Knowledge Management Models for the Smart Factory: A Comparative Analysis of Current Approaches

Patrick Tinz[1], Janik Tinz[1] and Stefan Zander[2]

[1]*Accso Accelerated Solutions GmbH, Berliner Allee 58, 64295 Darmstadt, Germany*

[2]*Hochschule Darmstadt, University of Applied Sciences, Schöfferstrasse 8B, 64295 Darmstadt, Germany*

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Abstract: This paper analyses current and well-known knowledge management models regarding their applicability to smart factories and the Industry 4.0. In form of a literature study, we surveyed the specific challenges and requirements that smart factories and the ongoing digital transition in the industrial sector introduce to knowledge management systems and models. In the second part, we then expound the extent to which those requirements are supported by well-established knowledge management models in form of a comparative analysis. A central result of this work is that an Industry 4.0 compliant knowledge management needs to incorporate aspects that emphasize human-machine and machine-machine interaction together with data protection and privacy concerns, besides other well-researched and established aspects.

1 MOTIVATION

Knowledge is now considered an important production factor (Karagiannis, 2003). The ongoing digital transition in the industrial sector, subsumed under the terms *Industry 4.0* (Ustundag and Cevikcan, 2018), *smart manufacturing* (Kim and Yoon, 2018), *Factories of the Future* (European Commission, 2013) or *Industrial Internet*[1], introduces new challenges and requirements to the knowledge management in smart manufacturing facilities (Feng et al., 2017). In this context, knowledge management models play a crucial role as facilitators for implementing digitized knowledge-centered value creation chains and networks (North and Maier, 2018). A knowledge management model can be defined as an attempt of formally or semi-formally systematizing knowledge-centered artifacts and activities, the logical basis of which is derived from different epistemological interest and observational perspectives (Probst and Romhardt, 1997). The usefulness of such a model should always be evaluated in relation to a knowledge management model's and its supportive community's aim of interest. Knowledge management systems provide smart factories with the possibility to implement and deploy newly established value-creation networks more efficiently and effectively and support their amalgamation with internal manufacturing processes and resources.

Given the importance and relevance of knowledge management systems and models for handling the digital transition in smart factories and Industry 4.0, the present paper analyzes two main research questions:

RQ1. *Which new challenges imposed by the ongoing digital transition need to be considered by knowledge management systems to meet the demands of smart factories?*

RQ2. *To what extent are those challenges already reflected in current and well-known knowledge management models?*

For answering RQ1, we list a set of knowledge management challenges in smart factories gathered through a literature study. Those challenges serve as criteria for the comparative analysis framework we deployed for answering RQ2, in which the following knowledge management models have been analyzed:

(a) The *Holistic Knowledge Management Model* introduced by Jessica Seiderstüker (Seidenstücker, 2017) that extends the well-known DIKW model (Rowley, 2007) with additional value-creation phases and organizational dimensions.

(b) The *Knowledge Stairway Model for Industry 4.0* developed by Klaus North and Ronald Maier (North and Maier, 2018) is an adaptation

[1]The Industrial Internet Consortium: https://www.iiconsortium.org/index.htm

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of the traditional knowledge stairway towards the demands of smart factories.

(c) The *ASHEN*[2] *Model* introduced by David Snowden (Snowden, 2000) that serves as representative of an organic knowledge management approach and favors the transition in organizational thinking from key-person dependency to knowledge dependency.

(d) The *Munich Knowledge Management Model* (Reinmann-Rothmeier, 2001) which integrates technological-oriented information management and human resource oriented competency management, the objective of which is to solve arising problems and situations in purposeful ways.

(e) The smart manufacturing centered knowledge management approach developed in the *Assist 4.0* research project[3] (cf. (Brandl et al., 2015)), that favors context dependent multimodal knowledge accessibility and delivery based on mobile and agent technology.

This work's objective is to make a contribution to the overall question about whether current knowledge management models meet the requirements imposed by Industry 4.0 and the ongoing digital transition. Readers get informed about the extent to which a certain Industry 4.0 specific requirement is facilitated by a knowledge management model and what specific purposes it pursues in general.

The remainder of this work is structured as follows: In Section 2, we outline the challenges and requirements that smart factories and the Industry 4.0 impose to knowledge management. The specific knowledge management models and systems that have been considered and analyzed in this work are introduced in Section 3. Section 4 then presents the comparative analysis framework and discusses the extent which a certain requirement is supported. This work concludes with a summary of all findings and a proposition of future actions in Section 5.

2 KNOWLEDGE MANAGEMENT CHALLENGES OF SMART FACTORIES

The following sections provides an overview of the challenges that have been discovered through a literature review. They serve as criteria of the comparative analysis framework that is presented and discussed in Section 4.

Knowledge Identification. The identification of possible knowledge gaps through human or algorithmic intervention requires transparency about existing and required knowledge (Frey-Luxemburger, 2014). In consideration of increasing decentralization and new technological developments such as Linked Open Data[4], identification means the acquisition of new knowledge from sources outside the company (cf. (Frey-Luxemburger, 2014)).

Knowledge Development. Knowledge development refers to the effort of an institution to develop not yet existing internal and external capabilities (cf. (Probst and Romhardt, 1997)) on the basis of existing knowledge. Knowledge development must take place with the involvement of all entities involved in the value creation process. An organization must always be open for new ideas and promote the creativity of its employees (Frey-Luxemburger, 2014).

Knowledge Exchange. Knowledge must be made available ubiquitously and through multi-modal ways in relevant departments so that existing information and experiences can be exchanged among individuals and systems. Incentive systems must be created to implement the exchange of knowledge (Seidenstücker, 2017). The exchange of knowledge is of central importance for the generation of new knowledge (Lehner, 2003).

Knowledge Use. A key aim of knowledge management is the productive use of the knowledge base, where the application of knowledge at the individual and community level must be promoted (Frey-Luxemburger, 2014). In addition, the use of highly networked machines and processes plays a role (cf. (North and Maier, 2018)). Corporate knowledge is created with great effort and is classified as strategically important, so it must be ensured that it is also used in daily life (Probst and Romhardt, 1997).

Knowledge Preservation. The acquired capabilities, experiences and documents must be stored efficiently and platform-independently, so that this

[2]ASHEN is an acronym for the model's components *Artefacts*, *Skills*, *Heuristics*, *Experience*, and *Natural Talent*.

[3]Assist 4.0 project page: https://hci.sbg.ac.at/assist-4-0/

[4]W3C's Web of Data initiative: https://www.w3.org/standards/semanticweb/data

corporate knowledge is available for future purposes (Frey-Luxemburger, 2014). Furthermore, regular updating is necessary to ensure the quality and validity of the knowledge base.

Knowledge Evaluation. In context of Industry 4.0, a knowledge evaluation is essential, since machines and humans jointly extract knowledge from different sources (Seeber et al., 2018) and the relevance of knowledge increases through an evaluation (Seidenstücker, 2017). Knowledge is evaluated by humans in combination with algorithmic decisions (Samulowitz et al., 2014) and by hybrid or combined approaches.

Human-machine Interaction. Human-machine interaction plays a central role for an Industry 4.0 enabled knowledge management (Kelly, 2015). New technologies such as augmented reality not only simplify the retrieval of knowledge, but also the generation of knowledge by creating multimedia content through the support of smartphones and smart glasses (cf. (Brandl et al., 2015)).

Machine-machine Interaction. The consideration of networked machines is essential for an Industry 4.0 capable knowledge management, because e.g. through predictive analytics approaches optimization possibilities of future maintenance and manufacturing processes can be derived (North and Maier, 2018)). The use of cloud-based services accelerates data analysis and communication between machines (cf. (Lechler and Schlechtendahl, 2016)).

Data Protection. Due to the increasing data intensity (generation, monitoring, linking, integration, et cetera) and networking of production facilities, the aspect of data security and privacy concerns in an Industry 4.0 enabled knowledge management is of particular importance. The contents must be secured with regard to data integrity, authentication, authorization and confidentiality (cf. (Brandl et al., 2015)).

3 KNOWLEDGE MANAGEMENT MODELS

This section provides a brief overview of the knowledge management models that are included in the comparative analysis, which is presented and discussed in Section 4.

The Holistic Knowledge Management Model (Seidenstücker, 2017) is based on the DIKW Model [5] (cf. (Rowley, 2007)). The DIKW Model according to Aamodt and Nygård illustrates the value chain of how information and ultimately knowledge are created from data (Aamodt and Nygård, 1995; Rowley, 2007). The resulting knowledge leads through a complex decision-making process to insights or wisdom. The model according to Seidenstücker supplements the value chain of collecting, using, enriching, sharing, evaluating and expanding (cf. (Seidenstücker, 2017)). Finally, the whole Model is labeled with the triads of technology, human and process (cf. (Seidenstücker, 2017)). The term technology deals with the collection of data. People should use data, give it a meaning and enrich it with experiences, so that knowledge is created. In the process, the knowledge is finally shared and evaluated.

Knowledge Stairway 4.0 (North and Maier, 2018) is an extension of the original Knowledge Stairway (North, 2016) and corroborates the value chain from the creation of knowledge to action competence and competitiveness. Knowledge is seen as the result of conscious or unconscious processing of information and forms the basis of action (North and Maier, 2018). Furthermore, the ability or disposition to act in a complex situation in an organized manner can be called as competence (North et al., 2018). Moreover, value creation is the result of the interplay of several competencies of individuals, networks, intelligent systems or institutions on the basis of their unique information and knowledge resources (North and Maier, 2018). The top level is called as competitiveness, which can be seen as a combination of several competencies. In addition, North represents the dimensions of people and organization (strategic knowledge management) versus the dimension of technology (operational knowledge management). The strategic knowledge management dimension describes the scrutiny of knowledge and competencies and as such serves as a “dynamising element” (North and Maier, 2018). The operational knowledge management dimension serves as “stabilizer” to always have the necessary knowledge available at the right place and at the right time (North and Maier, 2018).

The Munich Knowledge Management Model (Reinmann-Rothmeier, 2001) comprises not only the knowledge management process but also the objective and evaluation. The objective is to define normative, strategic and operational goals (Frey-Luxemburger, 2014). In addition, criteria will be established for the evaluation on which the

[5] DIKW is an acronym for the data-information-knowledge-wisdom continuum and is sometimes referred to as the “knowledge pyramid” or “knowledge hierarchy”.

implementation of knowledge management measures will be measured. The knowledge management process is divided into knowledge representation, knowledge communication, knowledge generation and knowledge use (Reinmann-Rothmeier, 2001). The identification, preparation and documentation of knowledge plays an important role in the representation of knowledge. With regard to knowledge communication, everything revolves around the exchange of existing knowledge. Knowledge generation includes aspects such as cooperation or mergers with other companies, but also the explication of implicit knowledge. The last process area is the knowledge use, which is about transforming knowledge into decisions, but also into products and services (Frey-Luxemburger, 2014).

The ASHEN Model (Snowden, 2000) combines the five areas artifacts, skills, heuristics, experiences and natural gifts (Schütt, 2003). The term heuristics describes a situation-related recommendation for action. Artifacts are storage media such as notebooks, in which explicit knowledge is stored. Natural gifts are abilities (implicit knowledge) that are bound to a human being. Skills are implicit knowledge that can be learned through training. Experience has developed over a period of time and represents an important knowledge base in the company. This model focuses on implicit knowledge, with that you can trace hidden and silent knowledge (Frey-Luxemburger, 2014).

Assist 4.0 explored new approaches to knowledge management in manufacturing in a practical context (Brandl et al., 2015). Assist 4.0 is a blueprint for established knowledge management models, as it examines the aspect of data protection and the use of new technologies such as augmented reality. For these reasons, this project distinguishes itself from other comparable projects. When creating knowledge content, not only text-based forms were examined, but also multimedia forms using mobile devices (e.g. data glasses). The basic idea of the concept can be described as "YouTube for the industry" (Brandl et al., 2015). This approach offers the possibility to record, evaluate and share experiences with other employees using mobile devices. In addition to editorial work, collaborative approaches were also researched. In securing the content, data integrity was examined on the one hand to ensure that the content was not manipulated during transport between the service engineer and the service provider, and on the other hand to ensure that only authorized content reached the service employee.

4 ANALYSIS & DISCUSSION

This section analyses the extent to which a certain requirement is supported by a knowledge management model. The results of the analysis are presented in Figure 1.

In the models of Seidenstücker and North, knowledge identification represents the beginning of the value chain. At Seidenstücker, new knowledge can be exploit through internal and external market research. On the other hand, sensors and neural networks provide syntax in the characters of the Knowledge Stairway 4.0. The other knowledge management models refer primarily to implicit knowledge.

The knowledge development is implemented in Seidenstücker's model trough the enrichment of internal and external market research results by humans. The ideas and creativity of the employees should be promoted through praise and recognition. Strategic knowledge management at North is responsible for critically reflecting organizational knowledge and partner knowledge. In the other knowledge management models, knowledge created from the processing of information, but also from experiences.

With regard to the exchange of knowledge, Seidenstücker exposes that there must be a cross-departmental and cross-location cooperation, in which there must be an environment of learning, sharing, open communication and fault tolerance (Seidenstücker, 2017). In the Knowledge Stairway 4.0 model, it becomes clear that communities and collaboration tools can be used to exchange knowledge. The three other knowledge management models relate to the exchange of knowledge and experience in knowledge communication.

In the model according to Seidenstücker and the ASHEN Model there should be an individual and common knowledge use. Knowledge Stairway 4.0 makes clear that the knowledge use must be characterized by fast, simple, comprehensive and ubiquitous access to the knowledge base. The Munich Knowledge Management Model focuses on the transformation of knowledge into decisions and actions, but also into products and services. In Assist 4.0 the knowledge is used during the activity.

The preservation of knowledge is implemented in the model according to Seidenstücker, Knowledge Stairway 4.0 and Assist 4.0 by a curator-role, who is responsible for the logical linking and maintenance of content for the development of a semantic network. The Munich Knowledge Management Model focuses on documentation, while the ASHEN Model uses heuristics and artifacts to implement knowledge preservation.

Criteria / Models	The Holistic Knowledge Management Model	Knowledge Stairway 4.0	The Munich Knowledge Management Model	ASHEN Model	Assist 4.0
Knowledge Identification	• Internal and external market research	• Sensors and neural networks	• Employee's knowledge and experience	• Focus on implicit knowledge	• Focus on implicit knowledge
Knowledge Development	• Enrich information • Promotion of the creativity of the employees	• Reflection on organizational knowledge and partner knowledge	• Processing of information and experiences	• Processing of information and experiences	• Processing of information and experiences
Knowledge Exchange	• Cooperation across departments and locations	• Collaboration Tools • Communities	• Focus on knowledge communication	• Exchange of experiences	• Exchange of experiences e.g. through augmented reality
Knowledge Use	• Individual and shared use of knowledge	• Access to the knowledge base	• Transformation of knowledge into decisions or actions	• Individual and shared use of knowledge	• Use during the activity
Knowledge Preservation	• Check for completeness and consistency by a curator	• Knowledge maintenance and updating by a curator	• Focus on documentation	• Documentation of heuristics and artefacts	• Knowledge maintenance and updating by a curator
Knowledge Evaluation	• Evaluation and commenting of contributions	• Principles of social media • Kuration	• Measurement of success during evaluation	• Employee communication • Evaluation in the process	• Principles of social media • Kuration
Human-Machine Interaction	• Preparation of content by technology	• Technologies like e.g augmented reality	• Not considered	• Not considered	• Technologies like e.g augmented reality
Machine-Machine Interaction	• Algorithms of machine learning	• Systems with automated learning and decision behaviour	• Not considered	• Not considered	• Networking of machines
Data Protection	• Restriction of read and write rights	• Not considered	• Not considered	• Not considered	• Possibilities for comprehensive data protection

Figure 1: A summarization of the comparative analysis results.

In Seidenstücker's model, Knowledge Stairway 4.0 and Assist 4.0, knowledge evaluation serves to increase the quality of the knowledge stock by incorporating principles of social media and curation. In the Munich Knowledge Management Model, this is guaranteed by the evaluation phase. In the ASHEN Model, knowledge evaluation is implemented mainly through communication between employees.

With regard to human-machine interaction, technologies such as augmented reality are referred to in the Knowledge Stairway 4.0 model and the Assist 4.0 project. Seidenstücker's model addresses this aspect superficially, the other models do not specifically considered this aspect.

The machine-machine interaction is addressed in Seidenstücker's model by utilizing machine learning algorithms. North presents the concepts "Augmented Intelligence" or "Cognitive Computing", which can learn scaled and communicate with humans in natural language (Kelly, 2015) in the Knowledge Stairway 4.0. "Augmented Intelligence" refers to the extension of the competence of experts by a system (Davenport and Kirby, 2016), "Cognitive Computing" to the integration of knowledge from different sources (North and Maier, 2018). Assist 4.0 is the leader in networking machines; the other models do not refer to this criterion.

Seidenstücker states with regard to data protection that a maximum of data security must be achieved (Seidenstücker, 2017). The Assist 4.0 concept is the only model that presents possibilities for full data protection. The other models do not consider data protection.

5 CONCLUSION

The present work contributes to the overall question of how well current and well-established knowledge management models are able to handle the new challenges and requirements introduced by Industry 4.0 and the ongoing digital transition in the industrial sector. It does that by analyzing two main research questions (see Section 1).

The question regarding the newly induced challenges (cf. *RQ1*) has been answered through a literature study that revealed that in addition to the already well-established knowledge processing tasks, smart factories introduce new aspects such as human-machine-, machine-machine-communication as well as data protection and privacy.

The extent to which those requirements are supported by current knowledge management models has been analyzed in the second part of this work (cf. *RQ2*). The analysis revealed that the aspects of human-machine-, machine-machine-communication as well as data protection and privacy are only selectively supported by current knowledge management models and initiatives.

These results also corroborate the fact that in Industry 4.0, humans and machines (both hardware and software) need to be considered as equitable partners that both participate in the knowledge creation and processing life-cycle. This perspective needs to be taken into consideration by future knowledge management models and it must be complemented by initiatives to establish an organization-wide continuous learning culture. Future works might built upon the validation of those findings and propose models that integrate the previously mentioned aspects in more Industry 4.0 compliant ways.

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