;
• Automated real-time commissioning of carrier (informing about decision on approval or rejection) via standardized interface; and
• Automated real-time transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface.

Stage 5 – Optimized full digitization

• Automated real-time selection of carrier in case of short-term changes (e.g. postponement of delivery date, delay of carrier);
• Automated real-time response to customer and notification of responsible parties;
• Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
• Automated analysis of carrier selection based on different criteria (e.g. service fulfillment);
• Automated analysis of carrier selection or data transmission in case of failure; and
• Self-learning abilities from solved cases of failure.

Receive product from source or make (sD1.8/sD2.8)
“The activities such as receiving product, verifying, recording product receipt, determining put-away location, putting away and recording location that a company performs at its own warehouses. May include quality inspection.” (SCOR, 2017, p. 2.5.13 and p. 2.5.33)

Stage 1 – Basic digitization

• Manual planning of picking waves in company’s warehousing system;
• Manual rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
• Product reception by storekeeper;
• Transmission of product information through manual scanning procedures (direct, visual contact);
• Manual product verification by storekeeper;
• Manual product arrangement in the warehouse based on, e.g. turnover rate, size of product;
• Manual sorting and shelving of received products;
• No product surveillance in the warehouse; and
• Manual recording of product location in the warehouse.
**Stage 2 – Cross-department digitization**

- Electronically supported planning of picking waves in company’s system;
- Electronically supported rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
- Transmission of stored product information via passive RFID transponder;
- Product verification by storekeeper supported through wearables (especially glasses);
- Relevant information situated in the field of view;
- Product arrangement by storekeeper supported through wearables (especially glasses);
- Display of storage location in warehouse and fastest route;
- Manual sorting and shelving of received products;
- Surveillance of product in the warehouse through 360° camera; and
- Electronically supported recording of product location in the warehouse.

**Stage 3 – Horizontal and vertical digitization**

- Automated planning of picking waves in cloud-based IoT operating system;
- Automated product reception by autonomously acting transportation system;
- Use of specific routes to navigate the transportation system;
- Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles);
- Automated transmission of relevant product information and documents via active RFID;
- Automated product verification via sensors;
- Automated intelligent product arrangement in warehouse based on turnover rate, size of product;
- Automated sorting and shelving of received products in RFID container;
- Product surveillance in the warehouse through sensors;
- Automated notification of responsible parties when reaching critical levels (e.g. humidity, temperature);
- Automated recording of product location in warehouse system; and
- Access to information for picking waves and storage of products through mobile device.

**Stage 4 – Full digitization**

- Automated real-time planning of picking waves in cloud-based IoT operating system;
- Automated real-time rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
- Automated real-time transmission of relevant product information and documents via active RFID;
- Real-time product surveillance in the warehouse through sensors; and
- Automated real-time notification of responsible parties when reaching critical levels (e.g. humidity, temperature).

**Stage 5 – Optimized full digitization**

- Automated real-time rescheduling of picking waves in case of delay (e.g. sourcing or production delays, carrier delays);
Automated route analysis of autonomously acting transportation system;
Automated real-time optimization of transportation system routes and of warehouse space for optimized utilization;
Automated rearrangement of products for an ideal autonomously acting transportation system with an optimized material flow;
Automated real-time notification and initiation of countermeasures when product reaches critical levels (e.g. humidity, temperature);
Automated analysis of surveillance data or data transmission in case of failure; and
Self-learning abilities from solved cases of failure.

Pick product (sD1.9/sD2.9)
“The series of activities including retrieving orders to pick, determining inventory availability, building the pick wave, picking the product, recording the pick and delivering product to shipping in response to an order.” (SCOR, 2017, p. 2.5.14 and p. 2.5.34)

Stage 1 – Basic digitization
• Manual retrieval of the required order;
• Manual determination of inventory availability;
• Manual planning of picking waves in the company’s shipping system;
• Manual rescheduling of picking waves in case of delay;
• Product collection by picker from storage location and delivery to shipping;
• Product verification by picker;
• Manual acquisition of picking the order from warehouse; and
• Manual product delivery to the previously defined loading point.

Stage 2 – Cross-department digitization
• Electronically supported retrieval of the required order;
• Electronically supported determination of inventory availability;
• Electronically supported planning of picking waves in the company’s system;
• Electronically supported rescheduling of picking waves in case of delay;
• Product collection by picker supported through wearables (especially glasses);
• Relevant information situated in the field of view;
• Display of production location in warehouse and fastest route or picking waves;
• Product verification through connection of glasses with passive RFID transponder;
• Electronically supported acquisition of picking the order from warehouse; and
• Electronically supported product delivery to the previously defined loading point.

Stage 3 – Horizontal and vertical digitization
• Automated retrieval of the required order;
• Automated determination of inventory availability;
• Automated planning of picking waves in cloud-based IoT operating system;
• Automated rescheduling of picking waves in case of delay (e.g. sourcing or production delay);
• Product collection from RFID container by autonomously acting transportation system;
• Use of specific routes to navigate the transportation system through warehouse;
• Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles);
• Automated product verification through sensors;
• Automated acquisition of picking the order from warehouse;
• Automated product delivery to previously defined loading point; and
• Access to information for product picking through mobile devices.

Stage 4 – Full digitization
• Automated real-time retrieval of the required order;
• Automated real-time determination of inventory availability;
• Automated real-time planning of picking waves in cloud-based IoT operating system;
• Automated real-time rescheduling of picking waves in case of delay (e.g. delay of sourcing, production or carrier); and
• Recourse to carrier information (e.g. carrier’s expected arrival time) for automated scheduling of picking waves.

Stage 5 – Optimized full digitization
• Automated real-time rescheduling of picking waves in case of delay (e.g. carrier delays);
• Automated real-time planning of picking waves in cloud-based IoT operating system;
• Automated route analysis of autonomously acting transportation system;
• Automated real-time optimization of transportation system routes;
• Automated analysis of planned picking waves, planned routes and product delivery to loading point or data transmission;
• Automated analysis of planned picking waves, planned routes and product delivery to loading point or data transmission in case of failure; and
• Self-learning abilities from solved cases of failure.

Pack product (sD1.10/sD2.10)
“The activities such as sorting/combining the products, packing/kitting the products, paste labels, barcodes etc. and delivering the products to the shipping area for loading.” (SCOR, 2017, p. 2.5.15 and p. 2.5.35)

Stage 1 – Basic digitization
• Manual sorting and combining of products to efficient bundles;
• Manual procurement and analysis of relevant information from various IT systems
• Product verification by picker;
• Manual configuration of an efficient (space saving) and resource-conserving packaging/packaging units with regard to product and logistic requirements, profitability and sustainability;
• Clear product identification via optical procedure (e.g. barcode, QR code);
• Electronic creation of product label;
• Transmission of product information through manual scanning procedures (direct, visual contact);
Stage 2 – Cross-department digitization

- Electronically supported sorting and combining of products to efficient bundles;
- Picker supported through wearables (especially glasses);
- Relevant information situated in the field of view;
- Display of necessary information for sorting and combining the right products;
- Product verification through connection of glasses with passive RFID transponder of product;
- Electronically supported configuration of an efficient (space saving) and resource-conserving packaging/packaging units with regard to product and logistic requirements, profitability and sustainability;
- Integration of passive RFID transponder into packaging;
- Clear product identification via radio-based procedure (e.g. passive RFID);
- Transmission of stored information (e.g. delivery note) via passive RFID transponder;
- Electronically supported verification whether label information’s correspond to content of supporting documents;
- Product surveillance during shipping with 360° camera;
- Electronically supported planning of picking waves in company’s system;
- Product collection by picker supported through wearables (especially glasses) and delivery to clearly marked loading area;
- Relevant information situated in the field of view; and
- Display of warehouse location of the product and fastest way to the loading area.

Stage 3 – Horizontal and vertical digitization

- Automated sorting and combining of products to efficient bundles by autonomously acting robot order-picking system;
- Product verification through active RFID transponder;
- Automated configuration of an efficient (space saving) and resource-conserving packaging/packaging units;
- Recourse to the packaging-specific parameters (e.g. profitability, sustainability, country-specific regulations, transport mode, price);
- Automated integration of sensors into packaging for monitoring changing circumstances;
- Sensor-reading of changing circumstances or environmental stimuli (e.g. humidity, temperature, mechanical load, shocks, tilts);
- Automated identification via sensors if packaging can be reused or recycled;
- Clear product identification via radio-based procedure (e.g. active RFID);
- Automated transmission of stored information (e.g. production and delivery information, order information) and documents (e.g. shipping documents) to RFID reader;
• Automated product surveillance during shipping via integrated sensors;
• Automated planning of picking waves in cloud-based IoT operating system;
• Product collection from RFID container by autonomously acting transportation system and delivery to clearly marked loading area;
• Use of specific routes to navigate the transportation system to loading area;
• Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles); and
• Access to information of product packaging through mobile devices.

Stage 4 – Full digitization

• Automated real-time sorting and combining of products to efficient bundles by autonomously acting robot order-picking system;
• Recourse to carrier information (e.g. delay, current utilization) for automated resorting and recombining of products to efficient bundles by robot order-picking system;
• Automated real-time configuration of an efficient (space saving) and resource-conserving packaging/packaging units;
• Recourse to customer requests or requirements (e.g. customized packaging design, receiving department’s measurement, customer’s storage, customer-specific texts) for product packaging via access to cloud-based IoT operating system;
• Recourse to carrier experience (e.g. manageability of product packaging) for product packaging; and
• Recourse to carrier information (e.g. delay) for rescheduling the product collection and delivery to clearly marked loading area or temporary storage.

Stage 5 – Optimized full digitization

• Automated real-time selection of the most suitable and cost-effective packaging/packaging units obtained by use of 3D-simulation;
• Automated real-time influence of carrier experience (e.g. manageability of product packaging) on packaging decisions;
• Automated interchange of the integrated IT system with IT systems of other factories for identification of practicable best practices and deduction of necessary measures;
• Automated search for new potentials and trends with regards to packaging solutions/improvements;
• Automated evaluation and implementation on the basis of sustainability and profitability;
• Automated analysis of data transmission, combination of products, configuration of packaging or integration of sensors in case of failure;
• Self-learning abilities from solved cases of failure;
• Automated route analysis of the autonomously acting transportation system;
• Automated real-time optimization of transportation system routes; and
• Automated real-time rescheduling of picking waves in case of short-term changes.

Load vehicle/product and generate shipping docs (sD1.11/sD2.11)

“The series of tasks including placing/loading product onto modes of transportation, and generating the documentation necessary to meet internal, customer, carrier and government needs. Shipping documentation includes the invoice. Optionally verify customer credit.” (SCOR, 2017, p. 25.16-17 and p. 25.36)
Stage 1 – Basic digitization

- Message to carrier including loading area’s location data and relevant information via phone, fax or e-mail;
- Manual planning of outbound logistics in company’s shipping system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. number of orders, transportation mode, carrier’s arrival time);
- Manual rescheduling of outbound logistics in case of internal delays;
- Manual notification about rescheduling to responsible parties;
- Transmission of production data and accompanying documents through manual scanning procedures;
- Loading of product onto transportation mode by picker;
- Manual documentation of the loading process;
- Manual inspection of the “legal safety standards” checklist (e.g. load security, transportation quality) for supply chain security; and
- Manual documentation of the execution and defects as well as development of measures in case of gaps.

Stage 2 – Cross-department digitization

- Message to carrier including loading area’s location data and relevant information via standardized interface;
- Electronically supported planning of outbound logistics in company’s system;
- Electronic assembly of relevant data in a one-page format;
- Electronically supported rescheduling of outbound logistics in case of internal delays;
- Electronically supported notification about rescheduling to responsible parties;
- Transmission of product data and accompanying documents via passive RFID transponder;
- Loading of product onto transportation modes by picker (supported through wearables – especially glasses);
- Relevant information situated in the field of view;
- Display of required loading equipment (e.g. lifting tool) and accurate lifting and carrying of (heavy) loads;
- Electronically supported documentation of the loading process; and
- Electronically supported documentation of the execution and defects as well as development of measures in case of gaps.

Stage 3 – Horizontal and vertical digitization

- Automated message to carrier including loading area’s location data and relevant information via standardized interface;
- Automated planning of outbound logistics in cloud-based IoT operating system;
- Automated rescheduling of outbound logistics in case of internal delays;
- Automated notification about rescheduling to responsible parties;
- Automated transmission of product data and accompanying documents via active RFID;
- Automated planning of product loading onto transportation mode and of necessary loading equipment (e.g. lifting tool);
• Loading of product onto transportation mode by picker supported through intelligent containers with self-unloading function;
• Automated documentation of the loading process;
• Automated inspection of the ‘legal safety standards’ checklist for supply chain security;
• Automated documentation of the execution and defects as well as development of measures in case of gaps; and
• Access to information for product loading via mobile devices.

Stage 4 – Full digitization

• Automated real-time connection of carrier’s vehicle information with product’s location data and provision of map information about loading area to driver’s mobile device;
• Automated execution of safety checks (e.g. identity control through face recognition) via the driver’s mobile device;
• Display of final unloading station including opening hours of receiving department, calculated route and customer-specific requirements;
• Automated real-time planning of outbound logistics in cloud-based IoT operating system; 
• Automated real-time notification about rescheduling to responsible parties;
• Integration of carrier into the safety concept: driver’s confirmation about safety concept via mobile device;
• Possibility for carrier to inform himself about the current safety concept and to transfer relevant safety checks via access to the cloud-based IoT operating system; and
• Automated notifications about changes in current safety concept.

Stage 5 – Optimized full digitization

• Automated loading of product into transportation mode by intelligent containers with self-unloading function;
• Automated analysis of data transmission, planning of outbound logistics as well as of product loading or documentation process in case of failure;
• Self-learning abilities from solved cases of failure; and
• Automated real-time rescheduling of outbound logistics in case of deviations (e.g. delay of carrier).

*Ship product (sD1.12/sD2.12)*

“The process of shipping the product to the customer site.” (SCOR, 2017, p. 2.5.18 and p. 2.5.37)

Stage 1 – Basic digitization

• Tracking of product and product-specific transportation criteria (e.g. temperature, tilt, moisture) during shipping not possible;
• Manual procurement of data; and
• Manual evaluation of logistic indicators (e.g. transport duration, transport quality).

Stage 2 – Cross-department digitization

• Tracking of product via 360° camera during shipping;
• Tracking of product-specific transportation criteria not possible;
• Electronic assembly of logistic indicators in a one-page format;
Manual identification of deviations of logistic indicators; and
Manual derivation and implementation of corrective measures.

Stage 3 – Horizontal and vertical digitization
- Automated tracking of product and product-specific transportation criteria during shipping via sensors;
- Continuously transmission of information on product state to responsible parties;
- Automated identification of deviations of logistics indicators;
- Automated derivation of corrective measures;
- Manual implementation of corrective measures;
- Automated adaptation of the route to unforeseeable changes/external factors of conditions (e.g. political commotion, natural disasters);
- Automated rerouting if rapid changes of conditions require such measures without an increase of shipping costs; and
- Access to tracking information via mobile devices.

Stage 4 – Full digitization
- Automated real-time tracking of product and product-specific transportation criteria during shipping via sensors;
- Automated identification of deviations of logistics indicators;
- Warning messages to drivers’ mobile device if product conditions turn critical;
- Automated derivation of corrective measures;
- Automated transmission of notifications to responsible parties;
- Automated decision about replacement for initial product, provision of spare parts or whether a service technician can solve the problem on the ground;
- Automated initiation of necessary measures based on the preceding decision;
- Automated real-time rerouting if rapid changes of conditions require such measures without an increase of shipping costs;
- Automated message to contracting company with alternative options choosing the preferred one if shipping costs change;
- Real-time tracking of product status by customer, carrier and contracting company via cloud-based IoT operating system; and
- Real-time evaluation of carrier’s performance and transportation structure data.

Stage 5 – Optimized full digitization
- Self-learning abilities based on real-time evaluation of logistic indicators;
- Automated real-time influence on carrier information and parameters (e.g. carrier loyalty) which are used for decision making (e.g. carrier selection);
- Automated real-time rescheduling of picking waves in case of short-term changes (e.g. delay);
- Automated real-time route analysis of shipping;
- Automated real-time optimization of these shipping routes;
- Automated analysis of tracking information, data transmission or automated decisions in case of failure; and
- Self-learning abilities from solved cases of failure.
Receive and verify product by customer (sD1.13/sD2.13)

“The process of receiving the shipment by the customer (either at customer site or at shipping area in case of self-collection) and verifying that the order was shipped complete and that the product meets delivery terms.” (SCOR, 2017, p. 2.5.19 and p. 2.5.38)

Stage 1 – Basic digitization

- Message to customer about delivery time and destination (either at customer site or at shipping area in case of self-collection) as well as actual product data via phone, fax or e-mail;
- Verification regarding complete delivery (e.g. right product, right quantity, right quality) and fulfillment of delivery terms by employee of receiving department;
- Documentation of product handover by employee of receiving department;
- Manual documentation of damages in case of loss;
- Manual decision about further procedure regarding the product; and
- Manual cause analysis and deduction of improvement potential.

Stage 2 – Cross-department digitization

- Message to customer about delivery time and destination as well as actual product data via standardized interface;
- Electronically supported documentation of product handover;
- Electronically supported documentation of damages in case of loss;
- Electronically supported decision about further procedure regarding the product; and
- Electronically supported cause analysis and deduction of improvement potential.

Stage 3 – Horizontal and vertical digitization

- Automated message to customer about of delivery time (including delays) and destination;
- Automated transmission of actual product data (e.g. dimensions and weight of product) and accompanying documents as well as hints for unloading (e.g. required unloading equipment);
- Automated notification for employee of receiving department upon arrival (e.g. product status, complete delivery, information about existing damages, delivery of spare parts, arrival of service technician);
- Automated verification regarding complete delivery and fulfillment of delivery terms through active RFID;
- Automated documentation of product handover in cloud-based IoT operating system;
- Automated preparation of product return in case of damages and transmission of required documents to customer;
- Automated documentation and transmission of logistic complaints; and
- Automated cause analysis of complaint including evaluation of RFID chip data (e.g. time and location of production, time and location of product packaging) and sensor data
- Access to information of product receive through mobile devices.

Stage 4 – Full digitization

- Automated real-time message to customer about of delivery time (including delays) and destination;
- Automated real-time transmission of actual product data (e.g. dimensions and weight of product) and accompanying documents as well as hints for unloading (e.g. required unloading equipment);
Automated real-time notification for employee of receiving department upon arrival (e.g. product status, complete delivery, information about existing damages, delivery of spare parts, arrival of service technician); and

Automated message to carrier about future improvement suggestions based on cause analysis.

Stage 5 – Optimized full digitization

- Self-learning abilities based on real-time evaluation of logistic indicators;
- Automated deduction of improvement potential based on analyzed data;
- Automated deduction of necessary measures to lower damages in transit and optimize packaging;
- Automated real-time implementation of corrective measures;
- Automated interchange of the integrated IT system with IT systems of other factories for an identification of practicable best practices;
- Automated search for new potentials and trends with regards to packaging solutions/improvements; synchronization via the cyber-physical-systems of the factory;
- Automated review of the degree of the improvement and measure implementation (target-actual comparison) by integrated IT system;
- Automated analysis of data transmission or automated decisions in case of failure; and
- Self-learning abilities from solved cases of failure.

Install product (sD1.14/sD2.14)

“When necessary, the process of preparing, testing and installing the product at the customer site. The product is fully functional upon completion.” (SCOR, 2017, p. 2.5.20 and p. 2.5.39)

Stage 1 – Basic digitization

- Manual scheduling of product installation date in company’s shipping system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. availability of service technician);
- Confirmation of product installation date to customer via phone, fax or e-mail;
- Manual rescheduling of product installation date and confirmation in case of rejection by customer;
- Manual compilation of required documents, equipment for service technician as well as spare parts (if necessary);
- Manual product installation, replacement of spare parts (if necessary) and testing by service technician;
- Documentation of product installation by service technician;
- Preparation of action plan by service technician in case of not fully functional product; and
- Order of necessary spare parts and manual rescheduling of product installation date.

Stage 2 – Cross-department digitization

- Electronically supported scheduling of product installation date in company’s system;
- Electronic assembly of necessary information in a one-page format;
- Electronic confirmation of product installation date to customer via standardized interface;
Electronically supported rescheduling of product installation date and confirmation in case of rejection by customer;
Electronically supported compilation of required documents, equipment for service technician as well as spare parts (if necessary);
Product installation by service technician supported through wearables (especially glasses);
Relevant installation information situated in the field of view;
Electronically supported documentation of product installation by service technician;
Electronically supported preparation of action plan in case of not fully functional product; and
Electronically supported order of necessary spare parts and electronically supported rescheduling of product installation date.

Stage 3 – Horizontal and vertical digitization

- Automated scheduling of product installation date in cloud-based IoT operating system;
- Recourse to company-specific parameters (e.g. availability of service technician, delivery time of spare parts);
- Automated transmission of product installation date to customer via standardized interface;
- Automated rescheduling of product installation date and confirmation in case of rejection by customer;
- Automated compilation of required documents, equipment for service technician as well as spare parts (if necessary);
- Automated transmission of relevant product data and hints for installing the product to service technician;
- Automated documentation of product installation in cloud-based IoT operating system;
- Automated preparation of action plan in case of not fully functional product;
- Automated order of necessary spare parts and automated rescheduling of product installation date; and
- Access to information for product installation through mobile devices.

Stage 4 – Full digitization

- Automated real-time scheduling of product installation date in cloud-based IoT operating system;
- Recourse to service technician data and experience (e.g. average product installation time);
- Recourse to customer-specific data or requests (e.g. opening hours of the receiving department, country-specific holidays, preferred product installation date);
- Within Frozen Zone: no consideration of further customer requests due to status of shipment;
- Postponement of product installation date by customer via access to cloud-based IoT operating system; and
- Automated real-time transmission of relevant product data and hints for installing the product to service technician.

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of product installation date in case of short-term changes;
- Automated real-time notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
Automated analysis of scheduling of product installation date, data transmission or documentation of product installation in case of failure; and
Self-learning abilities from solved cases of failure.

Invoice (sD1.15/sD2.15)
“A signal is sent to the financial organization that the order has been shipped and that the billing process should begin and payment be received or be closed out if payment has already been received. Payment is received from the customer within the payment terms of the invoice.” (SCOR, 2017, p. 2.5.21 and p. 2.5.40)

Stage 1 – Basic digitization
- Manual creation of invoice in company’s warehousing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. actual costs) and consideration of country-specific regulations;
- Transmission of invoice to customer via phone, fax or e-mail;
- Manual verification of money receipt within the payment terms;
- Manual creation of payment reminder if payment terms are overdue; and
- Transmission of payment reminder to customer via phone, fax or e-mail.

Stage 2 – Cross-department digitization
- Electronically supported creation of invoice in company’s system;
- Electronic assembly of relevant information in a one-page format and consideration of country-specific regulations;
- Electronic transmission of invoice to customer via standardized interface;
- Electronically supported verification of money receipt within the payment terms;
- Electronically supported creation of payment reminder if payment terms are overdue; and
- Electronic transmission of payment reminder to customer via standardized interface.

Stage 3 – Horizontal and vertical digitization
- Automated creation of invoice in cloud-based IoT operating system;
- Recourse to actual data (e.g. weight, size, shipping route, actual costs) as well as consideration of country-specific regulations;
- Automated transmission of invoice to customer via standardized interface;
- Automated verification of money receipt within the payment terms;
- Automated creation of payment reminder if payment terms are overdue; and
- Automated transmission of payment reminder to customer via standardized interface
- Access to invoice information through mobile devices.

Stage 4 – Full digitization
- Automated real-time creation of invoice in cloud-based IoT operating system;
- Choice of a predetermined invoice model by customer via cloud-based IoT operating system;
- Automated real-time transmission of invoice to customer;
- Automated real-time verification of money receipt within the payment terms;
Automated real-time creation of payment reminder if payment terms are overdue;
Automated real-time transmission of payment reminder to customer via standardized interface; and
Access to invoice information for customer via cloud-based IoT operating system.

Stage 5 – Optimized full digitization

Automated analysis of data transmission, creation of payment or payment reminder in case of failure; and
Self-learning abilities from solved cases of failure.

Corresponding author
Vanessa Felch can be contacted at: vanessa.felch@uni-bamberg.de