Chapter

Autonomous Warehousing: Development and Application of a Maturity Model

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Abstract

Warehouse systems are complex elements in the flow of goods and information in value-creating systems. Their efficiency and effectiveness depend to a large extent on the availability and continuity of information flow and their advanced technical and organizational resources. Recent technological developments in robotics, digitalization and Internet of Things open the pathway towards integrated and autonomous value chain operations. This book chapter describes the development of a measurement model to assess the maturity of autonomous warehouse systems beyond partially automated processes. The model considers technology readiness level, business process maturity as well as organizational capabilities. The maturity model is applied and discussed in a case study.

Keywords: warehouse, internet of things, autonomous systems, maturity model, case study

1. Introduction

Warehouse systems are elementary components of value creation systems to balance demand and supply with an optimal stock of goods. There is no management of value networks in which decisions do not have to be made about the right location, equipment and management of the warehouse. When design and warehouse management is properly understood, it has been shown to result in higher productivity, lower inventory and higher customer and employee satisfaction [1].

The corona pandemic has caused a rapid acceleration of the e-commerce market while highlighting the vulnerability of supply chains and the availability of materials, transportation, and production capacity. With the increasing importance of e-commerce, the demands on the warehouse are rising in terms of product variety, availability, and delivery times for the customer. It is not surprising that investments are currently being made in the management of value creation systems and their central element, the warehouse system [2]. Storage systems take on elementary tasks in the management of material flow: Goods receipt, put-away, storage, picking as well as dispatch. In addition to the actual storage and inventory management, further and diverse services are added, often resulting from a reconfiguration of the supply chain:

including packaging and labelling, quality controls, repairs, assembly, repackaging, reassortment, and more [3, 4].

In addition to high service performance, high warehouse-productivity is always understood as the goal. The most important factors affecting the productivity of a warehouse system include the number of employees and the degree of automation, which in turn interact with each other [5].

The adoption of technological developments is therefore inevitable for logistics productivity. The evolution of information and communication technology in the last decade resulted in the formulation of industry 4.0, Internet of Things or Cyber-Physical Systems, which we here use synonymously for the latest manifestation of digital development. The development of the digital transformation has been called a quantum leap, the 4th industrial revolution, which will radically change our economy, indeed our society [6]. It is therefore understandable that industry 4.0 will also have an impact on SCM, logistics and warehousing [7, 8].

There is a consensus that industry 4.0 pursues the goal of intelligent networking of products and processes in the value chain to increase process efficiency, improve customer service or offer more individualized products and services. We, therefore, follow the industry 4.0 definition applied for supply chain management of [8]:

a. products and services are linked to each other via the Internet

b. the digital linkage allows automated and self-optimized production of products and services, including logistics, without human interaction

c. the value network is controlled peripheral while system elements decide autonomously.

Industry 4.0 is thus expected to make logistics systems more decentralized, self-regulating and efficient. In this context, the core term autonomy is used widely, frequently and consistently. Therefore, we use autonomy also for the warehouse as part of the value chain and logistics. Using the term, it also forces a differentiation from automated warehouses or smart warehouses. Whereas the former relies more on central units with little self-regulation and the latter describes above all the efficiency effect in the warehouse process generated by transparency [7]. In the context of autonomous warehousing, it is thus assumed that the warehouse subsystem can be designed as a decentralized system of the value chain, self-regulating and without human interaction. At least during defined periods of time—a shift extension, additional shift, whole day or weekend—autonomous operation would impact positively the overall equipment efficiency. Identifying and understanding the gap between existing warehouse systems and the ideal situation of an industry 4.0 solution would indicate necessary progress and actions to be taken.

Hence, our research questions are:

a. How to describe the maturity level for warehouse systems?

b. How to assess the individual maturity level?

c. Can action and development paths be derived from this assessment?

We structured the paper accordingly to the recommended methodological approach of maturity model development [9], starting with a literature review, followed by the model-building approach and the model description. The paper continues with the model application on a single case study and closes with preliminary discussion of the results and conclusions for research and management.

2. Literature review

Based on the goal to measure areas of autonomy in warehouses, a literature review was performed. The following chapter will describe the methodological steps that were deployed to collect relevant information.

To begin with, relevant keywords for the search of the literature were derived. As the objective suggests, the main keywords would incorporate 'warehouse' and 'maturity'. Regarding warehousing in general, an important limitation was considered, namely the exclusion of 'data warehouses'. Therefore, the initial search term includes: 'warehouse maturity' – data warehouse. The search term is listed in quotation marks, which allows to search for exact matches in the title of a publication. Next, a search engine of google (scholar.google.com) was selected. This initial search for hits in the title led to only one result. Hence, the authors decided to enlarge the search to other functional areas including logistics (4.0), industry 4.0 and SCM in general. During

Nr.	Authors	Year	Title
1	Warehouse Research and Educational Council	2021	Warehousing & Fulfillment Process Benchmark & Best Practices Guide
2	Salhieh and Alswaer	2021	A proposed maturity model to improve warehouse performance
3	Logistikum Switzerland GmbH	2021	Warehouse Reference Process (Maturity) Model
4	Facchini et al.	2020	A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap for Future Research
5	Zoubek and Michal	2021	A Maturity Model for Evaluating and Increasing the Readiness of the company within the concept of Industry 4.0 with a focus on internal logistics Processes
6	Asdecker and Felch	2018	Development of an Industry 4.0 maturity model for the delivery process in supply chains
7	Competence Centre Medium-sized Businesses	2018	Self-Service to assess the readiness for industry 4.0 in a company
8	Leyh et al.	2016	SIMMI 4.0—A maturity model for classifying the enterprise-wide IT and software landscape focusing on Industry 4.0
9	Sony and Naik	2018	Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review
10	Santos and Martinho	2018	An Industry 4.0 maturity model proposal
11	Zoubek and Poor	2021	A Maturity Model for Evaluating and Increasing the Readiness of the company within the concept of Industry 4.0 with a focus on internal logistics Processes

Table 1.
Selected studies from performed literature review).

this first intervention, a higher amount of search hits was achieved. In total 11 additional hits were registered for the logistics 4.0 field. Next, 10 hits were counted for the area of industry 4.0 and finally, 5 relevant hits were registered for maturity models in SCM. For these results, titles, abstracts and summaries were analyzed. A second intervention was carried out and a deeper look at the publications revealed shortcomings, which led to the exclusion of 8 sources from logistics (4.0), 6 sources from industry 4.0 and 5 from SCM. On the other hand, a snowball-approach was deployed to investigate more into references made by relevant authors. This route led to 3 more interesting studies (2 from warehousing and 1 from industry 4.0). The final selection encompassed 11 papers that were further analyzed (**Table 1**).

2.1 Maturity dimensions

Since we were interested to find relevant dimensions in which the maturity of warehouses towards autonomy could be measured, we extended a request into our professional network of warehousing and SCM experts. The goal was to develop a reference process for warehousing that allowed to search for commonalities and deviations in the registered search results. These findings would eventually help us to confirm or to discard certain elements from the maturity model. The expert talks helped to confirm initial assumptions and extended the knowledge in this domain. As a summarization, the following essential process-steps were identified: deloading (of trucks), receiving, material handling and put-away, storage control (inventory management), picking, packing, loading (of trucks) and shipping. The expert rounds assisted in uncovering another selection of important functional areas that would complement the initial approach. These are the yard management as well as management of information technology, which is critical for the seamless flow of information, goods and finances. The dimensions identified were then mirrored against the papers to find commonalities and differences.

As shown in **Table 2**, the first comparison of the reference process with existing literature highlights important findings. In comparison to the Maturity Model of WERC [10], it is found that all aspects of the reference process, apart from de-loading and yard management, could be confirmed. Subsequently, the reference processes were investigated regarding the study of Salhieh and Alswaer. **Table 2** demonstrates that less commonalities could be identified. At least receiving, put-away, picking and shipping could be confirmed as overlapping process steps. Unlike the previous model, Salhieh and Alswaer clearly refer to maturity levels and recommend the usage of 5 different maturity levels. Lastly, the reference process was mirrored against the previous work of the authors. Related to an external project, the authors outlined a basic model to describe interactions and dependencies in modern warehousing. The comparison reveals that most of the process steps could be confirmed, apart from receiving, storage control, packing and shipping. As previously, 5 maturity levels were listed.

As outlined in the previous part of this chapter, the analysis was later extended into the area of logistics (4.0). This comparison is based on three studies. The first one covers the development of a maturity model for logistics 4.0 and includes a roadmap for further research [11]. The second paper goes into details regarding a framework for logistics maturity assessments, respectively with a portion that considers internal logistics [12]. Lastly, Asdecker and Felch present the development of maturity model for the delivery process in supply chains [13]. Unlike the previous comparison, the authors proceed without a detailed comparison against the reference process. The results were not fruitful enough and there were not enough commonalities to justify further discussion.

	Reference process	WERC[a] (2021)	Salhieh & Alswaer (2021)
Functional areas	De-loading	n/a	n/a
	Receiving	Receiving and inspection	Receiving
	Material handling and put away	Material handling and put away	Put away
	Storage control	Storage and inventory control	n/a
	Picking	Picking	Picking
	Packing	Packing	n/a
	Loading	Load consolidation	n/a
	Shipping	Shipping	Shipping
	Yard mgt.	n/a	n/a
	IT mgt.	Warehouse mgt system (WMS)	n/a
	Maturity levels	n/a	5

[a]*Warehouse Education and Research Council*

Table 2.
Analysis of commonalities and differences of warehouse reference process in warehousing literature.

Contrasting, the section of literature related to industry 4.0 brought up interesting findings. Firstly, the reference process had to be adapted, since industry 4.0 covers more areas than warehousing alone. Commonly established models describe the vision of industry 4.0 with a variety of aspects: Business models, digital products & services, processes, production, social aspects, organizational factors, IT and digitalization and logistics. The first selected publication originates at the 'Competence centre for medium-sized business of North Rhine-Westphalia' and was later adapted by another company since public funding halted [14]. Next, the paper of Leyh et al. is referred [15]. The scientists consider assessing the IT and software landscapes of enterprises and propose a model for companies to increase their readiness for industry 4.0. Thirdly, the paper of Sony and Naik was selected, in which a literature review provides the basis to discuss the key ingredients for evaluating industry 4.0 readiness in organizations [16]. Fourthly, a study of Santos et al. is referenced, who discuss and propose an industry 4.0 readiness model [17]. Lastly, an additional study by Zoubek et al. was selected. It addresses a maturity model which could assist in evaluating and increasing the readiness within the concept of industry 4.0 while considering a focus on internal logistics processes (**Table 3**) [18].

Like the foregoing section, the goal of this comparison is to identify corresponding and deviating aspects regarding constituent elements of industry 4.0. Considering the information that can be extracted from the readiness assessment of NRW's competence centre, most of the elements seem to reappear. The same applies to the paper of Leyh et al., although the emphasis on digitalization, integration and cross-sectional technology implementation is stronger. Sony and Naik and Santos and Martinho mostly confirm previous findings but underline the importance of smart, respectively intelligent products, services and processes. From the comparison with the more general study of Zoubek and Poor, the emphasis is put on production and logistics as well as information technology.

elements	NRW	Leyh et al.	Sony and Naik	Santos and Martinho	Zoubek and Poor
Business model, digital products & services	Business models	Digital product development	Smart product, smart services	Smart products, smart services	n/a
Processes	Process mgt.	n/a	n/a	Smart processes	n/a
Production	Planning, control of production	n/a	n/a	Smart factory	Production
Social aspects	Human-machine-interaction	n/a	Employee adaptability towards I4.0	Work-force	n/a
Organization, Strategy	n/a	Vertical, horizontal integration	Organization, strategy, Top mgt. Support	Organizational strategy, structure, culture	n/a
IT, Digitalization	IT Systems	Cross-sectional technology	Level of digitalization of organization, extent of digitalization of supply chain	n/a	IT
Logistics	Logistics, distribution, mgt. of public procurement	n/a	n/a	n/a	Logistics
Maturity levels	5	5	n/a	6	6

Table 3.
Analysis of design elements in industry 4.0 literature.

2.2 Maturity levels

Apart from the maturity dimensions that were discussed, a second approach was used to study the maturity levels of different models. While maturity dimensions point to the area where the measurement for maturity will take place, levels are used to assess a certain readiness in a particular area. To perform this assessment, it is important to consider that maturity levels should be chosen coherently and either in a quantitative or qualitative way. This definition also affects the interpretability of the results.

Regarding the first group of papers that were analyzed, mostly similar layouts of maturity levels were found. Due to a paywall, the maturity levels of WERC's maturity model could not be accessed. The research of Salhieh and Alswaer refers to 4 different maturity levels. To assess the maturity of areas like integrated warehouse performance measures, the two scientists propose levels starting from negligible, low, moderate or high. Each of the levels has more details to it, for example, a negligible maturity level would correlate with sub 25% usage or deployment of a certain measurement, while a high maturity level would correspond to the usage of performance measures that is in the range of 75–100%. Next, the investigations of Logistikum Schweiz GmbH resulted in 5 maturity levels. In the Warehouse Reference Process Model, various dimensions are addressed. As an example, the assessment in Yard Management Maturity refers to manual, mechanized, automated, digitally augmented or lastly, intelligent dark. To exemplify, the final intelligent dark maturity level would describe that all the work and services are done in an autonomous way, including autonomously operating robots. Regarding the findings in the industry 4.0 section, mostly consistent levels were found. The competence centre for medium-sized businesses suggests 5 different levels. The starting point is marked by paper transfer of data, transfer of paper data in digital form, general usage of ERP systems, and digital data completeness until the automatic transfer of data. In a similar fashion, Leyh et al. suggest the application of 5 maturity levels. To assess the maturity of the IT landscape the following levels are used: basic digitization, cross-department digitization, horizontal and vertical digitization, full digitization and optimized full digitization. While Sony and Naik would not address the details of maturity models, suitable considerations can be found for the studies of Santos and Martinho as well as for Zoubek and Poor. Both suggest 6 maturity levels in their models. Structurally, they only differ slightly from the previously investigated models. This differentiation is based on the first, initial maturity level, which is congruent for both, as their first levels start at zero actions, respectively zero shares of implemented initiatives.

To summarize this comparative representation, all reviewed maturity models relate to well-established components of industry 4.0. If this comparison is extended to warehousing, some notable differences come to attention. While it is obvious that industry 4.0 maturity models address basic functions like process management, production and logistics, additional elements like social, organizational and technological viewpoints are addressed as well. These elements are rarely represented in functional maturity models, like maturity models of logistics processes or applied technologies in logistics.

3. Model building approach

Regarding the model development, a suitable methodological approach has to be chosen. Comparable investigations refer to the work of De Bruin et al. [9]. In their seminal paper, the scientists presented an often-cited approach that assists in developing specific maturity assessment models.

The approach is based on six subsequent phases: (1) scope, (2) design, (3) populate, (4) validate, (5) test and deploy and (6) maintain. Since this study is not a longitudinal study, only the first five phases will be used.

Phase 1: Scoping in the first phase of scoping, a decision must be made whether the model will address general or domain-specific use, which determines the scope and boundaries of the suggested model [9]. Apart from this decision, it is important to consider and include further stakeholders in the development of the model. This should ensure that possible benefits that result from the development or result from the use of the model can be shared with experts and vice-versa, experts can help and contribute to the model and its development stages. The exchange with science and industry is of great importance because it allows to build on existing knowledge and insights from previous research.

Phase 2: The design phase centres around five subsequent criteria, that determine the further layout of the model. They are intended to clarify the audience, the method of application, the driver of application, respondents and the application itself. For this study, the audience is mainly warehouse managers because they are directly involved in initiatives regarding the organizational and technological development of their facilities. Furthermore, the second audience of interest are consultants and auditors, who are often involved in guiding and accompanying warehouses. The principal method of application will be mostly based on structured interviews. Based on the clarification of the reason, why such a model should be applied and for whom it will be developed, the next chapter addresses the remaining design aspects.

Phase 3: Populate: The next phase is centred around the population of the maturity models in terms of content and requires the description of model components and model subcomponents [9]. This description clarifies what content needs to be measured for any given component or subcomponent. According to DeBruin et al., various approaches are suited to define the contents of each subcomponent. For example, a thorough literature review could be suited, as well as empirical approaches such as stakeholder interviews, surveys, focus groups and in-depth case studies. For the present study, a combination of approaches was chosen. Firstly, a literature review was conducted to identify basic components and subcomponents. Secondly, the study used individual expert talks and semi-structured interviews to validate the findings and to check if certain aspects need to be further adjusted. The results of the literature review are discussed in a previous chapter. The feedbacks resulting from the expert talks largely confirmed initial viewpoints and assisted in validating the principal assumptions of the maturity model.

Phase 4: Model validating: The validity and reliability of the maturity model in scope are in the focus of the fourth phase of model development, according to DeBruin et al. validity and reliability are important building blocks to ensure and strengthen the relevance and rigor of the model [9]. While the validity of the model is supposed to secure the correlation between factual and intended measurements, the reliability addresses if the obtainable results are accurate and repeatable. As in previous sections, referring to DeBruin et al. reveal different approaches to ensure such requirements. Surveys, interviews or literature reviews are among the options to be used in this regard. For the present study, all maturity dimensions and maturity levels are grounded in previous research publications and were validated in expert interviews. Therefore, the validity and reliability are confirmed.

Phase 5: Test and deployment. Within the last consecutive phase of model development guidelines [9], the deployment of the model is addressed. Following the guidelines of DeBruin et al., this phase aims to clarify the generalizability of the model pursued. This can be achieved by applying the model within suitable case studies. DeBruin et al. refer to two separate approaches. In the first place, it is suggested to test the model within an audience consisting of stakeholders, who were directly or indirectly involved in the development of the model itself. Secondly, the generalizability can be extended by discussing the model with an audience that is not part of a stakeholder group, respectively is external to the domain of warehouse maturity research. By pursuing these two steps, the general acceptance of the model can be reflected and confirmed. For the research at hand, the testing of the model was done by discussing it with members of a specific focus group that is committed to develop the warehouse of the future and consists of various warehouse operators, consultants and solutions providers with extensive experience in this domain. As a result of discussions, it could be found that the majority agrees with the proposals made by the authors. These discussions not only helped to ensure acceptance and demand for the model but also assisted in enriching the initial building. The focus group mentioned above also involves research partners from two universities of applied sciences. From each of the partners, one person who was not involved in the model development was asked to review the model and provide feedback to the authors. Like the first group, the authors could not learn about contributions that would question the current state of the model. To summarize, this initiative led to further confirmation of the model proposed.

4. Definition of the maturity model

As discussed in the previous chapters, the search for commonalities and differences in antecedent maturity assessment models mainly led to findings that underline the process-oriented view. By considering this view, the initial model will assess the most important areas of action within a warehouse, such as unloading, receiving, put-away, storage, picking, packing, loading and shipping. During the investigations into maturity dimensions from other domains such as logistics and industry 4.0, more contributing aspects are identified. Notably, the maturity models from the domain of industry 4.0 extend the initial process model. Regarding the first group of findings, the results that were obtained by comparing warehouse and industry 4.0 models pointed to additional important features, such as a general process-oriented approach, people, technology adoption and implementation and lastly organizational aspects. These features are considered relevant because they refer to the approach that industry 4.0 concepts take. These concepts are important for the present research, as this study is interested in assessing warehouse maturity regarding the realization of a fully autonomously operating warehouse – a concept deeply grounded in the environment of industry 4.0.

By combining these findings, it becomes apparent that the classical approach of a two-dimensional view, that most maturity models incorporate, starts to evolve. Currently, each dimension added to the model requires more attributes to be considered. The perspective of process control by management, the relevance of people in focused processes and the organization itself have consequences for each of the maturity dimensions. It can be safely assumed that for each of these elements, individual maturities can be assessed and therefore addressed for improvements. Hence, the proposed maturity model includes for the first dimensions process-related 'dimensions' and for the second dimension, intersectional factors like process and people management, technology applied and the organizational design (**Figure 1**).

As presented in the previous section, mostly consistent findings pointed to the usage of either 5 or 6 maturity levels. As explained by DeBruin et al. [9], it is important that all the levels are clearly defined, distinct and logically progressing from one to another. Furthermore, the authors underline the importance of all requirements and

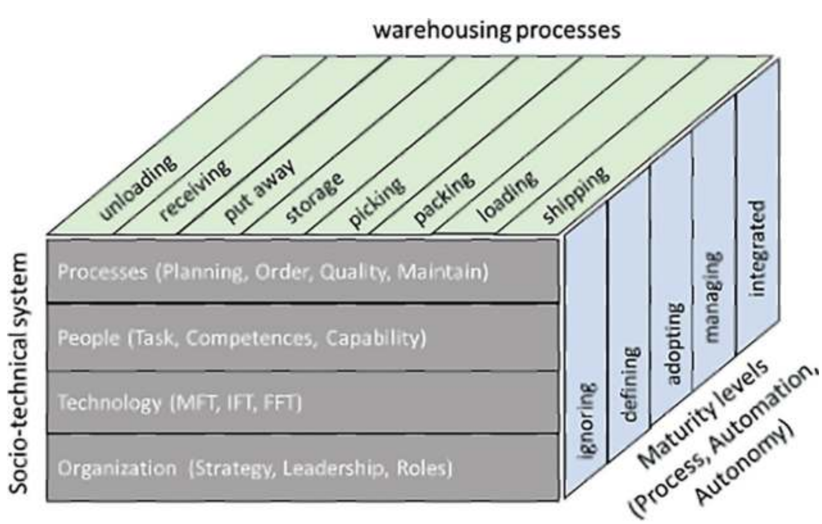

Figure 1.
Warehouse maturity assessment model.

Maturity level	Description
Ignoring	No awareness regarding needs for integration of advanced technology into operations. Missing knowledge about potentially beneficial advanced solutions, that could enhance flow of goods, information, finances.
Defining	Need for integration is acknowledged, but missing knowledge in terms of implementation. Knowledge of advanced solutions available, but missing knowledge in terms of application.
Adopting	Basic steps for integration of advanced technology initiated. Implementation of some advanced solutions, that enhance the flow of goods, information, and finances.
Managing	Integration is driven forwards and affects most business areas. Most of the solutions currently available are implemented to enhance and improve operations.
Integrated	Top level of integration is established, synergies show their full potential. All advanced solutions on the market are implemented, resulting in a seamless and optimized flow of material, goods, and information.

Table 4.
Description of generic maturity levels.

how the measurements are detailed. In this reasoning, maturity levels are supposed to represent a certain degree of maturity in their respective dimension and allow for improvements in a chosen field of interest. To operationalize the measurements, every level needs respective denotation and furthermore, a general description. The present approach proposes 5 generic and logically succeeding maturity levels, which are portrayed in the following table (**Table 4**).

Reflecting on the foregoing sections, the above illustration shows the warehouse maturity assessment model. In the upper-top area, the warehouse process-oriented dimensions are recognizable, while on the right-hand side the maturity levels are shown vice-versa. In comparison to other existing maturity models, the differences are becoming clearer as illustrated by the bottom area, which additionally integrates the socio-technical viewpoint. A socio-technical system usually considers three main building blocks: a technological, an organizational and a workforce-related, respectively human-oriented one. To complement the process-oriented maturity dimensions and interlink them with the socio-technical system, this study considers an additional, generic process management layer for this model. This link between the shopfloor-related warehouse processes and the management of those processes allows for a more complete and holistic analysis of other important aspects of warehouse maturity. Any process in each warehouse setting builds on organizational elements, technological equipment and foremost on people. Furthermore, processes can be characterized by flows of different types. The flow of goods (MFT) often marks a starting point, followed by the flow of information (IFT) and the flow of finances (FFT). Another important aspect to consider is the way organizations document their own processes. Such documentations mark an essential orientation for employees and managers who are involved in developing and improving current processes.

Since this study aims to measure maturity in various areas of warehouse operations, the above-listed maturity dimensions need to be adjusted individually. The required adjustments will still follow the above-defined generic maturity dimensions but will slightly differ to capture the specific nature of maturity in selected warehouse maturity dimensions. As per follows, the required adjustments in the case of one exemplary maturity dimension, the process of unloading trucks, shall be presented.

As **Table 5** shows, the individual adjustments span over all sub-elements that were identified to be important per singular process-step. **Table 5** extends these denotations by addressing the sub-element of organization, where three more important elements were found.

As listed in **Table 6**, the extended denotations for the maturity levels of the sub-element of organizational aspects are detailed.

Maturity dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Process documentation	Not documented	Partial analogue documentation, no centralized storage	Centralized storage, analogue documentation	Partially digitized, slight deviations in analogue vs. digital storages possible	Fully digitized, centralized, always available via dedicated platform solution (e.g., QMS[a])
Material flow	Manual unloading, manual transfer	Mechanically supported unloading (e.g., with forklifts)	Manual unloading to conveyor systems	Partially automated unloading (i.e., with automated forklifts and conveyor systems)	Automated, resp. autonomous unloading with robotic equipment
Information flow	Manual processing of information, data islands	Data available in ERPs, no automated exchange of data between functional areas	Flow of data widely automated, available for pre- & anteceding process steps	Flow of data end-to-end available, automatic exchange of data between stakeholders	Digitized, fully automated exchange of data, ongoing use for optimizations
Technology	No automation, service provision 100% manually	Partial automation, human activities supported by mechanical equipment	Limited automation, human-machine-cooperation	High automation, humans in charge of controlling only	Autonomous service provision, without any human interventions
People	Semiskilled, no technical formation, no technical further education	Completed traineeship, and/or professional maturity, no technical further education	Completed traineeship and/or professional maturity, technical further education done in last 3–5 years	Completed traineeship and/or professional maturity, recently completed technical further education	Completed traineeship and/or professional maturity, more than one recent technical further education, additional recent specific diplomas

[a]*Quality management system*

Table 5.
Exemplary description of maturity dimensions for the process "unloading of trucks".

Organization	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Coordination	Little coordination between roles and functions	Ad hoc coordination, if initiated and/or required	Sporadic meeting for coordination	Matters of coordination regularly discussed	High coordination of roles and functions
Culture	Absent company culture, potentials for improvement are not seen	Barely opened culture, potentials for improvement seen, but not discussed	Rather open culture, potentials for improvements seen and sporadically discussed	Mostly open culture, potentials for improvement are recognized and discussed regularly	Very open culture, systematic reviewing of potentials for improvement, implementations to follow
Resources	Scarcity of resources, pressing needs cannot be satisfied	Scarcity of resources, required resources are granted rarely	Resources obtainable but complicated procedures, usually delayed	Resources obtainable through pre-defined procedures, rather timely	Resources can be easily obtained, pre-defined procedures available, very timely and direct

Table 6.
Description of maturity dimensions for the process 'unloading of trucks'.

5. Case study

Sample firm: As an initial partner for the first application of this maturity assessment, a company was selected which is engaged in providing warehouse facilities for pharmaceutical products. This company's business is best described as a 'pre-wholesaler'. According to this business type, the selected company is providing logistical services for pharmaceutical companies. Typically, this includes warehousing and transportation of pharmaceutical products from the manufacturers to wholesalers, hospitals and in some cases to pharmacies directly. The business of pre-wholesaling is special, as the supplier of such services does not take title to the products they are storing, and ownership stays with the manufacturer until delivery is complete. Furthermore, pre-wholesalers do not maintain customer relationships with the intended recipient of the product, but with the manufacturers who pay a fee for the services used.

This company describes itself as very engaged in the digital transformation of its operations and has already undergone some small steps and test projects. Therefore, this company seems to be well suited for the application of the maturity model proposed. The company is described by roughly 100 million dispatches p.a. and about 200 employees. Since its establishment, the company is engaged in improving its customers' storage needs and providing various value-added services.

Data collection: To conduct an initial maturity assessment, the authors had to develop a questionnaire. As explained in the foregoing sections, the main building blocks of this questionnaire include warehousing processes as the main rationale for describing the maturity dimensions and corresponding maturity levels. In total, the questionnaire considers six questions per dimension. Regarding all dimensions (7), the total sum of questions equals 42 questions. The questions are directed to learn more about the specific state of maturity in the dimensions along the warehouse processes and can be detailed as follows:

- What is the maturity level of the documentation in this process? Is it possible for employees to access the documentation at any time if questions need to be resolved or the process is going to be reflected for improvements?

- What stage does the maturity have regarding the flow of material in the process of unloading trucks? Is the manual handling of material overweighing or do you already use assisting technologies to ease the effort and streamline the process?

- How would you describe the maturity of the flow of information? Does the organization tend to manual workings and share handwritings between functions or is it already more automated and using electronic interfaces?

- Which technologies are used in this process? We would like to identify all the technologies in place and assess individual maturity levels for each of them.

- To be able to assess the maturity of the workforce, please provide the state of formation and technical expertise for each of them?

- How would you describe the maturity of the organization itself in this subprocess? This question includes and addresses three more aspects: the coordination between roles and function, the state of the company culture and the availability of resources.

The qualitative results that would be collected by this survey allowed the achievement of the principal objective.

Findings: The semi-structured interview allowed for capturing information not only tied directly to the questions involved but also information that helps to understand contextual aspects.

Regarding the first question, respondents stated that the entire process documentation for the unloading process is stored digitally and accessible through a quality management system, which equals the highest level of maturity (5 of 5). Furthermore, the entire documentation is updated once per year through a predefined and participatory process. Every 3 years, all documents and instructions are subject to revision, guided by an external auditor. As assumed, the process documentation is indeed being used for internal advanced training. Apart from regulated measures, spontaneous initiatives like CIPs[1] or unexpected other events could trigger an update within the documentation. The company acknowledges room for improvements regarding the use of digital signatures for increasing safety and accountability.

As for the second item of the questionnaire, the respondents explained that the flow of material within the process of unloading trucks is mainly mechanically supported by equipment such as forklifts. Regarding this information, the company reaches 2 out of 5 possible maturity degrees. The respondents further explained that they were pursuing a small number of initiatives to test a higher degree of automation using automated guided vehicles. In view of the maturity of the flow of information, diverse results were registered. Firstly, the interviewees pointed out that there is still a data island within the company since a considerable amount of data is not digitized at all and is handled by using and sharing handwritten memos (maturity level 1). At the

[1] Continuous improvement process.

same time, the company relies on an enterprise resource planning system (ERP) that enables and supports business processes and communication with clients (maturity level 2). A further nuance could be registered, as some limited operations are also using streamlined electronic data interchange (EDI; maturity level 3). In turn, no unequivocal maturity level could be identified but rather a distribution over three different maturity levels became apparent.

The next item covered the maturity levels of technology applied in the process of unloading trucks. The respondents listed the different technological solutions currently in use, while the researchers connected them separately with maturity levels. A diverse picture began to emerge, starting with equipment of types such as forklifts, video surveillance and entry doors – which were counted in the category of least maturity, as they were all manually operated. The second level of maturity could be seen in equipment such as a packing machine, scanning devices and several displays (used for showing order-related information to shop-floor workers) as well as a semi-automated, web-based IT-system for the provision of slots for incoming trucks. In this category, the technologies assisted humans in their work but were not yet fully automated.

Regarding the next section, the maturity of the workforce was investigated. Since there was a total of 18 employees involved in this subprocess, the assessment turned out to be rather difficult. After several talks, the assessment team and the respondents concluded, that the 4th maturity level (5 as highest level) would be suited the most as it applies to more than 90% of the 18 employees. It was clarified that the job profiles were diverse and differentiating requirements were in place. The 18 employees can be distributed to different sub-areas within the unloading process, 2 of them to the area of ambient storage, 3 workers are in charge for regular daily business (e.g., administrative work), 6 persons to the area of goods receipt and 7 more were engaged with shopfloor activities, such as operating forklifts.

The last section of the semi-structured survey addressed the maturity of the organization, respectively selected important organizational features. The first item of interest points to the importance of internal coordination between functions and roles. The interviewees declared that most of the coordination takes place in the form of rather irregular internal meetings. Although in some cases, the meetings are scheduled and follow pre-defined protocols. In sum, the maturity level for the coordination falls between levels 3 and 4. The second item of this category directs to the state of the company culture. Like the foregoing assessment, the respondents explained that the company culture is mostly open, where potentially interesting external contributions—such as innovative technology—are openly acknowledged, while the discussion on such aspects is rather rare. The respondents were not completely unambiguous, and some pointed out that the assessment might also hit the 4th level of maturity here, which corresponds with slightly increased awareness towards valuable contributions. Finally, the item of resource management and availability was highlighted. Again, it was laid out that in most cases, the request for additional resources is often characterized through rather complicated procedures but could also be sped up, if there is a critical demand to meet.

6. Discussion

The main goal of this research was to develop the principal building blocks of a warehouse maturity model and to apply them to a real case. To reach this objective, we initially performed a literature review to explore available maturity models that address warehouse maturity towards automation and, more importantly, autonomy. We found that there is a relative scarcity of models to build on. Therefore, our model is based on warehouse processes as an orientation for developing maturity dimensions. Because the concept of industry 4.0 postulates a holistic transformation of business models a focus on process maturity does not match with an integrated approach. Aspects such as technology management, the way the organization works internally and the importance of the workforce will have an impact and should be considered when assessing maturity in warehouses. By the integration of the industry 4.0 model as well as organizational maturity, we enriched the process model in order to achieve an integrated maturity model for the autonomous warehouse. To apply and test the maturity model, we used a single case study of a midsized logistics service provider. The main business activity is pre-wholesaling for pharmaceutical products; the main service is warehousing for manufacturers of pharmaceutical products and related value-adding logistics services. For the assessment itself, we used document analysis, semi-guided interviews with operators and management, process walks as well as interactive workshops to capture in-depth information, and to discuss and interpret the findings. The assessment was performed by three researchers in one day workshop. In the maturity assessment conducted, the process was able to identify and confirm both the current state and the development needs for an autonomous warehouse system.

Our observations allowed for a multi-dimensional view of the maturity of the warehouse system of this company. The predefined levels were easy to understand and sufficient in differentiating levels. The application procedure ensures a concise assessment providing further insights into how the company handles challenges and opportunities as well as how to meet customers' increasing requirements.

As the maturity levels were pre-described, the assessment is a semi-qualitative approach. Therefore, it gives room for individual understanding and interpretation. The selection of interview partners, as well as the workshop structure, allows to establish an integrated understanding of the actual situation. As industry 4.0 postulates an integrated transformation, which affects not only technology but also people and organization as well, the model was not able to describe and evaluate the inter-relationship between technology, organization and people maturity. It seems to be obvious that technology impacts organizations and people, but the knowledge and design for it require further investigations.

7. Conclusion

In the last decade, many technological innovations became readily available for warehouse operators across the globe. It is a challenge for any warehouse operator to select the most fitting and efficient technologies to stay competitive among other factors on the market. The change towards networked and intelligent operations is ongoing and the pressure to innovate is one of many driving factors. Maturity models can mark an important waypoint in this challenge since they allow an efficient qualitative as-is analysis of operations and are able to support the development of integrated roadmaps. In this light, the authors aimed to develop and test such a maturity model in a practical environment.

For the development of the maturity model, we built on the recommendations by DeBruin et al. [9] and considered relevant literature and expert interviews to validate and ensure reliability and rigor of the maturity model. By using a single case study, we initially deployed and tested the maturity model and the application procedure for the good receiving process from unloading trucks to storing the goods.

The maturity model for the future of warehousing integrates maturity dimensions of process, technology and organization, which is postulated by industry 4.0. The model describes in detail the maturity in five levels, in two dimensions and subordinated categories. In total 32 elements.

The application of the model in a single case study results in a correct, comprehensive and intuitive reproduction and representation of the actual warehouse situation landscape.

The new model includes and considers aspects from industry 4.0 approaches such as autonomy and organizational design. By this, our model outlines a more holistic approach to the digital transformation of warehousing as part of an autonomous value chain. We have tested the model on a single case study in Switzerland, which does not allow to make assumptions on any other industries, company sizes or countries. Even we may recognize low maturities and gaps for each company, there is no indication of reasoning to invest for achieving a higher level. The context-specific application of the model may rise drivers and hurdles for continuous warehouse developments.

For warehouse management as a socio-technical system that considers people, process, technology and organization, the application of the model gives opportunities for improvement in a holistic way: maturity in logistics processes, technology and organization. Using this model as a starting point to design the transformation roadmap for the warehouse of the future gives awareness about the interrelationship in multiple dimensions. Even if we do not know exactly the interrelationships between the dimensions, it makes clear that digital transformation in logistics is more than implementing technology. It will affect management processes as well as roles, rules and according technical and collaborating skills.

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