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# Evaluation of Industry 4.0 Applications in Production

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## Abstract

Industry 4.0 promises many potentials in production. Examples are a data-driven optimization of production processes of individual machines, driverless transport systems, and assistance systems. Nevertheless, companies are still hesitant to invest in Industry 4.0 applications. Studies show that one of the main reasons for that is the unclear economic benefit. In this work, we present a systematic approach for the evaluation of Industry 4.0 applications in production. The main goal of the systematic is to create transparency over the evaluation process of an investment in an Industry 4.0 application in production. The evaluation of a concrete technical solution in an existing production system is supported. As a theoretical foundation, a characterization of investments in Industry 4.0 applications is given. From that, a procedure model is derived. It puts the activities to be carried out, the tools to be used and results in a temporal context. The application of the systematic is shown on the basis of an application example.

**Keywords** Industry 4.0 · Evaluation of investments in production

## Introduction: Potentials of Industry 4.0

Today, manufacturing companies are more exposed than ever to global competition (Brecher et al., 2011). This is accompanied by the development that companies are increasingly forced to develop more and more variants of their products in order to meet the requirements of their customers. The term mass production for individual customers was created (Wiendahl et al., 2014). Small and medium-sized companies in particular face the challenge of developing both high-tech and mid-tech products in order to open up promising market opportunities and secure their current financial situation (Enck & Stanzel, 2016). The development makes it increasingly difficult

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for companies to operate profitably on the market. In order to operate successfully, companies must react flexible to customer requirements at competitive prices. In addition, the modern factory operation is characterized by more and more specialized machines. A high degree of complexity in the production system and a high capital investment is the result. This increases the uncertainty of investments and poses a challenge for liquidity planning (Buck, 2009; Lingau et al., 2015).

Companies are trying to meet the rising demands by an increasing use of information technology. Central keywords are Smart Factory and the use of Cyber-Physical Systems (CPS). They are representative for the goal of digitizing a production at the time of Industry 4.0 (Krückhans & Maier, 2013). According to Kagermann et al., Industry 4.0 creates new forms of value creation (Bauer et al., 2013). Industry 4.0 refers to the technical integration of CPS in production and logistics and the use of the internet of things and services in industrial processes (Bauer et al., 2013).

In order to seize the potentials, investments in corresponding Industry 4.0 applications are necessary. It will be crucial to be able to determine the profitability of the planned investments at an early stage (Seiter et al., 2015; Gleich et al., 2015). However, the amount of new technical solutions makes it difficult to prioritize and subsequently select the optimal application possibilities. Companies are cautious because they are unable to assess the technical and economic potential of Industry 4.0 applications (Wischmann et al., 2015).

This problem is reflected in numerous studies on the barriers to the introduction of Industry 4.0. The central obstacles identified were the unclear economic benefits and an excessive need for investments (Bley et al., 2016; Graumann et al., 2016). As part of a survey by Koch et al., 235 companies from the manufacturing and information and communications industries were surveyed across Germany. Just under half of the respondents (46%) stated that the unclear economic benefits and excessive investment were among the two most important challenges (Koch et al., 2014). Especially small- and medium-sized companies still have some catching up to do (Graumann et al., 2016; Mauerer, 2017).

In addition, many companies find it too time-consuming to deal with the new technologies and their benefits (Graumann et al., 2016). Today's methods for decision making do not address the challenges of investment evaluation of Industry 4.0 applications. As a result, many decisions on investments in production remain intransparent and may be held back. There is a lack of a systematic approach to the evaluation of Industry 4.0 applications in an existing production system, which also meets the requirements of small and medium-sized enterprises.

This paper presents a systematic approach for the evaluation of investments in Industry 4.0 applications in production. Its goal is to make the process of evaluating a respective investment transparent.

The paper is structured as follows: After the analysis of the problem in “*Analysis of the Problem*,” the current methods are presented in “*Current Methods*.” “*Systematic for the Evaluation of Industry 4.0 Applications in Production*” presents the systematic approach for the evaluation of investments in Industry 4.0 applications in production in brief, whereas “*Application of the Systematic*” shows the application of the systematic. The paper ends with a conclusion and an outlook in “*Conclusion and Outlook*.”

## Analysis of the Problem

The aim of the problem analysis is to identify the need for action for a systematic approach for the evaluation of Industry 4.0 applications in production. In order to do so, “[Analysis of the Problem](#)” presents a vision of Industry 4.0. Afterwards, production on the way to Industry 4.0 and the introduction of Industry 4.0 applications are described. Furthermore, investment decisions and the challenges in the evaluation of Industry 4.0 applications are evaluated. The section closes with a problem delineation.

## Vision of Industry 4.0

Dumitrescu et al. describe a comprehensive vision of Industry 4.0 based on the automation pyramid. The automation pyramid represents a company from the management level, through the operational, process, and control level to the field level (Dumitrescu et al., 2015). Three overarching aspects of Industry 4.0 can be shown with the help of the automation pyramid: vertical and horizontal integration and comprehensive systems engineering (Dumitrescu et al., 2015). This is shown in Fig. 1.

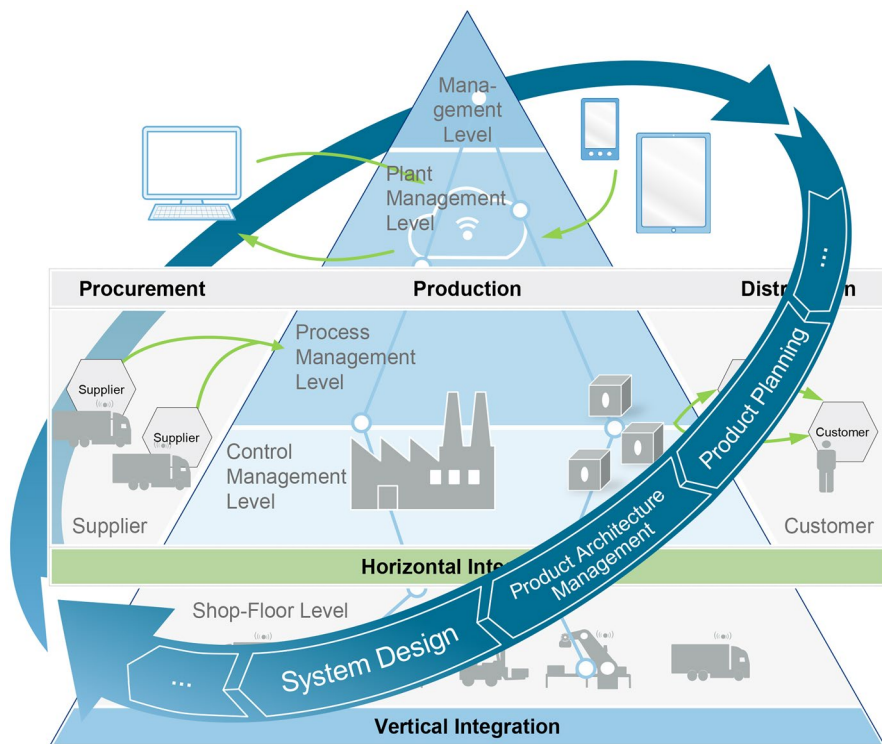


Fig. 1 Vision of Industry 4.0 (Dumitrescu et al., 2015)



Vertical integration represents the linking of IT systems on the different hierarchical levels of a company. These range from the field level via the control and process control level to the management level. This enables processes to be synchronized across different company levels. Thus, vertical integration is key to the Smart Factory, in which flexible structures are enabled by digital models, data, communication, and algorithms (Dumitrescu et al., 2015). Horizontal integration describes cross-company networking. IT systems for the various process steps of procurement, production, and distribution are integrated into a consistent solution. This enables dynamic cooperation and ad hoc networking between the parties involved throughout the entire supply chain (Dumitrescu et al., 2015). Comprehensive systems engineering is an integrated, cross-domain approach to the development of multidisciplinary technical systems (Dumitrescu et al., 2015). The technical system is at the centre of this approach and comprises all development activities. Interdisciplinarity and a holistic approach to problems are essential (Dumitrescu et al., 2015).

**Conclusion:** The vision Industry 4.0 with its three aspects of vertical integration, horizontal integration, and comprehensive systems engineering shows how investments in Industry 4.0 applications can have a cross-departmental impact. This represents a great challenge for an investment evaluation of corresponding investments. It remains the question of how Industry 4.0 applications impact the production.

### Production on the Way to Industry 4.0

The goals or rather the impact of Industry 4.0 applications in production can be illustrated by the classification of production concepts according to Kuhn and Grundkonzepte (2008). It is shown in Fig. 2.

The classification structures production concepts with the two criteria flexibility and productivity. Five ideal–typical production concepts are presented within the portfolio. These range from the transfer production line, the flexible production line, the center production, and the production cell to the workshop production (Kuhn & Grundkonzepte, 2008).

While the transfer production line is the most productive, it is also the least flexible. The workshop production is the least productive one but also the most flexible one. The other production concepts are on a line between the two mentioned (Kuhn & Grundkonzepte, 2008).

**Conclusion:** The presented production concepts represent idealized forms of organization and often appear in a mixed form. At the same time, the concepts on the diagonal from top left to bottom right represent technically feasible production concepts that are considered economical. The area on the bottom left is uneconomic. With the help of Industry 4.0 applications in production, an attempt is now being made to get closer to the area in the upper right-hand corner of the diagram.

This raises the question of how a structured approach to the introduction of Industry 4.0 applications in production looks like.

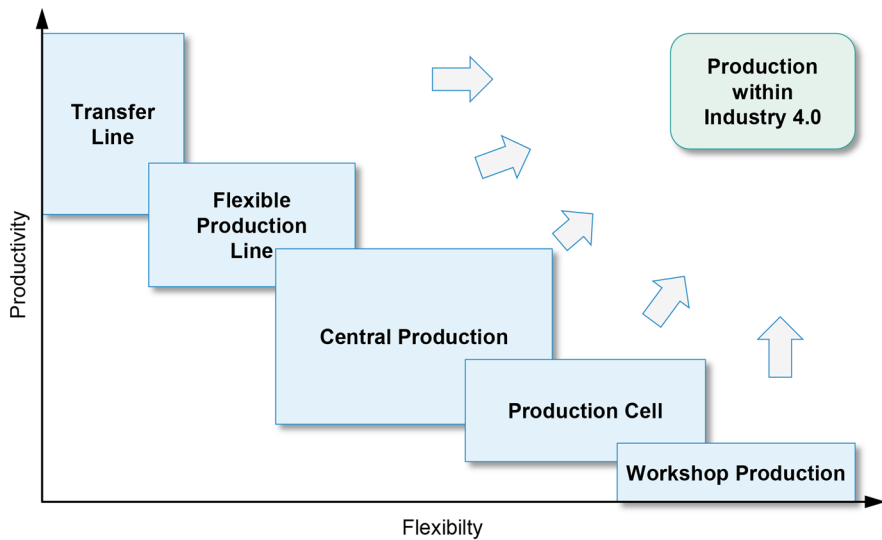


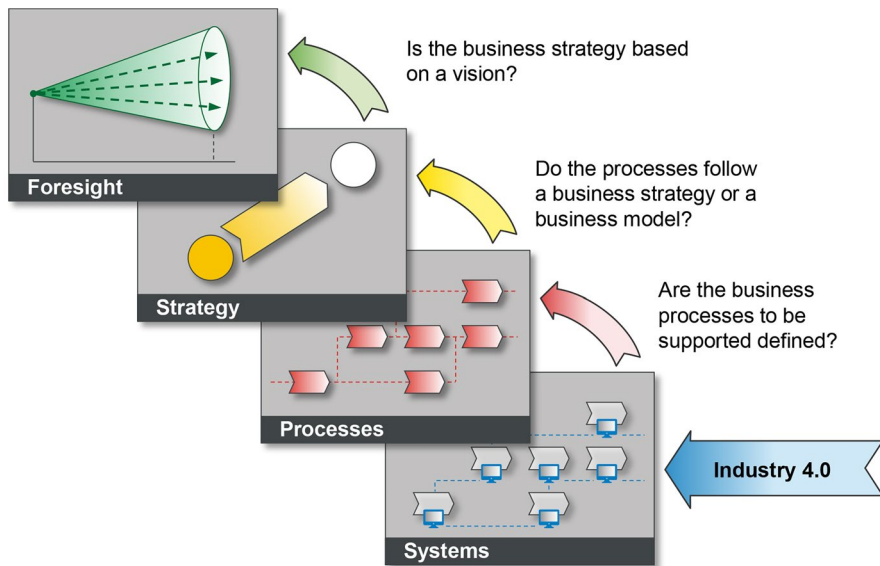
Fig. 2 Classification of production concepts (Kuhn & Grundkonzepte, 2008)

### Introduction of Industry 4.0 Applications in Production

The 4-level model for future-oriented business management describes an ideal–typical process for the introduction of new systems in a company (Gausemeier & Plass, 2014). The process is applicable to the introduction of Industry 4.0 applications in production. Figure 3 shows the 4-level model for future-oriented business management.

The model is divided into the four levels: foresight, strategy, processes, and systems. Within the framework of the foresight, it is necessary to anticipate the development of markets, technologies, etc. in order to recognize tomorrow's opportunities and threats for the established business at an early stage (Gausemeier & Plass, 2014). The second level is strategy. Here it is necessary to develop business, product and technology strategies in order to exploit opportunities early. The basis for this is the knowledge gained in the foresight level (Gausemeier & Plass, 2014). The processes represent the third level. They are to be designed according to the motto "structure follows strategy" (Gausemeier & Plass, 2014). The fourth level is the systems level. Based on the preliminary work, systems are selected and introduced to support the processes (Gausemeier & Plass, 2014).

In corporate practice, this ideal–typical process for introducing new systems is not often carried out. In particular, small and medium-sized companies often do not have the necessary resources or competencies. Instead, a concrete technical solution is evaluated independently of the processes, strategy and foresight. Subsequently, the processes are questioned and checked whether they still fit into the business strategy and the future design (Dumitrescu & Gausemeier, 2018).



**Fig. 3** 4-level model for future-oriented business management (Gausemeier & Plass, 2014)

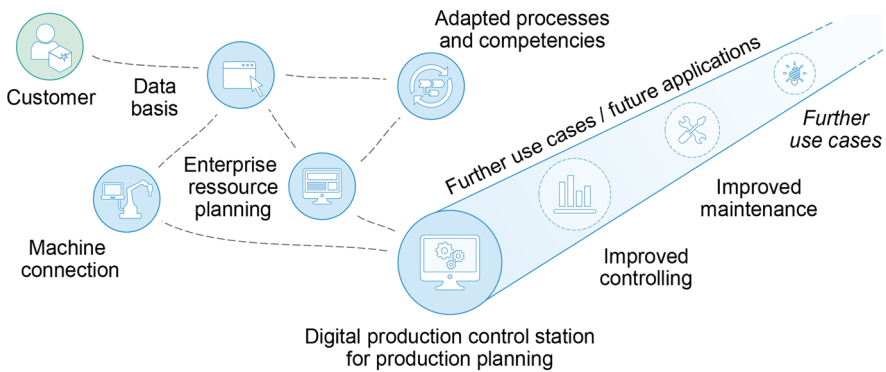
**Conclusion:** In order to be applied in business practice and to meet the needs of a well-founded investment evaluation, a systematic for the evaluation of Industry 4.0 applications in production must be both easy to use and take into account the given infrastructure within companies. Furthermore, it shows the necessity to look at the Industry 4.0 application as a system-theoretical perspective.

### System-Theoretical Perspective of an Industry 4.0 Application in Production

The technology-induced approach shown above can have far-reaching consequences. Large investments in, e.g., IT or production resources can shape a production system in the long term. One reason for this is the investment costs and thus the long-term commitment of financial resources. Since companies must be able to react to a wide variety of environmental requirements at any time, Buck says that the design of production units is mainly based on the degree of environmental turbulence (Buck, 2009; Heesen, 2016).

In addition, an Industry 4.0 application can be understood as a socio-technical system with many dependencies on other systems. According to Bauer et al. a socio-technical system is the interaction of employees, technologies, and work organization to fulfill a work task (Bauer et al., 2013).

An Industry 4.0 application is therefore not only to be regarded as a technical solution or as a pure operating resource at a workplace, but as a socio-technical system which is part of a higher-level socio-technical system. From a systems theory perspective, the characteristics of an Industry 4.0 application in production can be



**Fig. 4** Industry 4.0 application form a systems theory perspective (Haberfellner et al., 2015)

summarized under an increasing number and variety of system elements and increasing variability and dynamics (Haberfellner et al., 2015). This is shown in Fig. 4.

The increasing number and variety of system elements can be illustrated using the example of a production control system. Generally, it only fulfils its functions to the full extent if the production control system is networked with other systems. These could be, for example, an enterprise resource planning system or machines in production. A comprehensive and coherent data basis is essential. In order to obtain this data, processes often have to be adapted, competencies have to be built up with the systems or customers have to be integrated.

In addition, there is the changeability or dynamics of the system in the sense of the system's expandability. Thereby the Industry 4.0 application is often used as a kind of infrastructure or as a kind of platform for a variety of possible functions, applications and resulting use cases. In order to evaluate the benefits of this platform it is therefore necessary to anticipate and assess future functionalities and potential benefits.

However, these potential benefits are of a very long-term and uncertain nature (Joppen et al., 2019). To estimate and to evaluate the potential benefits in a reliable way represents a central challenge. This is not least due to the fact that a great amount of capital is tied up (Bungard, 2009).

**Conclusion:** The consideration of the Industry 4.0 application as a socio-technical system with its manifold relations to the surrounding system implies that there are many views of the system. In the context of evaluating an Industry 4.0 application in production, it is necessary to specify the manifold relationships and to take into account the different views of the system. In this way, a wide range of stakeholders have to be included in the evaluation of an Industry 4.0 application in Production.

## Investment Decisions

Taschner describes an ideal–typical process of an investment decision in the form of a business case with five phases (Taschner, 2013). This is shown in Fig. 5.

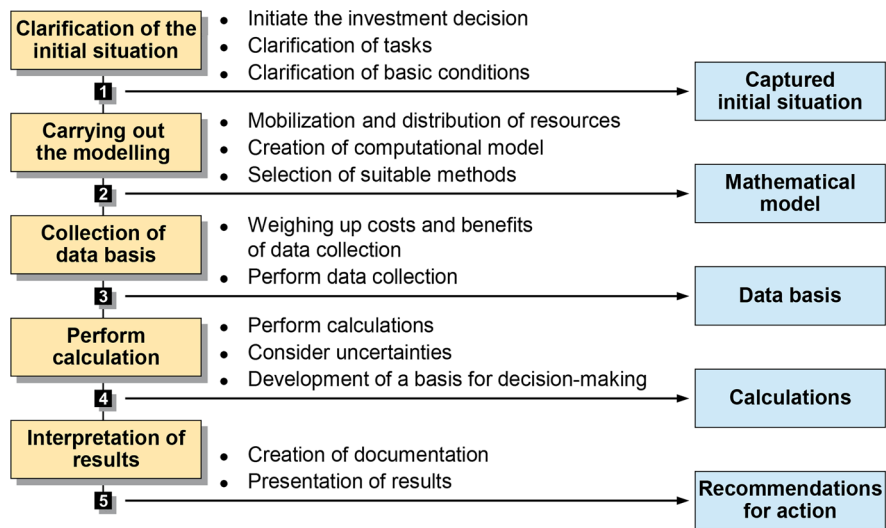


Fig. 5 Ideal-typical process of an investment decision (Taschner, 2013)

Phase 1 represents the clarification of the initial situation. In this step, the process of the investment decision is initiated and the persons involved are defined. A distinction must be made between the client, the decision-maker, and the calculator of the business case. The three roles can be carried out by different persons (Taschner, 2013). According to Taschner, the tasks of the business case have to be defined in such a way that a number of clearly defined alternatives are created (Taschner, 2013). Furthermore, the basic conditions of the business case must be clarified. The time frame including the defined milestones as well as the resources has to be clarified. The result of the first phase is the captured initial situation (Taschner, 2013).

At the beginning of phase 2, the necessary resources have to be mobilized and distributed for the modeling of the business case. It is important to ensure that the business case addresses the correct task and calculates it correctly. Basically, the creation of the business case does not differ from other types of projects from this point on (Taschner, 2013).

Within the model definition, a simplified image of reality is created. It is necessary to separate the essential from the rest and to reproduce the real contexts in an appropriate way (Taschner, 2013). Then, a suitable calculation method is selected. This determines the financial mathematical rules with which the inputs are processed and what kind of outputs are generated from them (Taschner, 2013). A distinction is made between static and dynamic methods. Different methods can also be combined. It should be taken into account that not all methods always come to the same result (Taschner, 2013). This can make interpretation difficult (Taschner, 2013).

Phase 3 is the collection of the data basis. This is an often underrated or neglected step. Obtaining the data is often difficult and expensive. Since uncertainty cannot be eliminated in a business case, the data collection is a balancing of the costs and

the benefits which data provide for the usability and robustness of the business case (Taschner, 2013).

The object of phase 4 is the calculation. The input data of the business case have to be processed with a suitable financial mathematical method. While doing so uncertainties have to be taken into account in order to create a basis for decision-making. (Taschner, 2013).

The last phase is the interpretation of the results. The documentation is created, containing the evaluation object and the assumptions (Taschner, 2013).

**Conclusion:** The idealistic process for the development of a business case according to Taschner represents a possible basis for a systematic evaluation of Industry 4.0 applications in production. Still, this process does not take specifics of Industry 4.0 applications in production into account and thus has to be adapted. One aspect is the missing support in collecting the data for the evaluation of an Industry 4.0 application in production.

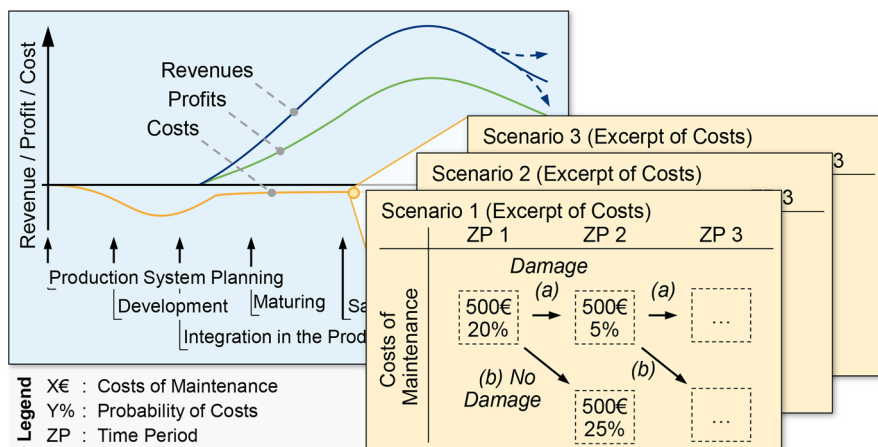
## Data and Information Needed to Evaluate Investments

Investment calculations are symbolic decision models (Kruschwitz, 2011). Accordingly, the result is just as correct (or wrong) as the initial information of the calculation model (Kruschwitz, 2011). This emphasizes the importance of a sound data basis for an investment decision. Nevertheless, data collection is often the “stepchild of the entire process” (Taschner, 2013). The reason is that input data are often difficult to obtain; procurement implies high costs and uncertainty in the data basis cannot be completely eliminated. In addition, measuring the uncertainty in the data basis is only possible at great expense. Furthermore, the output of a business case is usually considered more important than the input (Bieg et al., 2016; Taschner, 2013).

Assuming that an investment decision is calculated using the net present value method, the costs of the investment object, the cash flows, and an interest rate for the capital costs are required. From this, the net present value and the amortization time can be calculated.

The high effort required to obtain a sound data basis can be illustrated by the life cycle of a resource in a production system. This is based on a typical product life cycle. Figure 6 shows the development of costs, revenues, and profits over the phases of production system planning, development, introduction, maturity, saturation, and descent (Joppen et al., 2018).

Each of the three diagrams costs, revenues, and profits can take any number of processes. This is illustrated by the example of alternative cost scenarios in the figure, which shows a decision tree for maintenance or servicing costs over several time periods. In the example, it is assumed that a machine failure in the time period (TP 1) occurs with a probability of 20% and costs 500€. If the damage occurs and the machine is repaired, the probability of a damage in TP 2 decreases to 5%. If there is no damage, the probability in TP 2 increases to 25%. Subsequently, there are again



**Fig. 6** Typical course of costs, revenues and profits over the life cycle of an investment in production (Joppen et al., 2018)

several alternatives for TP 3. According to this logic, the decision tree becomes very large very quickly (Joppen et al., 2018).

**Conclusion:** In the context of evaluating an Industry 4.0 application in production, the calculation of one or more decision trees is not a problem. In literature, there are many examples of how to use decision trees. Examples are (Hundt, 2015; Peters, 2015), and (Schawel & Billing, 2009). Much more difficult is the variety of possible scenarios and the procurement of the data basis. A separate scenario can be determined for each variation in the example shown. The information on this is often not available or very difficult to estimate (Joppen et al., 2018).

In addition, Pümpin emphasizes that potentials — and thus also digitization potentials — are subject to a typical life cycle. Potentials themselves are characterized by a long-term perspective and a high degree of uncertainty in their evaluation (Pümpin, 1992). In the case of expandable software solutions is the decisive factor that the applications and thus the potentials are often not known at the beginning.

A systematic for the evaluation of Industry 4.0 applications in production thus needs to support the user in anticipating the potentials, the benefits and in collecting the relevant data.

## Problem Delineation

Within the problem analysis, three central fields of action for a systematic evaluation of Industry 4.0 applications in production were identified.

- (1) **Structuring of investment decisions in the context of Industry 4.0:** The investment decision must first be structured. This applies to the investment object, the evaluation process and the tools to be used.
- (2) **Analysis of Industry 4.0 applications from a systems theory perspective:** When evaluating an investment object, the effects from the surrounding system and on the surrounding system must be taken into account. These can have a great influence not only on the technical solution but also on the economic efficiency of the solution.
- (3) **Support in data collection for an evaluation:** The basis for any investment evaluation is data collection. This often proves to be problematic. Reasons for this are, e.g., the high effort for a well-founded data collection and the uncertainty of the data. Another reason is the fact that certain data are simply not available in a company. Thus, the third field of action demands the support in collecting the data for an economic evaluation.

## Current Methods

The preceding problem analysis has shown the need for a systematic approach for the evaluation of Industry 4.0 applications in production. Contents of this section are existing approaches which are relevant in tackling the problem of evaluating Industry 4.0 applications in production.

### Overview Over the Current Methods

The relevant current methods from different scientific fields can be structured into 6 categories. The first category are methods from the field of investment calculation. Classical methods of investment calculation are divided into static and dynamic methods. An example of a static method is the cost comparison statement (Götze, 2014). An example of a dynamic method is the Net Present Value (Götze, 2014). In addition, there are approaches such as sensitivity analysis for the consideration of uncertainty in investment calculations (Brugger, 2005).

The methods from the field of investment calculation are a solid tool set to calculate investment decisions. Still, the methods can only be a part of a systematic for the evaluation of Industry 4.0 applications in production. For example, they do not support the specification of the investment object and the capturing of the input data for a business case.

The second category are holistic, domain-specific evaluation approaches. An example from business administration is the approach to evaluate strategies for Industry 4.0 according to Gleißner (Gleißner, 2017). An example from the field of engineering science is the approach to planning and evaluating the use of RFID according to Rhensius (Rhensius & Dünnebacke, 2009). The function point method is an example from computer science (Wieczorrek & Mertens, 2011).



The holistic, domain-specific evaluation approaches often focus on specific problems like the evaluation of RFID. The transferability is not given. Furthermore, the methods do not support the capturing of the data for a business case.

The third category are approaches to system analysis and evaluation are described. There are approaches to assess the flexibility and mutability of production systems such as those by Rogalski (Rogalski, 2009) or Wiendahl et al. (Wiendahl et al., 2005) as well as approaches to assess the complexity of production systems such as those by Steward (Steward, 1981).

The approaches to system analysis and evaluation are promising for the analysis of an investment object. They do not support the evaluation process itself though.

The fourth category are indicator systems that may present a possibility for structured data collection. The numerous approaches can be divided into general and specific indicator systems. An example of a general system of key performance indicators is the DuPont System of Financial Control, whereas an example of a specific system of key performance indicators is the value stream system with a focus on production according to Gottmann (Gottmann, 2016).

The indicator systems are helpful in structuring the data of an investment evaluation. They do not support the analysis of the investment object or the evaluation itself for example.

The fifth category are methods for potential identification and data analysis. Within this context, creativity techniques are to be considered, as well as approaches for process analysis and methods of foresight. Gausemeier et al. provide an overview of these approaches (Gausemeier & Plass, 2014).

The methods for potential identification and data analysis are a way to identify the potential benefits of an Industry 4.0 application. They do not help in the evaluation process themselves and can thus only be a part of the systematic.

The sixth category are methods of decision support. Examples are simple methods like the utility value analysis (Zangemeister, 1976) and more comprehensive approaches like TOPSIS (Peters & Zelewski, 2007).

The methods of decision support are a way to evaluate investments. Still, the results are only on an ordinal scale. That means, e.g., that utility values have to be compared to monetary values in order to make an investment decision, which often leaves the user in the dark.

## Conclusion Regarding the Current Methods

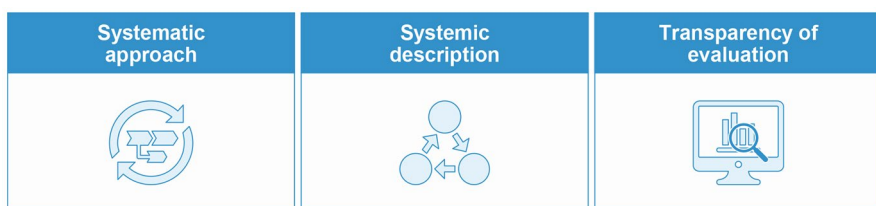
Within the assessment of Industry 4.0 applications in production, a number of methods from the state of the art have to be considered. None of the current methods and no trivial combination of the approaches fulfills all requirements for an evaluation of Industry 4.0 applications in production. Generally, only aspects of the overall problem are addressed. The central weakness lies in the insufficient integration of an interdisciplinary approach and a systemic view of the Industry 4.0 application with approaches of investment calculation. The approaches

lack a support in structuring the investment object. It goes along with the fact that especially the transparent and structured analyses of the investment object as well as the data collection are not supported to a sufficient extent. Thus, there is need for action for the development of a systematic approach for the evaluation of Industry 4.0 applications in production.

## Systematic for the Evaluation of Industry 4.0 Applications in Production

The analysis of the current methods in “[Current Methods](#)” shows the lack of an approach for the evaluation of Industry 4.0 applications in production according to the requirements described in “[Analysis of the Problem](#).” “[Systematic for the Evaluation of Industry 4.0 Applications in Production](#)” addresses this need for action. The systematic approach for the evaluation of Industry 4.0 applications in production is presented. The systematic is intended to contribute to a goal-oriented, effective cooperation of different disciplines in the evaluation of an Industry 4.0 application in production. To this end, the systematic pursues the three objectives shown in Fig. 7.

- **Systematic approach:** The evaluation of an industry 4.0 application in production is often an intransparent task. Thus, it must be structured at first. It requires a systematic approach that guides the user through the evaluation process and thus enables the reproducibility of evaluation results.
- **Systemic description:** In the context of the evaluation, the investment object is to be understood as a complex socio-technical system. The system is related to many other (sub)systems both inside and outside a company. For a holistic evaluation, the (sub)systems and their relationships must be described and analyzed.
- **Transparency of the evaluation:** The evaluation problem is not to be considered as a mere technical nor as a mere business task. There are many stakeholders with different professional backgrounds involved. Transparency is therefore required throughout the entire evaluation process. This applies to the result of the evaluation as well as to the calculation and input of the process.



**Fig. 7** Goals of the systematic

## Elements of the Systematic

In order to achieve the above objectives in the context of an assessment of an Industry 4.0 application in production, the systematic comprises five elements. The elements are shown in Fig. 8 and are described in the following.

- **Characterization of investments in Industry 4.0 applications:** A reference model of an investment in an Industry 4.0 application in production lays the theoretical foundation of the systematic.
- **Procedure model:** It describes the necessary steps, puts them into a temporal context, and defines the methods to be used.
- **Methods for a systemic description of the investment object:** Various methods support the description of the technical solution, the recording of the environment of the solution and the structuring of the information.
- **Methods for a transparent evaluation of the investment object:** Various methods support the identification and recording of qualitative benefits and costs as well as their quantification. Furthermore, support is provided for the selection of a suitable calculation method.
- **Tool support:** The methods are realized in a tool to make them easier to apply.

The characterization of investments in Industry 4.0 applications and the procedure model are described in detailed in the following. Section V describes the application of the systematic with the help of an application example. Thereby the methods and the tool support are also described.

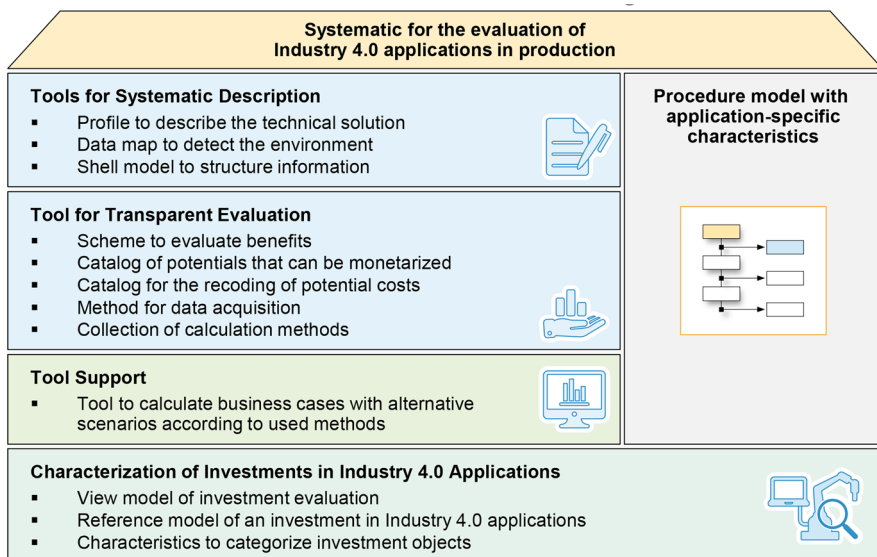


Fig. 8 Elements of the systematic

## Reference Model of an Investment in an Industry 4.0 Application in Production

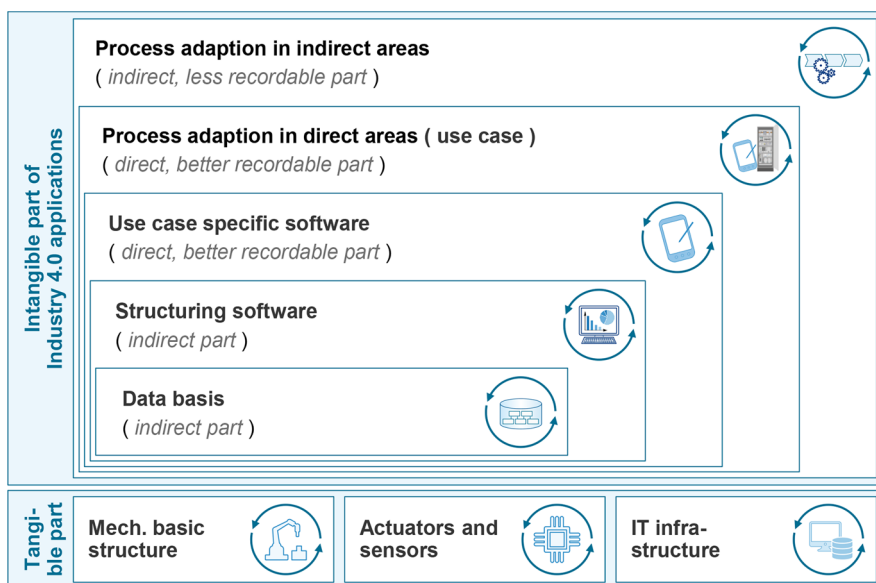
Basis for the evaluation of Industry 4.0 applications in production is an understanding of its structure and scope. For this purpose, a reference model of an investment in an Industry 4.0 application in production was developed (Joppen et al., 2019). It is shown in Fig. 9.

According to the reference model, investments in Industry 4.0 applications in production are divided into an intangible and a tangible part. The intangible part is divided into five layers, and tangible part is divided into three layers. Not all layers are always necessary for describing an Industry 4.0 application in production (Joppen et al., 2019).

The data basis is the lowest or respectively the innermost layer of the intangibles. It is the basis for any software and its application. It is of a structural nature whether corresponding data are available in an appropriate form in a company. This part is very difficult to measurable and to quantify (Joppen et al., 2019).

The data basis is generated, used, and processed by the software in a company. The pivotal point are structure-giving software systems such as enterprise resource planning systems, manufacturing execution systems, or certain authoring tools in the field of engineering. Generally, they have a huge impact on the business operation. Their benefits and their cost allocation are very difficult to determine due to their dissemination in the company (Joppen et al., 2019).

In addition, there is software which is designed for specific applications. These use case-specific software systems are generally based on the structuring software.



**Fig. 9** Reference model of an investment in an Industry 4.0 application in production (Joppen et al., 2019)

In the context of an investment evaluation, the use case–specific software is easier to allocate and to quantify. For example, the resulting costs can be directly assigned to one or more departments. Since the changes usually affect only a few areas or processes, the benefits can be recorded and quantified (Joppen et al., 2019).

The use case is a process adaptation in an area under consideration. These can be changes in production or assembly steps, for example. The process adjustments and the associated efficiency increases are usually relatively easy to describe and evaluate (Joppen et al., 2019).

Besides the technical aspects, the implementation of a use case often requires process adaptations in indirect areas. These are organizational measures in areas, which contribute the area of the use case. Their evaluation is difficult because of the extent of the processes across departments (Joppen et al., 2019).

In addition to the intangible area, the tangible part of an investment must also be taken into account. This represents the necessary hardware. The basic mechanical structure, the actuators and sensors and the IT infrastructure have to be taken into account. The tangible area of an investment is usually relatively easy to describe and evaluate (Joppen et al., 2019).

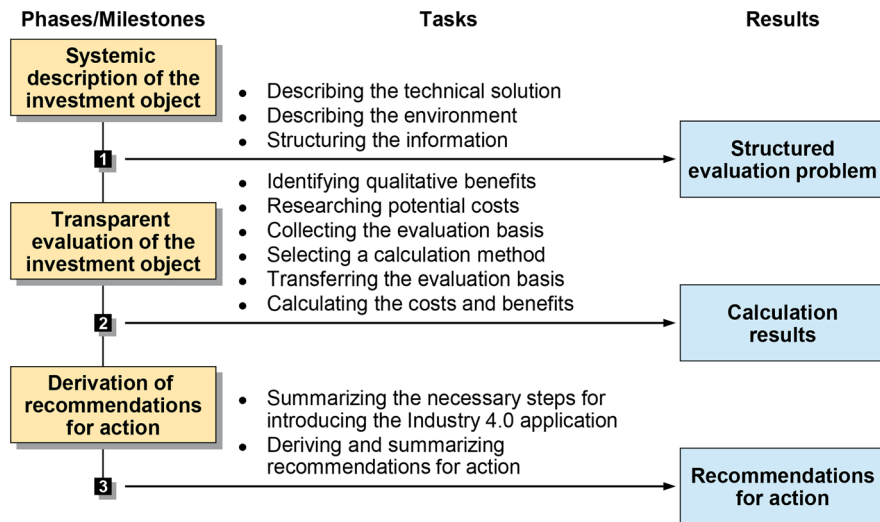
## Interpretation

The reference model of an investment in an Industry 4.0 application in production visualizes the following central insight: Only the use cases provide a benefit. All other layers in the reference model represent necessary conditions or requirements for its implementation and generate only costs. If several use cases are considered, synergy effects can arise in the requirements. For example, several use cases can be based the same database, the same software, or the same indirect process changes. Investments in Industry 4.0 applications in production thus often generate high costs in the short term, while the positive benefits have a long-term character (Joppen et al., 2019).

## Procedure Model of the Systematic

The procedure model of the systematic is divided into the three phases “systemic description of the investment object,” “transparent evaluation of the investment object,” and “derivation of recommendations for action.” It comprises all necessary steps to carry out an assessment of an Industry 4.0 application in production. It is shown in Fig. 10.

Phase 1 is the systemic description of the investment object. At first, the technical solution is described with the help of fact sheets. Since often times not all information is available from the beginning, the profiles are to be supplemented in the course of the evaluation process. Then, the environment of the Industry 4.0 application as well as relevant use cases are identified and recorded with the help of a data map. The recorded information is then structured with the help of a shell



**Fig. 10** Procedure model of the systematic

model for structuring investments in industry 4.0 applications in production. The result of the first phase is the structured evaluation problem.

Phase 2 is the transparent evaluation of the investment object. At the beginning of this phase, the qualitative benefit must be recorded. This is done with the help of a scheme for the evaluation the benefits of investments in production. A catalogue of monetizable potentials in production can support this. Furthermore, costs must also be researched. A cost catalogue for Industry 4.0 applications in Production provides support. With the help of a method for data collection for investments in production, the assumptions regarding the benefits are to be quantified and the researched costs are to be checked or complemented if necessary. In this course, the different business case scenarios are to be defined.

Afterwards, a suitable calculation method is selected. A collection of calculation methods is provided to assist in the selection process. After choosing a method, the data for the evaluation is transferred into the tool support. The benefits and costs are calculated on this basis. The results of this phase are the calculation results.

Phase 3 is the derivation of recommendations for action. The necessary steps for the introduction of the Industry 4.0 application in production are documented in an implementation roadmap. Finally, recommendations for action are derived and summarized in a management summary. The central results of this phase are the evaluated Industry 4.0 application and the recommendations for action.

Industry 4.0 applications can vary in scale and complexity, and so can the level of investment. If the investment is manageable, it is not necessary to go through the entire process model. An example of this case is a data-driven optimization of a machine. In this case, only phase 1 and phase 3 of the process model are run through. Phase 2 can be replaced by a simple cost estimate.

## Application of the Systematic

The application of the systematic for the evaluation of Industry 4.0 applications in production is shown with the help of an application example. The following subsections present the application example at first and then the application of the systematic structured by phases of the systematic.

### Application Example

The application example considers a switchgear manufacturer. The introduction of tablets in production as wiring assistance shall be economically evaluated. The tablets show the employees in production concrete work instructions for wiring a switchgear with a three-dimensional drawing. Without the tablets, the employees use a printed circuit diagram to wire a switchgear.

The example of the tablets as wiring assistance is representative for an Industry 4.0 application in production. The supposedly small investment, or rather the supposedly small project for the introduction of the tablets, is by far more than just buying the physical objects of the tablets. The introduction addresses each of the three dimensions of Industry 4.0: vertical integration, horizontal integration and comprehensive systems engineering (Joppen et al., 2019; Joppen & Kühn, 2017).

The vertical integration is addressed due to the fact that various company divisions must be networked from the field level to the company management level in order for the tablets to work. The horizontal integration is addressed since the switch gear manufacturer needs the relevant data for the tablets from his customers and thus has to be digitally connected to them. Furthermore, the system can be extended over its life cycle in the sense of continuous engineering. Once the infrastructure and database have been set up, further use cases can be identified and implemented in the adjacent process steps. The basis for all process steps are the digital models or the digital twin of the switchgear. This investment is to be evaluated (Joppen & Kühn, 2017).

### Phase 1: Systemic Description of the Investment Object

At the beginning of the evaluation process, the problem and the investment object has to be analyzed and structured. For this purpose, the technical solution is first described in the form of a profile.

### Describing the Technical Solution

The object under consideration is a wiring assistant. This requires a corresponding software. It is described in a fact sheet. The fact sheet of the technical solution is shown in Fig. 11.








Application: Software for electrical wiring		
Editor: R. Joppen		As from: 23.03.2017
<b>Objectives:</b> 		
<b>Software function- alities:</b> 		
<b>Input objects:</b> 	<ul style="list-style-type: none"> <li>Assistance in electrical wiring of switchgears for a more efficient process</li> <li>A 3D model shows the design of the switchgear and enables easy orientation while wiring</li> <li>A digital ToDo list shows the next steps for wiring</li> <li>A filter function enables similar work steps to be processed together</li> <li>ECAD data (parts list, electrical wiring lists)</li> <li>3D model of switchboards</li> </ul>	
<b>Output objects:</b> 	<ul style="list-style-type: none"> <li>Assistance in electrical wiring in the form of a digital ToDo list with a 3D model</li> </ul>	
<b>Software infrastr.:</b> 	<ul style="list-style-type: none"> <li>Software for assistance in electrical wiring (EPLAN Smart Wiring)</li> <li>Connection to structuring engineering software (EPLAN P8)</li> <li>Software for 3D CAD of switchboards (EPLAN Pro Panel)</li> </ul>	
<b>Hardware infrastr.:</b> 	<ul style="list-style-type: none"> <li>Devices in production (e.g. tablets)</li> <li>Desktop-PCs</li> <li>Server for data storage</li> <li>WLAN in manufacturing hall</li> </ul>	

Fig. 11 Fact sheet of the technical solution

The aim of the technical solution is to provide assistance in the wiring of switching systems. The required software functionalities are a 3D representation of the switchgear structure, a digital todo list of the upcoming wiring steps, and a filter function for the work steps to be performed. The input and output objects as well as the software and hardware infrastructure are also included.

The final fact sheet is shown. In particular, the lower part of the profile, i.e., the input and output objects as well as the software and hardware infrastructure, was supplemented on the basis of the following work. They resulted from the recording of the environment with the data map and the structuring of the information in the shell model.



## Recording the Environment with the Data Map

The second step is to identify and analyze the environment and use cases of the potential investment. A data map is used. It is used to map and analyze IT systems and data along the processes. In the application example, the order processing process is to be analyzed. Figure 12 shows an excerpt of the data map of the application example for evaluating tablets in production. It shows the current status of the company before the introduction of tablets in production.

The process steps are recorded at the top level. This is usually more aggregated than a detailed process description. One of the first processes included in the application example is the offer calculation. The consumer lists and the circuit diagram are the basis for this. The calculation is performed manually in the Excel software, and the documents are stored in a document repository. The subsequent offer is created in the ERP system ProCoS. The data from the calculation is transferred manually. The result is a signed offer in form of a paper document.

If the offer is accepted by the customer, the switchgear is wired in the further process. Unless the customer sends an update, the circuit diagram from the document storage is used for wiring.

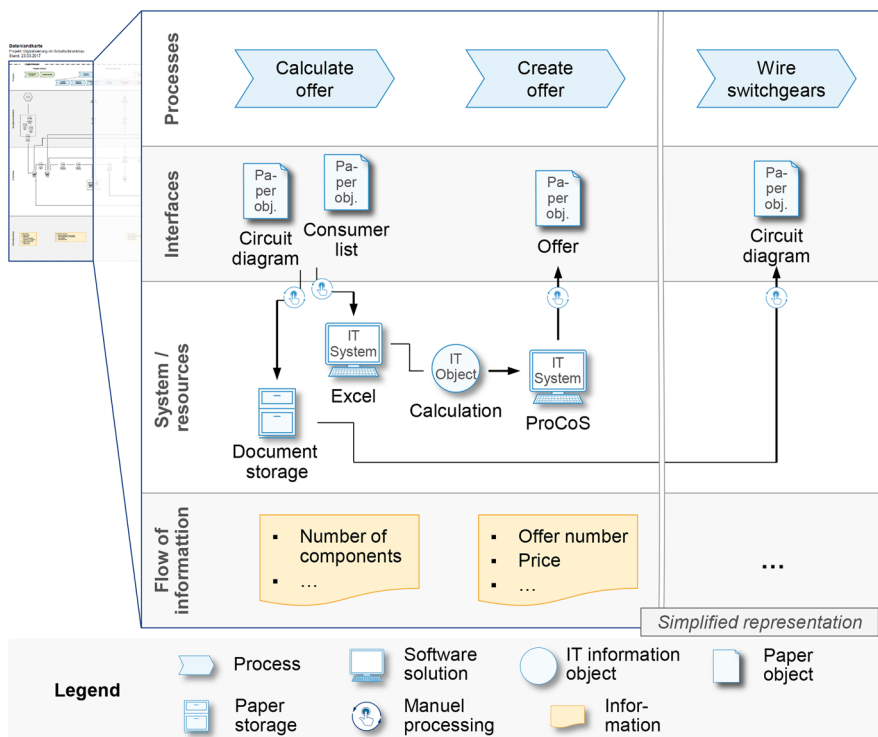


Fig. 12 Excerpt of the data map of the application example

The mapping of the processes with the data map represents a comprehensive recording of the initial situation. It describes the environment of the investment object with a focus on IT.

## Structuring the Information in the Shell Model

In the course capturing the initial situation, numerous possible use cases are identified. These are recorded and structured with their prerequisites in the shell model for structuring Industry 4.0 applications in production. The sum of all use cases with the respective framework conditions describes the Industry 4.0 application. Figure 13 shows an excerpt of the shell model for structuring the tablets in the production of a switchgear manufacturer.

The initial use case of the assisted wiring through the tablets in production represents the starting point in the shell model. This is the process adaptation in the direct area of a production. Two use case-specific software solutions are required to implement this. These are on the one hand the software Smart Wiring, which is the software of the wiring assistant. On the other hand, the software Pro Panel is needed, with which a 3D view of a switchgear can be created. This is necessary for the routing of the wiring. In addition, there is the structure-giving software. It fundamentally shapes the engineering processes. In this example, the engineering software EPLAN P8 is used to create the circuit diagrams (Joppen et al., 2019).

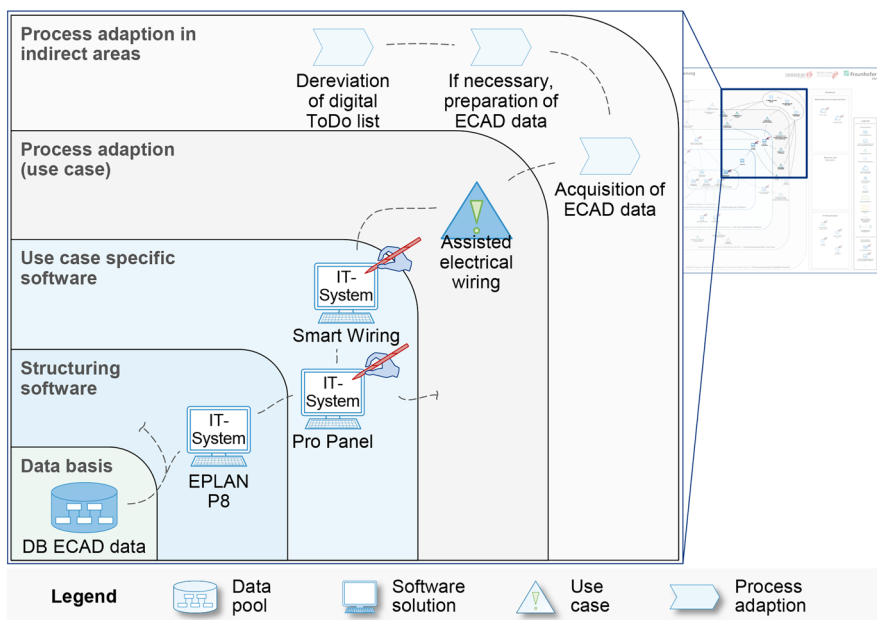


Fig. 13 Excerpt of the shell model of the application example

The lowest level is the data basis with the ECAD data. The circuit diagram and a 3D model of the switchgear are required to work with the use case-specific software and implement the use case. In the case of the switchgear manufacturer, however, the data basis is often not available. Often times, customer (i.e. a machine manufacturer) creates the ECAD data. These are passed on in non-machine-readable file formats. Thus, different process adjustments in the indirect area are added. The data must often be actively procured by the switchgear manufacturer. This usually requires incentives for the customer. Subsequently, the data may have to be prepared and the digital to-do lists for the use case-specific Smart Wiring software derived (Joppen et al., 2019).

The structured evaluation problem represents the central result of this phase. In the following, it is used for a transparent evaluation of the investment object.

## Phase 2: Transparent Evaluation of the Investment Object

Once the evaluation problem has been structured, the data basis for the evaluation has to be recorded. This includes both the benefits and the costs.

## Recording the Qualitative Benefit

At first, the benefits of the tablets in production are recorded qualitatively. A scheme for the evaluation of investments in production is used. The creativity method helps to collect and to evaluate the benefits of investments. This is done for each Use Case of the Industry 4.0 application. If, for example, the three use cases of assisted wiring, 2-shift operation, and order tracking are evaluated, the scheme is filled out for each of these use cases. Figure 14 shows the completed scheme for the use case of assisted wiring in the production of a switchgear manufacturer.

The potential process innovation was recorded in the Performance/ Quality category. The process innovation can manifest itself in different ways. For example, the assembly can be carried out separately from the wiring process. The same applies to picking and printing of equipment labels.

The reason for the process innovation is that the employees without the tablets have to read the circuit diagram for each work step, determine the cable routes for selected cables, assemble the necessary cables, wire them, and then mark them. Due to the lack of an overview of the entire circuit diagram, the employees repeat this for few cables. Generally, the work steps take place at different locations in production, which leads to considerable walking distances. With the help of the wiring assistance on the tablets, the employees can carry out the individual steps, such as the assembly for a much larger number of cables, since they can display similar cables via a filter in the software. This saves employees considerable walking times between the work steps. According to this logic, different potentials were found and specified in seven of the categories.

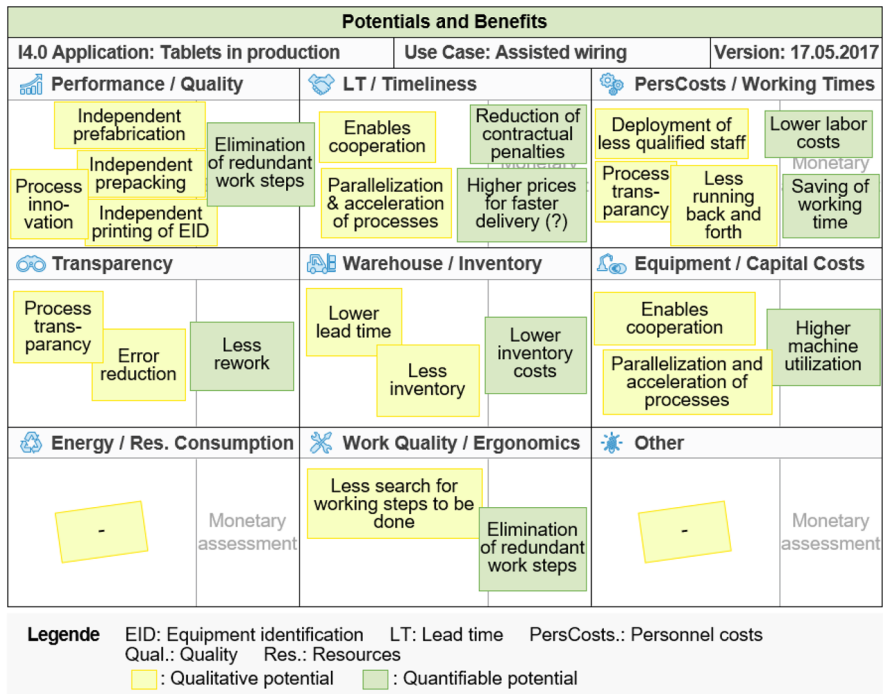


Fig. 14 Scheme for the evaluation of investments in production with an example

## Recording Costs with a Cost Catalogue

Afterwards costs are recorded. This step supports the following step. The cost catalogue for Industry 4.0 applications in production is run through, and it is checked which cost components apply. In the application example for the introduction of tablets in production, costs are first incurred for process recording and analysis, followed by an assessment of the infrastructure and identification of potential. An excerpt from the cost catalogue used is shown in Fig. 15.

## Recording the Data Basis for the Evaluation

After the qualitative benefits have been identified and the costs researched, the quantitative data basis for the investment evaluation is recorded. This is done using the method of data collection for investments in production (Joppen et al., 2018). The application method for data collection for investments in production is shown in Fig. 16.

The basis of the workshop method is a life cycle model from product or production system planning to descent. The phases are plotted from left to right. An area for general assumptions is added. The benefit and cost elements are recorded along the life cycle phases. The various use cases are recorded among each other (Joppen

Life cycle	Cost type	Cost element	No.	Description	Reference
Production system design	Acquisition	Requirements analysis	1	Determine, record and process of change requirements	[VDI2884]
		process recording and analysis	2	Record and analyze current processes	[GP14]
		Review of infrastructure	3	Record technical infrastructure, IT system environment, existing interfaces and data	[JEK+18], [KJR+18]
		Potential identification	4	Determine, record and process of possible improvements	[GP14]
Development	Software	Software acquisition	16	Acquire relevant software	[MBS+19], [VDI2884]
		Software customizing	17	Customize chosen software solutions to the requirements of the company	[MBS+19], [AAA+09]
		Creating databases	18	Create and install databases	[JEK+18], [KJR+18]
		Connect to systems and databases	19	Create interfaces to the given databases for data exchange and conversion	[JEK+18], [KJR+18]
		Cloud provision and connection	20	Setup of infrastructure to provide software applications	[NP18], [Urb19-ol]

**Legend**     : is relevant for the application

Fig. 15 Excerpt from the cost catalogue

et al., 2018). For the tablets in production, the two use case–assisted wiring and 2-shift operation are shown.

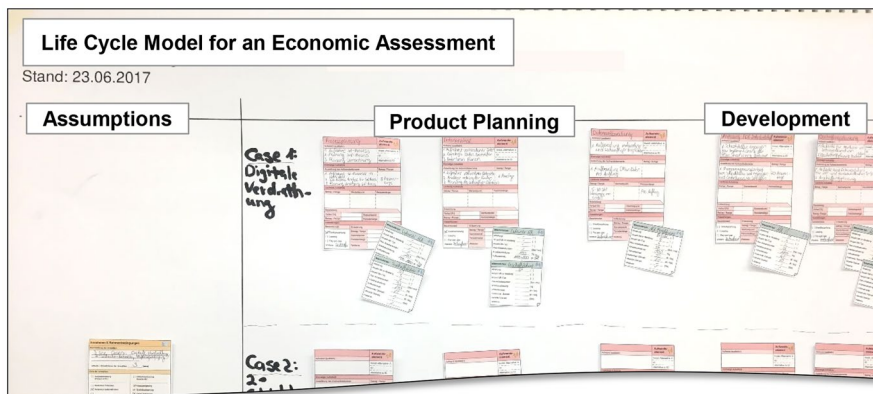


Fig. 16 Example use of the method for collecting data for investments in production (Joppen et al., 2018)

## Example of a Benefit Element in the Context of Data Acquisition

Within the scope of the assisted wiring use case, the potentials of “process innovation,” “enabling cooperation,” “use of less qualified employees,” “process transparency,” and “reduced throughput time” were described. These are derived from the scheme for the evaluation the benefits of investments in production shown above. The benefit element process innovation is shown in Fig. 17, together with the two resource elements to which it refers.

As described above, the benefit element process innovation can be subdivided into “detached pre-packaging,” “detached pre-picking,” and “printing detached equipment labels.” Detached pre-assembly leads to a saving of redundant work processes.

The effects of the detached pre-packaging, the detached pre-picking, and the detached printing of the equipment labels are evaluated with a total of approximately 25%. The assumption comes from an evaluation with a time recording. The three effects could not be meaningfully separated. The initiation and stabilizing of the processes to achieve this increase in productivity takes about 1 year. It will start about half a year after the start of the project to evaluate the tablets in production.

In order to make the productivity increase assessable, an assessment basis is added. The resource cards “employees in production” and “temporary workers in production” indicate that permanent employees and temporary workers in production are affected. In addition to the number of employees affected, the hourly rate is also added. This enables an evaluation of the economic benefits.


## Example of a Cost Component During Data Entry

Furthermore, fourteen cost elements for the implementation of the assisted wiring use case were recorded. These ranged from “process planning,” “data analysis,” “data preparation,” and “training — employee project planning” to “hardware replacement” at the end of the investment’s life cycle. The cost element “training — employee project planning” is shown in Fig. 18.


The costs for the training of employees from the project planning can be divided into the costs of the software provider and the costs arising from the participation of own employees. The costs by the software provider are directly quantifiable and are given as 800€ per person day. The costs due to the participation of the employees are to be determined by the number of days and the employee hourly rates. Thus, a resource card for the employees is to be attached to the project planning. This contains among other things the number of employees and the hourly rates.

Furthermore, efficiency losses are expected for the project planning staff due to the novelty of the software. It is estimated that the employees will achieve about 80 to 90% of their work performance in the first year. According to this approach, all costs and benefits of the investment are jointly anticipated and recorded in the workshop.

With the help of the quantitative evaluation basis, the evaluation of the profitability can then be carried out. For this, a calculation method has to be selected, the evaluation basis transferred to the tool support and then the benefits and costs calculated.

Process innovation		Benefit-Element 
Benefit (qualitative)		
(1) Detached prefabrication, detached pre-packing and detached printing of equipment identification		Invest.-Alt.: A ID: 11 Alt. to ID: –
Objective		
Impact of the Benefit-Elements		Evaluation
(1) Processes can be separated in a useful and functional way, e.g. it is possible to separate prefabrication, pre-packing and printing of equipment identifications in advance. This results in significant reduction of transit and non-productive times.		(1) approx. 25%
Course of Time		
Initial	Course	
(1) Get used to the new work steps until the increase in efficiency will have been implemented in full	Duration: Start: 0,5	

**Type of Employee: Temp. worker production** 

Department: \_\_\_\_\_

No. Empl. in Department: 35 [ - ]

No. Empl.-Type: 5 [ - ]

Planned working hours: \_\_\_\_\_ [h / week]

Workload: 100 [%]

Full cost rate year: \_\_\_\_\_ [€ / year]


Full cost rate h: 30 [€ / h]

Cost rate overtime: \_\_\_\_\_ [€ / h]

Current overtime: \_\_\_\_\_ [h]

Multiple machine operation: Yes [ ] No [☒]

Other: \_\_\_\_\_

**Type of Employee: Employee production** 

Department: \_\_\_\_\_

No. Empl. in Department: 35 [ - ]

No. Empl.-Type: 5 [ - ]

Production 38 [h / week]

100 [%]

37 [€ / h]

47 [€ / h]


- [h]


Yes [ ] No [☒]

Fig. 17 Example of a benefit element in the context of data acquisition

## Selecting a Calculation Method

A suitable calculation method is selected with the help of two overviews of calculation methods. The first overview structures the methods according to their type and their output. The overview is shown in Fig. 19.

Training – Employee project planning		Effort-Element 
Expenses (qualitative)		
(1) Costs of software provider		Invest.-Alt.: A
(2) Costs due to occupation of own employees from project planning		ID: _____
		Alt. to ID: –
One-time costs		
Effects of the cost element		Evaluation
(1) Costs for in house training		800€ pp
(2) In the time of training, employees cannot carry out their usual tasks.		3 days
Ongoing Expenses		
Amount/ Range	Starting Time	Pe
(1) & (2) 80 to 90% work performance in		
Development		
Course [%]		Starting Time
Amount/ Range		Period Length
Payments		
Payment model	Note	
<input checked="" type="checkbox"/> Direct paym.	Amount/ Range	
<input type="checkbox"/> Leasing	Starting time	
<input type="checkbox"/> Pay-per-Use	Period length	
Further _____	Further	

**Type of Employee: Project planning** 

Department: \_\_\_\_\_

No. Empl. in Department : 8 [ - ]

No. Empl.-Type : 6 [ - ]

Planned working hours: 38 [h / week]

Workload: 100 [%]

Full cost rate year: 50 [€ / year]

Full cost rate h: 65 [€ / h]

Cost rate overtime: - [€ / h]

Current overtime: - [h]

Multiple machine operation: Yes [ ] No [☒]

Other: \_\_\_\_\_

**Fig. 18** Example of a cost component during data entry

The second overview is a list of the methods with key questions, which reflect the focus of the method. The overview is shown in Fig. 20.

Several methods can be applied simultaneously within the process of an economic evaluation of an Industry 4.0 application. For example, the question of the current value of the investment and the interest rate of the investment was asked in the context of the evaluation of tablets in production. The net present value and the internal rate of return were therefore applied.

## Transfer of the Evaluation Basis into the Tool Support and Calculation of the Benefits and Costs

In the next step, the acquired calculation basis is transferred to the tool support and the calculation method to be used is selected. Figure 21 shows an excerpt of the calculation tool. To calculate the benefit, the benefit elements are entered one by one



		Method	
		Static	Dynamic
Output	Absolute [€]	(1) Cost comparison method (2) Profit comparison method (3) Break-even analysis	(6) Net present value method (8) Final-value of assets method (7) Annuity method (9) Full financial plan method
	Relative [%]	(4) Return on Investment	(10) Internal rate of return method (11) Debit interest rate method
	Period [years]	(5) Static amortization method	(12) Dynamic amortization method

**Fig. 19** Overview of calculation methods according to their type and their output

into the tool support. The structure of the benefit elements in the tool support is the same one as the structure of the workshop cards shown before.

The benefit element process innovation is described in more detail with the qualitative benefit more efficient wiring. The effects of more efficient wiring are entered with a 25% saving in working time in the process step of wiring. The wiring process step takes about 50% of the working time. This corresponds to 19 h per week. It is also noted that only ten employees are affected. Five permanent employees and five temporary workers in the production department will initially work with the wiring assistance. The permanent employees in production are created as employee class 1 in the tool and the temporary workers are created as employee class 2. A separate benefit or cost element is created in the tool for each affected employee class to which a benefit or cost component applies. The benefit elements and the calculation basis are used to calculate benefits over the years. The calculation extends over ten years, since the use cases are implemented with a delay.

## Presentation and Evaluation of Results

In the presentation and evaluation of results, the effects of the different use cases are considered separately and as an overall result. For each use case, the average case (that is, the average expected result) and the worst and best case are displayed. For the application example, Fig. 22 shows the results of the three use cases mentioned above. The calculation results are the central result of the second phase.

No.	Method name	Focus or key question of method	Reference
1	Cost comparison method	Which investment costs the least?	[Pog15]
2	Profit comparison method	Which investment earns the most profit?	[Pog15]
3	Break-even analysis	From what sales volume are the costs covered by sales revenues?	[GDE+19]
4	Return on investment or average return analysis	How high is the profit caused by an investment in relation to the invested capital?	[GDE+19]
5	Static amortization method	How long does it take to recover the invested capital from the average payments of an investment?	[Göt14]
6	Net present value method	What is the value of the investment today or what is the value of the investment discounted to today?	[Hee16]
7	Annuity method	What sequence of equally high payments per period does an investment generate?	[Göt14]
8	Final-value of assets method	What is the capital gain of an investment at the end of the planning period?	[Pog15]
9	Full financial plan method	What is the pattern of payments attributable to an investment?	[Göt14]
10	Internal rate of return method	What is the return on the investment?	[SS16]
11	Debit interest rate method	What is the critical interest rate at whose use the final asset value is zero?	[Göt14]
12	Dynamic amortization method	How long does it take to recover the capital invested from the proceeds of an investment?	[Göt14]

**Fig. 20** Overview of calculation methods with key questions, which reflect the focus of the method

### Phase 3: Derivation of Recommendations

In the final phase, the recommendations for action are derived and the results are summarized in a two-page management summary. The management summary compiles the relevant information about the investment decision. Page one of the management summary of the application example is shown in Fig. 23. The second page of the management summary contains an implementation roadmap. It is shown in Fig. 24.

The recommendation is to further promote the investment, since it promises, among other things, very large efficiency increases in production. Due to the dependence on the provision of the digital models by the customers, it can currently only be implemented economically for a small proportion of the orders. The digital models are needed for the Industry 4.0 application to work. Today, however, these are usually not provided by the customers or only in insufficient quality. It is assumed that the provision of the models will be better in the future and that the investment will therefore be much more advantageous.

The tablets will initially serve as digital wiring assistance. The use cases will be successively expanded. The main objective is to create transparency in the order processing,

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◀ **Fig. 21** Excerpt from tool support for the calculation of the benefits

which among other things, provides the possibility for employees to work together on orders. Central assumptions are that customers will provide the digital models (i.e. the ECAD data) against a (possibly also monetary) incentive and that additionally produced products can be sold completely. Furthermore, it is assumed that the share of digital models provided by component manufacturers is continuously increasing.

This results in two central costs for implementation. Firstly, there is the one-time structuring of products and orders for the targeted procurement of digital models. On the other hand, this is the continuous procurement of the digital models for the use of the wiring assistance.

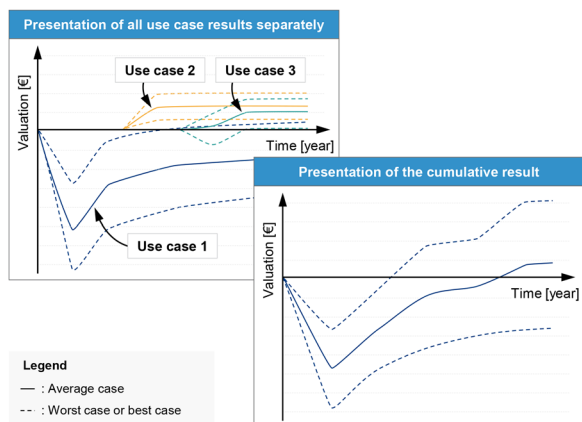
The central opportunities of the investment are standardized and significantly accelerated wiring, more flexible allocation of employees, and increased transparency in the order processing process. The central risks are the dependence on the provision of the digital models by the customer and the possibly costly, unpaid work for the preparation of the digital models. Project planning staff are required to prepare the models. This shifts the workload from production to the upstream processes.

Three influencing factors are considered central to implementation controlling. These are the percentage of orders which are processed with the help of the tablets, the percentage of orders that are planned by the switch gear manufacturer and the effort required to prepare digital models.

The implementation roadmap sets the necessary elements for the implementation of the use cases in a temporal context. An excerpt of the implementation roadmap of the application example is shown in Fig. 24.

The roadmap shown includes the first three use cases to be implemented. The first use case to be implemented is the assisted wiring. This is the basis for the following use cases. A number of measures are necessary to implement the assisted wiring. The measures can be divided into the four categories organization, IT systems, data, and hardware.

**Fig. 22** Excerpt from the calculation results



**Investment overview: Tablets in production (1/2)****Contact person:** Robert Joppen**Status:** 12.11.2017

**Recommendation for action:** The investment promises, among other things, a very large potential for increasing efficiency in production and should therefore be further pursued. Due to the dependence on the provision of digital models by the customers, it can only be implemented economically for a small proportion of orders at the present time. It is assumed that the provision of the models will be better in the future and therefore the investment will be much more advantageous.

**Description**

- Use of tablets in the production for a digital wiring assistance
- Successive expansion of the use cases and functionalities of the tablet

**Objectives and benefits**

- Acceleration of the wiring
- Creates transparency in order processing and enables controlling
- Enables joint order processing and more flexible staff deployment

**Main assumptions**

- Customers today do not provide usable digital models, but do so against an incentive (which may be monetary)
- Additionally produced products can be completely sold

**Implementation Costs**

- Unique structuring of the processes
- Continuous procurement and preparation of digital models

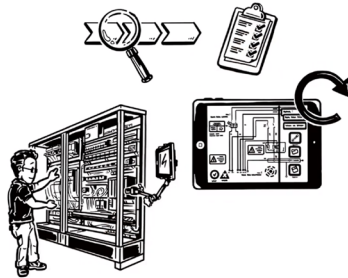
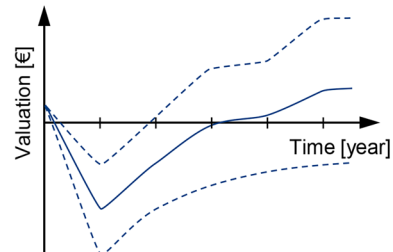
**Graphical representation**

Image source: DIGITAL IN NRW, 2017

**Anticipated Result****Central Opportunities**

- Wiring can be standardized and significantly accelerated
- Employees can be deployed more flexibly
- Increase of transparency in the order handling process

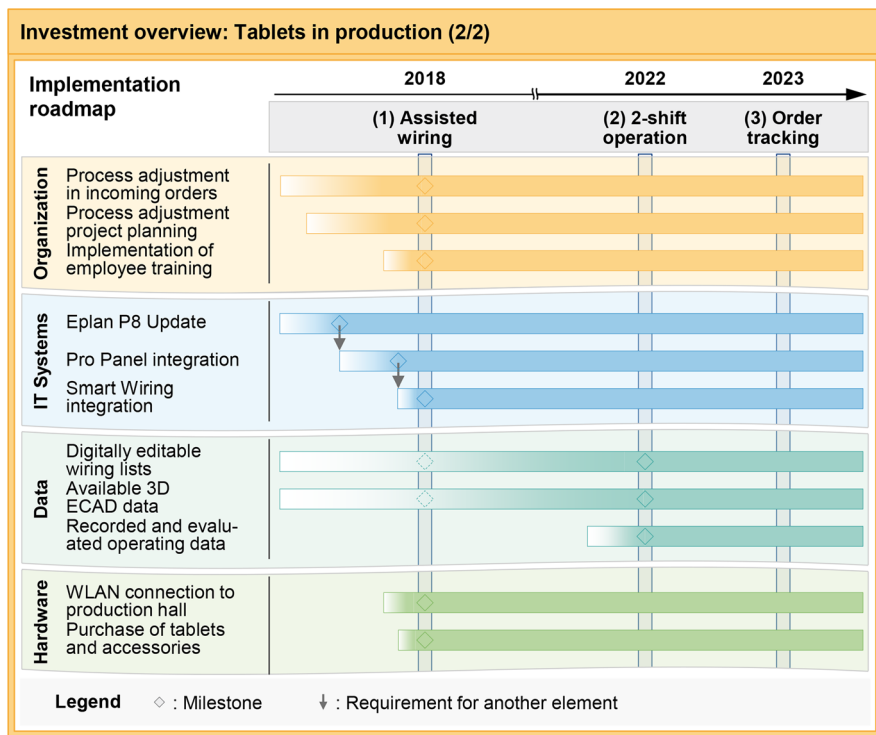
**Central Risks**

- Dependence on the provision of digital models by the customer
- For the often unpaid preparation of the models, employees are needed in project planning, savings are made in production

**Central factors for implementation controlling**

- Percentage of digitally assisted wired jobs
- Percentage of independently projected orders
- Effort for the preparation of digital models

**Fig. 23** Management summary of the investment evaluation (1/2)



**Fig. 24** Management summary of the investment evaluation (2/2)

The recommendations for action are thus the central result of the third phase. For the user of the systematic, the management summary is the basis for the decision on the investment in the Industry 4.0 application in production.

## Conclusion and Outlook

Industry 4.0 promises numerous potentials. Nevertheless, many companies are still hesitant to invest in Industry 4.0 applications in production. One main reason is uncertainty about the profitability of an investment.

The cause of this uncertainty is threefold. First, there is a lack of a structured approach to the evaluation of Industry 4.0 applications in production. The second central challenge is the analysis of Industry 4.0 applications from a systems theory perspective. The third central challenge is the lack of support in the data collection for an evaluation of the Industry 4.0 application.

This work presents a systematic approach to evaluate an Industry 4.0 application in production. The approach consists of five elements:

- a characterization of investments in Industry 4.0 applications, which provides the theoretical basis for an evaluation,
- a process model based on the characterization, which puts the activities to be carried out, the tools to be used and results in a temporal context,
- tools for a systemic description of the investment object, which support the user in describing, structuring and delimiting the Industry 4.0 application to be evaluated as a system within the production system. Here, particularly in a workshop format, the data map enables the Industry 4.0 application to be described as a system within a system and thus to involve various stakeholders and domain experts in the evaluation process.
- tools for a transparent evaluation of the investment object, which support the user in carrying out the evaluation of the Industry 4.0 application transparently,
- a tool support for an easy application of the system. On the one hand, the developed methods are provided with graphical elements to make them easy to understand. On the other hand, the tool support is based on the method for data acquisition for investments in production. This allows a simple transfer of the data collected in the workshop into the tool support with a direct further processing.

Future research addresses the transferability of the systematic beyond the production context into other areas. Furthermore, it should be examined whether and to what extent the financing should be integrated into the concept. Since the developed approach addresses, among other things, the missing data basis for an evaluation, an adapted procedure for large companies with a sound data basis or with established key figure systems is to be examined. Finally, the approach can be supplemented by various simulations, such as those of market assumptions.

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