Application of an Industry 4.0 Assessment Model: A Case Study Application in Material Supply for Assembly

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Abstract: Material supply in production companies is currently facing numerous challenges. This paper therefore pursues the goal of analysing the potential of single Industry 4.0 concepts for the further development and efficiency optimization of material supply in assembly in an industrial case study. The determination of potentials in the context of the individual case study at an internationally active rail vehicle manufacturer is done by using a maturity level based Industry 4.0 assessment. Subsequent semi-structured interviews have been conducted to further explore the potential and feasibility of the identified Industry 4.0 measures for optimizing efficiency of material supply in assembly. This study represents an application oriented research for validation of a previously developed Industry 4.0 assessment model.

1 INTRODUCTION

Digitalization is having a considerable impact on companies and in some cases are placing completely new challenges on the entire organization (Parviainen et al., 2017; Sony, 2020). This makes it important for companies to constantly develop and adapt to new conditions in order to maintain the company's success in the future.

After a long period of organizational optimisation based on Lean Production and the introduction of Lean methods for waste reduction (Dallasega et al., 2015; Jiang et al., 2021), in particular, the proclaimed fourth industrial revolution, known as Industry 4.0, is intended to contribute to maintaining competitiveness by applying the most innovative technologies (Oztemel & Gursev, 2020; Shuttleworth et al., 2022). Thus, it is essential for companies to design their own strategy and roadmap for long-term sustainable digital transformation (Martinez-Olvera, 2022).

In addition to the digital transformation of manufacturing and assembly systems also supporting areas like production logistics and material supply are showing a high potential for applying Industry 4.0 concepts and technologies (Junge, 2019).

For many companies, however, the transformation to Industry 4.0 represents a major challenge (Vuksanović et al., 2020; Nardo et al., 2020). In addition to a missing overview of existing Industry 4.0 concepts and technologies, they lack the knowledge of how such concepts can be implemented and which ones should be given priority in terms of introduction. However, in order to successfully manage this challenge and to find one's way in the development of a comprehensive "big picture", it is important for companies to go through a self-assessment and to determine the potential laying in Industry 4.0. To give other manufacturing companies an example of how to face this challenges a case study based research has been conducted and results are summarised in this paper.

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2 RESEARCH QUESTIONS AND METHODOLOGY

The aim of this case study research carried out in collaboration with a Swiss rail vehicle manufacturer was to analyse the potential of Industry 4.0 for optimizing the efficiency of internal material supply in assembly and to test and validate a previously developed Industry 4.0 assessment model (Rauch et al., 2020) for derivation of the most suitable Industry 4.0 technologies for these purpose. The investigation is carried out with a specific view on production logistics, especially in the field of material supply of the assembly department. The following research questions can be defined:

RQ1: Which Industry 4.0 concepts show a high potential for efficiency optimization for material supply in assembly at the case study company?

RQ2: To what extent is a maturity level based Industry 4.0 assessment helpful in the selection of those Industry 4.0 concepts?

For this purpose, a mixed method research approach has been applied combining quantitative research (Industry 4.0 assessment model) as well as qualitative research (based on semi-structured interviews). The determination of potential Industry 4.0 technologies is based on a maturity-based Industry 4.0 assessment model according to Rauch et al. (2020). This comprises a catalogue of a total of 42 individual Industry 4.0 concepts identified by literature analysis, as well as four standard strategies to assist in the introduction of corresponding measures. This approach provides an overview of the current status of Industry 4.0 technologies applied in the case study company. Using this approach, the significance of potential Industry 4.0 technologies is encoded and the current status and medium-term target status of individual Industry 4.0 concepts or technologies in the company are determined. These findings then form the basis for a preselection. Based on this analysis, semi-structured interviews with 10 experts from the company has been conducted to, to examine in more detail the feasibility of implementation and to derive a roadmap for implementation. This holistic roadmap is intended to guide the case study company to implement selected Industry 4.0 concepts in this field of material supply. Finally this paper discusses the findings and lessons learned of this case study research and provides an outlook for further research.

3 OVERVIEW OF THE APPLIED INDUSTRY 4.0 ASSESSMENT MODEL

The model considered is based on a total of 42 Industry 4.0 concepts and technologies identified by systematic literature analysis (Rauch et al., 2020). These concepts are assigned on a first level to four dimensions as follows:

1. **Operational Dimension:** Focus on operational and operational processes;
2. **Organizational Dimension:** Focus on organizational and management-oriented processes;
3. **Socio - cultural Dimension:** Focus on corporate culture and employee-related issues;
4. **Technological Dimension:** Focus on data and process-oriented technologies.

In addition, a second sub-level contains a total of 21 defined categories to which the individual concepts are assigned. An overview of these two levels, including all 42 Industry 4.0 concepts included in this assessment model, is summarized in Table 1.

Table 1: Industry 4.0 dimensions, categories and concepts (Rauch et al., 2020).

N°	Level 1	Level 2	Level 3
1	Operations	Agile Manufacturing Systems	Agile Manufacturing System
2			Self-Adapting Manufacturing Systems
3			Continuous and Uninterrupted Material Flow Models
4			Plug and Produce
5		Monitoring & Decision Systems	Decision Support Systems
6			Integrated and Digital Real-Time Monitoring Systems
7			Remote Monitoring of Products
8		Big Data	Big Data Analytics
9		Production Planning and Control	Enterprise Resource Planning / Manufacturing Execution System
10	Organization	Business Model 4.0	Digital Product-Service Systems
11			Servitization and Sharing Economy
12			Digital Add-on or Upgrade
13			Digital Lock-In
14			Freemium
15			Digital Point of Sales
16		Innovation strategy	Open Innovation
17		Strategy 4.0	Industry 4.0 Roadmap
18		Supply Chain Management 4.0	Sustainable Supply Chain Design
19			Collaboration Network Models
20	Social-Culture	Human Resource 4.0	Training 4.0
21		Work 4.0	Role of the Operator
22		Culture 4.0	Cultural Transformation

Table 1: Industry 4.0 dimensions, categories and concepts (Rauch et al., 2020) (cont.).

N°	Level 1	Level 2	Level 3
23	Technology	Big Data	Cloud Computing
24		Communication & Connectivity	Digital and Connected Workstations
25			E-Kanban
26			IoT and Cyber-Physical Systems
27		Cyber Security	Cyber Security
28		Deep Learning, Machine Learning, Artificial Intelligence	Artificial Intelligence
29			Object Self Service
30		Identification and Tracking Technology	Identification and Tracking Technology
31		Additive Manufacturing	Additive Manufacturing (3D Printing)
32		Maintenance	Predictive Maintenance
33			Telemaintenance
34		Robotics & Automation	Automated Storage Systems
35			Automated Transport Systems
36			Automated Manufacturing/Assembly
37			Collaborative Robotics
38			Smart Assistance Systems
39		Product Design and Development	Product Data Management and Product Lifecycle Management
40		Standards 4.0	Cyber-Physical System Standards
41		Virtual Reality, Augmented Reality, and Simulation	Virtual and Augmented Reality
42		Virtual Reality, Augmented Reality, and Simulation	Simulation

For each of these concepts, corresponding maturity levels are defined in a Likert scale from 1 to 5. In order to improve understanding, a brief description of the respective maturity level is always accompanied by a relevant example. Figure 1 shows an example of a section of the assessment model with their Industry 4.0 concepts and associated maturity levels.

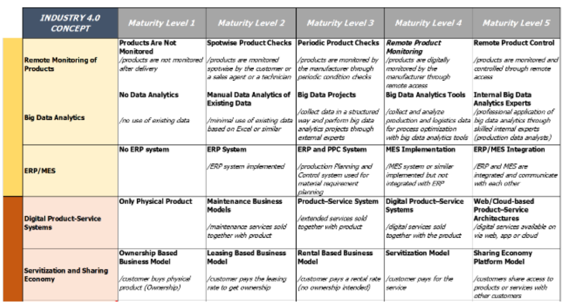

Figure 1: Maturity levels of the Industry 4.0 assessment (Rauch et al., 2020).

In addition to the current state of implementation of Industry 4.0 concepts, an aspired target state and the significance / potential of the individual technologies are assessed on the basis of the maturity levels. The current state of implementation of individual concepts and technologies is referred to as the "I4.0 Score". The information on the future maturity level is the "Target Score". This should take into account both the factors of medium-term achievability of the targeted state and realistic feasibility of implementation. The additional information on the importance of the respective concept is likewise provided on the basis of a Likert scale, from 1 to 5. This value is of corresponding relevance, as not every concept appears to be equally important for the respective company. This assessment is thus an expression of the potential of the individual Industry 4.0 concept in the case study company. Figure 2 shows the fields to be encoded by the user to determine the "I4.0 Score" and "Target Score" as well as the "Importance".

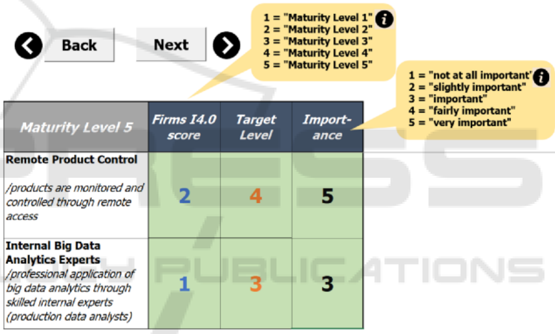

Figure 2: Fields to be filled in by the user of the assessment model (Rauch et al., 2020).

The assessment regarding the current and the medium-term target state form the basis for calculating the so-called "I4.0 Gap". This thus describes the difference between the stated "I4.0 Score" and the "Target Score" of the company. As a result, this expression provides a helpful quantification with regard to the difficulty of achieving the desired target state of the individual Industry 4.0 concept. For evaluation purposes, the "I4.0 Scores" and the "Target Scores", are visually represented in radar diagrams for operational, organizational, socio-cultural and technological (further subdivided into process-driven and data-driven levels) dimension. Figure 3 shows an example of the result of such a "Gap Analysis", which is generated automatically by the assessment tool.

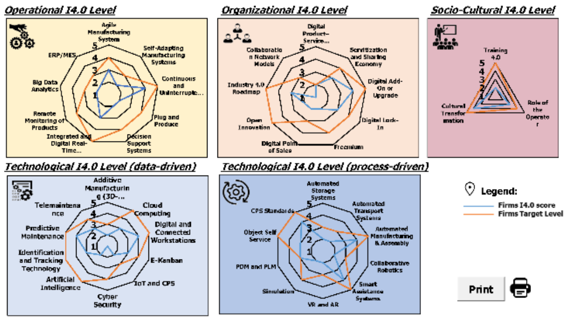

Figure 3: Automatically generated radar charts in the Industry 4.0 assessment (Rauch et al., 2020).

To support the gradual and systematic implementation of Industry 4.0 concepts, the collected data are combined in a standard strategy matrix. This matrix is divided into four quadrants:

- Quick-Wins: high potential - low gap.
- Must-haves: high potential - high gap
- Low Hanging Fruits: low potential - low gap.
- Money Pits: low potential - high gap.

The following Figure 4 shows a schematic representation of the standard strategy matrix.

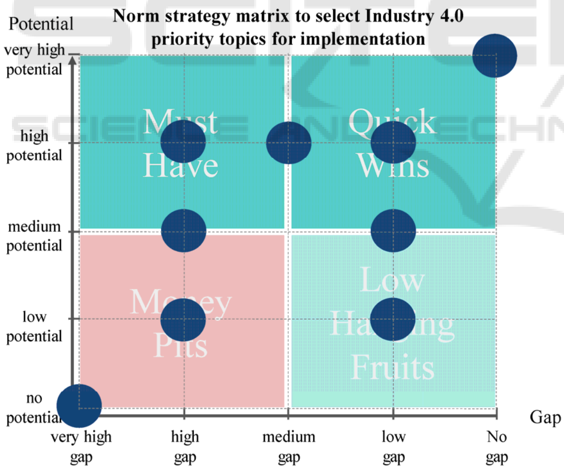

Figure 4: Standard Strategy Matrix (Rauch et al., 2020).

4 CASE STUDY APPLICATION

In the following, we apply the presented method in combination with semi-structured interviews to a case study company. The case study company is an internationally active rail vehicle manufacturer with two plants employing a total of up to 1,300 people.

4.1 Research Design

In general, the research design can be seen as the way in which the investigation is designed (Kuckartz, 2014). In addition to the description of the approach, this also includes the selection of the methods, the study participants, and the approach for data preparation and subsequent data analysis (Becker et al., 2017).

The investigation within the empirical research part of this study is basically conducted as a single case study at a European rail vehicle manufacturer. By means of the individual case study as a general research design, this work analyses the potentials and applicability of Industry 4.0 technologies for the efficiency optimization of the material supply in the assembly department. Because of the same "data source" in the industrial case study, the individual results of the investigation can therefore be directly related to each other. This makes it possible to generate an individual result for the case study company, which thus contributes significantly to answering the first research question (Lamnek & Krell, 2016).

The single case study in this work is based on a mixed methods design using a sequential approach, namely the qualitative in-depth approach ("explanatory design"). In a two-phase procedure, data is first collected quantitatively, within the framework of the previously presented maturity-based Industry 4.0 assessment and analysed by using descriptive statistics. In a second step, the results of the quantitative part will be better understood with the help of qualitative interview research. In this sense, the results of the quantitative survey will be used to design semi-structured expert interviews. In these interviews, explanatory gaps that arose from the maturity-based Industry 4.0 assessment are to be closed in a targeted manner. Accordingly, the interviews conducted have been evaluated using a qualitative content analysis.

In this data collection, 15 identified managers and experts of the case study company took over the role of study participants in the first step of the investigation (quantitative Industry 4.0 assessment). Persons from different organizational levels (management, department management, team management, group management, employees) have been selected. They work in the departments "Systems and Processes", "Production", "Logistics", "Purchasing" and "Digital Products". In this way, the analysis from different perspectives on Industry 4.0 technologies and their potential with regard to optimizing the efficiency of the company's material supply in assembly is intended to be as comprehensive as possible.

10 of the before mentioned 15 study participations have been identified as experts in the field and have been selected for the semi-structured interviews. Either these interviewees have specific knowledge of the company's internal material supply of assembly due to their professional fields of activity, or they have a fundamental technical knowledge of the topic of Industry 4.0, its technologies or also of the general process management at the case study company.

4.2 Results of the Industry 4.0 Assessment

The results in this section ("I4.0 score", "Target Score", "Importance") always refer to average values (arithmetic mean), which were formed on the basis of the information on the Industry 4.0 self-assessment model. The result is a visual representation of the current status and the desired target state, as well as the gap between these specific states.

In the first step of the analysis, the focus was on the participants' responses to the current status of the individual concepts. The ratings tend to be at a low level. This can be deduced from the results, as only one concept has an average score of greater than 4. In addition, the standard deviations and coefficients of variation determined indicate that there is not really a uniform opinion among the responses in these cases. It can therefore be concluded that there are most probably different levels of knowledge regarding the current maturity of the respective Industry 4.0 individual concepts. Starting with the concept with the highest average maturity rating, the ten individual concepts or technologies with the highest ratings are listed below in Table 2. Ratings in Table 2 to Table 4 are always indicated in a range from 1-5.

Table 2: I4.0 Score - Top 10 Industry 4.0 concepts.

Industry 4.0 concept	Average	Standard Dev.	Variation coefficient
E-Kanban	4,25	1,26	30%
Automated Warhouse Systems	3,50	0,63	18%
Cloud Computing	3,17	0,77	24%
Computer Aided Design	3,08	0,73	24%
Cyber Security	2,92	1,17	40%
ERP-MES	2,83	0,42	15%
Technology Partnerships	2,83	1,24	44%
Open Innovation	2,75	1,07	39%
Sustainable Supply Chain Design	2,67	1,25	47%
Acceptance and Warranty	2,67	0,91	34%

In the analysis of the target state, the following order emerged on the basis of the participants' responses to the "Target Score" column, as shown in Table 3, for the ten concepts with the highest average ratings. The standard deviation and coefficient of variation shows a quite coherent opinion of the study participants regarding the target to be achieved.

Table 3: Target Score - Top 10 Industry 4.0 concepts.

Industry 4.0 concept	Average	Standard Dev.	Variation coefficient
E-Kanban	4,83	0,36	7%
Automated Warhouse Systems	4,58	0,63	14%
Technology Partnerships	4,42	0,75	17%
ERP-MES	4,33	0,84	19%
Open Innovation	4,25	0,91	21%
Digital and Connected Workstations	4,25	0,80	19%
Cyber Security	4,25	1,05	25%
Business Process Mining	4,25	1,07	25%
Digital Shopfloor Management	4,17	0,80	19%
Industry 4.0 Roadmap	4,17	0,83	20%

In the next step of the presentation of results, the average importance of the individual Industry 4.0 concepts is shown according to the assessments of the survey participants in the "Importance" column of the assessment model (see Table 4).

Table 4: Importance - Top 7 Industry 4.0 concepts.

Industry 4.0 concept	Average	Standard Dev.	Variation coefficient
E-Kanban	4,58	0,74	16%
Identification and Tracking	4,25	0,82	19%
Automated Warehouse Systems	4,25	0,77	18%
ERP-MES	4,25	0,82	19%
Cyber Security	4,17	1,10	26%
Industry 4.0 Roadmap	4,00	1,04	26%
Real-Time Monitoring	4,00	1,00	25%

Seven of the top 10 individual concepts have a value greater than or equal to 4. According to the Industry 4.0 assessment model used, this means that the participants in the study rate them as "important" to "very important". The standard deviation and the coefficient of variation for the "Importance" rating were calculated. These two values indicate that opinions on the topics of "cyber security", "Industry 4.0 roadmap" and "real-time monitoring" diverge more than the other top level concepts.

Based on the results of the study the Standard Strategy Matrix has been created (see Figure 5). These helped the research team together with the company management to select the Industry 4.0 concepts that are of highest importance to reach the set goal. Doing this the research team defined as a threshold a potential (“importance”) of minimum 4.

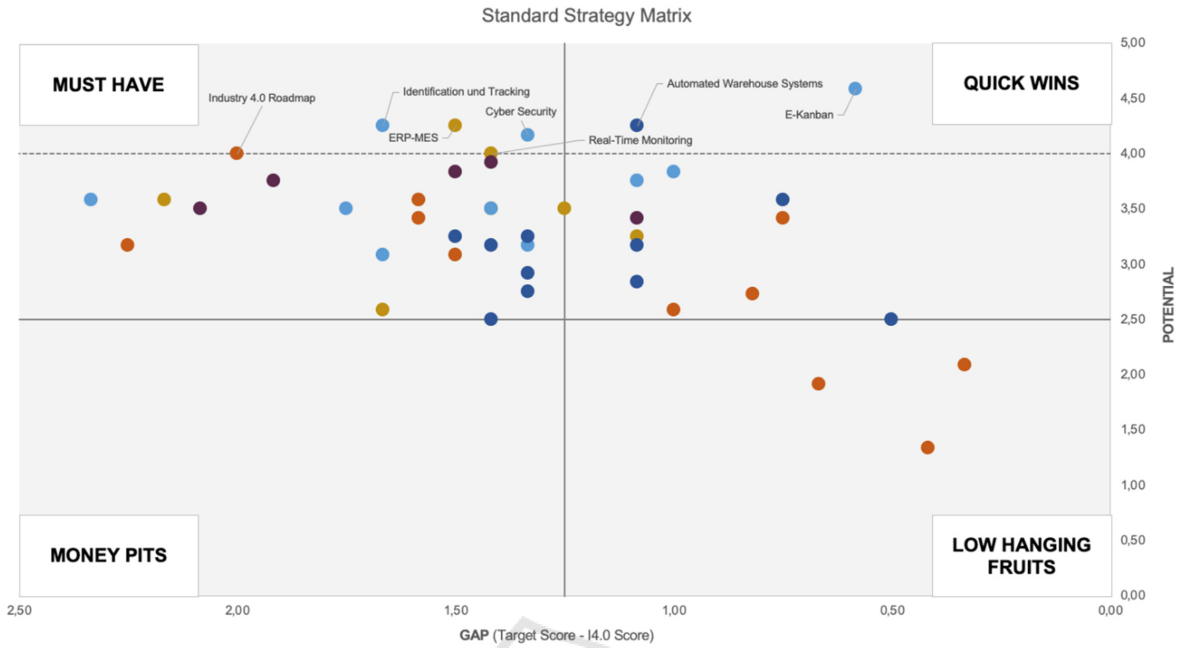

Figure 5: Standard Strategy Matrix in the case study.

In accordance to this threshold, the following seven Industry 4.0 concepts have been identified as key concepts for optimizing the efficiency of the internal material supply in assembly:

1) Industry 4.0 Roadmap
2) Identification and Tracking
3) ERP-MES
4) Real-Time Monitoring
5) Cyber Security
6) Automated Warehouse Systems
7) E-Kanban.

4.3 Implementation Roadmap based on Semi-structured Interviews

The interview results of the semi-structured interviews refer to the key concepts identified in Section 4.2. The following main questions have been used in the interviews:

1. Where do you see the specific potential of each individual concept with regard to the area of internal material supply of the assembly? What does it entail?
2. Have you ever had any experience with the implementation of the indicated concepts? If so, what is your experience?"
3. If we take a more concrete look at each concept, how do you evaluate its feasibility to be implemented in the case study company?
4. How do you think are new technologies and processes accepted by the employees? What could be done to facilitate the change?

Based on the selected Industry 4.0 concepts and the interviews, an implementation roadmap has been created.

The duration for the introduction of the individual Industry 4.0 concepts was derived from the estimates and suggestions of the interview participants. According to the interview analyses, the creation of an Industry 4.0 roadmap stood out as the first step in the overall further development toward the target status. Following this, the expansion of the current Kanban system into an E-Kanban system should be started. As a reason for this, the interview participants mentioned the easy manageable effort for an E-Kanban. This is because a Kanban system is already in use. Immediately following, the implementation of an identification and tracking system is considered important. A major reason for this is, for example, the issue of internal material losses and large numbers of search processes. In the same course, the effort for the introduction of a real-time monitoring is seen. In the next steps, the implementation of the topic "ERP-MES", as well as that of the automatic storage systems, especially for the area of the pallet warehouse, should be initiated and carried out. The topic "Cyber Security" is considered as a measure to be treated continuously throughout the implementation project. This means that parallel to the introduction of the individual concepts mentioned, work is constantly being carried out on this. This is because a reduction of security gaps and possibly data losses, manipulations or entire system failures due to cyber-attacks cannot be postponed, but must be started out immediately.

4.4 Identified Challenges for Implementation

Based on the results of the interviews the following challenges for implementation could be identified and supported the project team in risk mitigation:

1) Industry 4.0 Roadmap:
   - High effort and needed time for elaboration of the roadmap;
   - Lack of expertise;
   - Finding consensus among stakeholders.

2) E-Kanban:
   - Insufficient space in the warehouse;
   - Poor article definition and standardization;
   - Matching between Kanban inventories and ERP system.

3) Identification and Tracking:
   - Clarification of the specific mode of operation;
   - Lack of capacity among internal IT specialists.

4) Real-time Monitoring:
   - Correct master data maintenance;
   - Data protection;
   - Predefinition of optimal process parameters.

5) ERP-MES:
   - Correct master data maintenance;
   - Lack in employee qualification;
   - High cost.

6) Automated Warehouse Systems:
   - Infrastructural adjustments;
   - Temporary storage of stocks;
   - Different load carriers.

7) Cyber Security:
   - Possible interface problems;
   - Increased competence requirements for the parties involved;
   - Identification of the data to be protected.

An additional challenge relevant for all planned changes is employee acceptance (see also Sony & Mekoth, 2022). The general attitude of employees and managers at the case study company toward the implementation of new technologies and concepts of Industry 4.0 is considered by the interview participants to be rather conservative and reserved. One of the main aspects mentioned in this context is that the products to be produced are always customized products with a high diversity of components.

5 DISCUSSION

The discussion section is subdivided in a part discussing the potential for generalisation of the presented approach. A next part discusses then identified limitations as well as the relevance to theory and practice.

5.1 Generalisation of the Approach

The results of the individual case study may well be of use to general production companies as well. Particularly for large companies and companies in the rail vehicle industry, the insights into which individual Industry 4.0 concepts have a high potential for optimizing the efficiency of material provision in assembly can be of great interest. In particular, however, the information on the potential background and the implementation also offer the companies great added value. Namely, precisely these companies have similar structures, financial resources or even employee numbers and qualifications due to their size. With this information, they can drive forward the further development of material provision more quickly and in a more targeted manner.

5.2 Limitations and Implications

Despite the results achieved, the elaboration has shown that certain limitations also go hand in hand with this. One point here is that only people from within the company took on the role of study participants during the data collection. Thus, there is certainly a limitation, in the sense of a restricted company view. Integrating external consultants, experts or even supply partners in the selection of the study participants would lead to an improved quality of the results and increase the objectivity.

The research presented provides a practical picture of the potential of individual Industry 4.0 concepts for optimizing the efficiency of material provision in assembly and its implementation. Thus, the results provide information with regard to a clearly practice-relevant goal, namely the further development and increase in efficiency of company-internal processes. Thus, this work has a much greater practical relevance than relevance to theory.

6 CONCLUSION AND OUTLOOK

As a results of this case study research based work, both initially set research questions could be answered.

First of all the results of the Industry 4.0 assessment and the semi-structured interviews showed which concepts for optimizing the efficiency of material supply in assembly have high potential, if there is given feasibility for implementation and how they can be introduced as part of a holistic Industry 4.0 concept in the case study company.

Secondly the applied approach using the proposed Industry 4.0 assessment model proved to be very helpful. According to the own experience in its application and feedback from the study participants, the model helped above all to gain an overview of possible Industry 4.0 concepts and to determine the current status in the implementation as well as the desired target state.

As outlook for the future the research team will apply the model to other case study companies to gain a broader overview of the applicability in different industry sectors. The case study company will now start the implementation of the seven shortlisted key concepts for Industry 4.0 based on the proposed time plan.

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