A Guideline for the Successful Implementation of Industry 4.0 Solutions
Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

Across the world, the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University with its 900 employees stands for successful and forward-thinking research and innovation in the area of production engineering. Active in four different fields, research activities not only relate to fundamental theories and findings, but also to the application of findings in an industrial context. Furthermore, practical solutions are developed to optimize production. The WZL covers all sub disciplines of Production Technology with its four chairs of Production Engineering, Machine Tools, Metrology and Quality as well as Manufacturing Technology.
Industry 4.0: Implement it!

A Guideline for the Successful Implementation of Industry 4.0 Solutions

Günther Schuh
Wolfgang Boos
Christoph Kelzenberg
Johan de Lange
Felix Stracke
Jens Helbig
Julian Boshof
Christoph Ebbecke
Industry 4.0: Implement it!
Contents

- Introduction
- Presentation of Use Cases
- Organizational Framework for the Implementation of Industry 4.0
- Process for the Development and Implementation of Industry 4.0 Use Cases
- Industry 4.0 Maturity Model for Target Determination and Idea Filtering
- Quantitative Assessment of Industry 4.0 Use Cases
- Summary and Outlook
- Appendix
Introduction

Since 2011, the term Industry 4.0 has been a hallmark of the entire manufacturing industry. It describes the so-called fourth industrial revolution, which promises the provision of benefits for manufacturing companies by means of digital networking. Industry 4.0 can be understood as the real-time capable, intelligent, horizontal and vertical networking of people, machines, objects as well as information and communication technology (ICT) to dynamically control complex systems. The goal is the optimization of production processes, products and services by means of state-of-the-art technologies.

In contrast to the previous industrial revolutions, the fourth industrial revolution did not only originate from the continuous development and mechanization of manufacturing companies, hence from within the market. It was created and proclaimed by the federal government of Germany as a strategic future project. Therefore, it is not surprising that in the early years after proclamation, a broad discourse emerged about the definition, scope and objectives of Industry 4.0. Hence, companies have been hesitant and acting stepwise in engaging with the topic. By now, not only the understanding of the term Industry 4.0 has sharpened, but the topic has become known in the broad mass of producing companies. In Germany, 80% of all manufacturing companies assess Industry 4.0 to be strategically relevant and 89% of the companies expect an even increasing strategic relevance of Industry 4.0 in the future.

More than 7 years after its postulated start, the current balance of the implementation of Industry 4.0 is disillusioning. Only 45% of the companies occasionally use Industry 4.0 solutions, while a further 20% of the companies plan to introduce solutions in the near future. In conclusion, companies are still far away of the completion and comprehensive realization of Industry 4.0.
But why has the implementation of Industry 4.0, despite the promising strategic benefits among the whole industry, not taken place so far? A fundamental reason, besides high investment and development costs, is the lack of organizational structures and specifications. Companies often lack suitable target-oriented concepts and a structured approach in order to introduce Industry 4.0 into their entire organization. Hence, the introduction of Industry 4.0 is often focused on single Use Cases and solutions that are only implemented in selective areas and do not exceed the pilot status. At this point, an analogy to the development and implementation of the Lean Management concept at the end of the 1990s can be reasoned. That concept also rose wide interest in the manufacturing industry. However, it took several years to install suitable organizational elements and structures such as production management systems, lean management departments and lean management positions in order to implement the concept holistically. This guideline “Industry 4.0: Implement it!” addresses the described problem and provides impulses and recommendations in the form of a concept for the comprehensive implementation of an Industry 4.0 strategy. For this purpose, concrete organizational structures, processes and instruments are introduced to support the successful operative implementation of Industry 4.0.

To convey the content in a practical way, two Use Cases are contemplated which are presented first and exemplarily applied in the following chapters.

Enjoy reading the guideline and all the best for the subsequent implementation!

Sincerely,

Günther Schuh
In an exemplary company, it has increasingly come to the situation that employees use a video chat application to call their colleagues from other company locations to support each other in case of machine failures and setup problems. Due to the frequent use of this medium for problem solving, it has been identified as a weak point in the production process.

After intensive consultations, the company agreed to develop an Industry 4.0 solution with its employees using Smart Glasses. The glasses enable a user-friendly way to transmit the wearer’s field of vision. It is also intended to project relevant information, e.g. assembly instructions or machine data, into the receiving end of the Smart Glasses’ field of vision. This form of communication is supposed to simplify the transfer of knowledge between employees and to optimize maintenance and setup processes.

Smart Glasses are an umbrella term for different types of intelligent data glasses that project digital information into the wearer’s field of vision. Augmented Reality (AR) and Virtual Reality (VR) are generally differentiated. The use of AR is based on using an integrated camera to identify objects and display the corresponding information. AR is particularly useful for hands-off activities and therefore provides opportunities for remote maintenance activities as well as for process visualizations. In the context of remote maintenance, an employee can use Smart Glasses while working at the machine in question so that a maintenance expert at any location can observe and comprehend the activities on a screen. Instructions or helpful information (e.g. extrusion drawings or assembly steps) can directly be displayed in the employee’s field of vision. This way, complex maintenance tasks can be conducted by less trained personnel with remote support. VR is particularly suitable for training purposes, but is not elaborated at this point.

Because of their weight, limited comfort and limited runtime most smart glass models can only be used for a limited timeframe. Additionally, a reasonable use of Smart Glasses demands an internet connection at all deployed locations. Lastly, the high effort of integrating new Use Cases hinders companies from employing Smart Glasses comprehensively.
**Presentation of Use Case**

**Data Lake**

In the course of a “digitization offensive” an exemplary company has extensively invested in capturing data in recent years, but is very dissatisfied with the derived findings and potentials so far. Internal analyses quickly identified the reason for that. Instead of implementing a coordinated strategy, investments were made plant- and department-specific and in many different systems with interfaces non- or insufficiently existent. Problems are currently handled by internal lean managers extracting excel files. With this analysis and digital networking with other relevant data takes a long time. Nevertheless, analysis results have a very high value for the company. For instance, that a bottleneck in the assembly process was linked to a wrong delivery order. Additionally, several product complaints could be traced back to an incorrectly calibrated measuring device.

The management does not want to accept the high effort and long reaction times any longer. However, the intended Industry 4.0 solutions for the identification of correlative connections require access to the large amounts of captured data. Due to the reason that many systems and the uncoordinated interfaces are used, this is not immediately feasible. At this point, a company-wide Data Lake provides remedy. It is a central “reservoir” for all data which is created in a company. No matter if production, development or logistics data – all data is united at a central (virtual) place to guarantee its maximum availability.

Unlike a Data Warehouse, neither structures nor gathering schemes are defined for the collected data. While a Data Warehouse focuses on high (process) efficiency for interactive analyses and reports as well as information is individually prepared for the user, a Data Lake enables the detection of new connections in unprocessed data. It is especially useful when it is unclear whether a benefit can be generated from the gathered data. The Data Lake is divided into raw data and processed, integrated and quality checked data. The Governance poses as a policy concerning data protection, security and quality. The frontend acts as an interface to the user to depict information and analysis results.

Due to its function, the Data Lake provides the requirements for a deeper understanding of daily processes and their interactions. It should be noted that a Data Lake does not generate direct financial benefits while requiring a large initial investment. The profits of a Data Lake are generated by combining it with other Industry 4.0 solutions in a company.
The implementation of lean thinking has been practiced in companies of the western world since the 1990s. The past has shown that the direct adaption of the Japanese mindset does not inevitably result in a successful implementation. A decisive factor for the successful implementation of lean thinking was and still is the adjustment of organizational structures. The adjustment of organizational structures plays an equally important role in the implementation of Industry 4.0 solutions in a company. In the framework of this guideline, the objective of the following chapter is to outline organizational framework conditions that must be established for the implementation of Industry 4.0.

For the implementation of Industry 4.0 solutions organizational prerequisites need to be introduced. On the one hand, this includes the creation of new entities and their integration in existing organizational structures. On the other hand, existing entities selectively need to be assigned to new or additional functions. The organizational framework describes which additional entities as well as existing entities with new functions need to be implemented within an existing organizational structure to successfully realize Industry 4.0 solutions in manufacturing companies. Entities which need to be newly created are the Industry 4.0 Steering Committee including a Global Industry 4.0 Manager. Additionally, the Industry 4.0 Garage and the Industry 4.0 Plant Manager represent new entities, whereas the management and the plant itself are already existing entities. Inside manufacturing plants necessary adoptions need to take place to implement the Industry 4.0 Plant Manager and the Industry 4.0 plant projects within the existing organizational structure of the plant.

The top management as the highest entity for leading and steering an organizational structure is not modified regarding organizational composition or responsible functions. By setting objectives and allocating financial resources, the management can influence the entities that need to be newly created.

The company management’s central contact point for the implementation of Industry 4.0 solutions is the Industry 4.0 Steering Committee. This entity needs to be newly created. The Industry 4.0 Steering Committee consists of an Industry 4.0 manager (Global Industry 4.0 Manager) as well as several experts from different departments, e.g. an IT expert or a project management expert of the manufacturing company. One of the central tasks of the Industry 4.0 Steering Committee is the superordinate steering of all Industry 4.0 projects in the company. Furthermore, the Industry 4.0 Steering Committee evaluates whether an Industry 4.0 project should be initiated, rejected, focused or concluded.

There are two options for the processing and implementation of Industry 4.0 projects. On the one hand, ideas for potential Industry 4.0 Use Cases can come up on the shop floor and be steered as a plant-specific Industry 4.0 project. Normally, these are short-term projects that temporary Industry 4.0 project teams work on besides their regular daily business.

Every plant employs a local or a so-called Industry 4.0 Plant Manager to coordinate projects on-site. The second option to develop Industry 4.0 solutions is their realization inside a so-called Industry 4.0 Garage. The Industry 4.0 Garage is responsible for processing long-term projects with open or unknown results. The target is to enable employees to explore, develop, test and
validate Industry 4.0 Use Cases and Industry 4.0 solutions detached from daily business.

Whereas the organizational framework depicts the general company order, configuration options exist for each entity. They consider different company framework conditions and support the definition of specific characteristics of the mentioned entities. The different configuration options serve as an instrument to differentiate the processing intensity of important and unimportant projects. Hereafter, each entity will be described in detail. Additionally, the possible configuration options are outlined regarding their support of processing Industry 4.0 projects.

5% of the revenue is planned to be invested in Industry 4.0 solutions by companies until 2020.

(PwC 2016)
Industry 4.0 Steering Committee

From an organizational point of view, the Industry 4.0 Steering Committee has a central role for a successful implementation of Industry 4.0. The committee poses as a starting point for decisions for each prospective development and implementation of Industry 4.0 solutions. Beside the evaluation of the Industry 4.0 projects, the Industry 4.0 Steering Committee supports the projects through coaching and change management. Due to a bundling of expertise, the Industry 4.0 Steering Committee serves as a contact point for successful implementations. Furthermore, it is responsible for managing the Industry 4.0 Garage and for reporting to the top management.

The Industry 4.0 Steering Committee consists of different persons to fulfill the intended function. The role of the Global Industry 4.0 Manager needs to be newly created. The Global Industry 4.0 Manager leads the Industry 4.0 Steering Committee full-time and manages the companywide organization of all Industry 4.0 projects. The focus is on coordinating and synchronizing all Industry 4.0 projects. For instance, this includes the standardized documentation of all projects to ensure that the gathered experiences from current Industry 4.0 projects are being used for the evaluation of future projects. Further tasks are proposing and evaluating Industry 4.0 projects, executing the required change management as well as coaching. For all the tasks mentioned, the other members of the steering committee support as experts, if needed.

Beside the Global Industry 4.0 Manager, all further members of the Industry 4.0 Steering Committee can already be found in the current organizational structure. They receive their additional responsibility for the Industry 4.0 Steering Committee because of their expertise which can be consulted for decision processes and other tasks of the committee if needed. The selection of responsible personnel for the Industry 4.0 Steering Committee is only based on the required expertise.
The following expert competencies are essential for the correct evaluation and consulting support of Industry 4.0 projects:

• IT-specific knowledge
• Process knowledge
• Organizational knowledge
• Project management knowledge

Persons with these competencies could for instance be the heads of the IT division, supply chain management, Project management or Lean management.

The work structure of the Industry 4.0 Steering Committee is based on cyclical meetings. This means the Global Industry 4.0 Manager meets the experts of the Industry 4.0 Steering Committee in regular, defined time sequences. If important decisions about existing or future Industry 4.0 projects need to be made, the Global Industry 4.0 Manager can call for ad hoc meetings with the members of the Industry 4.0 Steering Committee.

Two central configuration options of the Industry 4.0 Steering Committee are the number of committee members and the available budget. The quantity of members of the Industry 4.0 Steering Committee can vary based on the intensity of the Industry 4.0 projects in a company, the correlation at hand being increasing numbers with increasing intensity. The budget defines the monetary scope of the Industry 4.0 Steering Committee. If the Industry 4.0 projects have a high value to the company, the Industry 4.0 Steering Committee receives a higher budget to support the respective projects with the desired intensity.
Plants

There are Industry 4.0 projects the management supports because of long-term and strategical decisions. However, the organizational structure is also required to provide opportunities that enable the processing of Industry 4.0 solutions that originate directly on the shop floor, indirect areas or the complete production process. To realize this requirement, a position of the so-called Industry 4.0 Plant Manager is newly created at each production plant. An Industry 4.0 Plant Manager is hierarchically subordinate to the plant management and his main task is to identify weaknesses of the production process on-site which Industry 4.0 solutions can optimize. Additionally, he is the central contact person for improvement suggestions from employees of each plant.

The Industry 4.0 Plant Manager presents the identified ideas to the Industry 4.0 Steering Committee to evaluate and decide. In case of approval by the Industry 4.0 Steering Committee, the Industry 4.0 Plant Manager is obligated to inform the plant management. Since the implementation of the Industry 4.0 plant projects is part of the operative daily business, the Industry 4.0 Plant Manager must obtain a capacity approval from the plant management. The Industry 4.0 Plant Manager is only allowed to form temporary Industry 4.0 project teams after receiving the respective approvals of the Industry 4.0 Steering Committee and plant management. The teams consist of interdisciplinary employees from the shop floor which suit the project processing best based on their knowledge and competencies. The team formation is based on close cooperation with the employees. Simultaneously, rules of labor reallocation are defined. For instance, this includes the designation of employees that take up on tasks that can temporarily not be fulfilled by the temporary Industry 4.0 project team based on capacity and competence. The Industry 4.0 Plant Manager is obligated to report the progress of projects to the Global Industry 4.0 Manager.
The configuration option of Industry 4.0 project processing within plants can particularly be controlled by the capacity approval of the plant management. For instance, if a project is supposed to be developed with high intensity, the plant management can relieve affected employees from their operative daily business entirely for the duration of the project. A project of low intensity and relevance can be expressed by only approving a fraction of individual capacity for every member of the temporary Industry 4.0 project team. A regulating lever of Industry 4.0 plant projects from the perspective of the Industry 4.0 Steering Committee lies in incentivizing the plant management. The plant management needs to be motivated to implement Industry 4.0 projects parallel to the operative daily business of a plant. For instance, the plant management could not only receive yearly objectives but also additional budgets for implementing Industry 4.0 projects. In addition, personal bonus payments for successful Industry 4.0 solutions can pose as a motivational factor.

**Industry 4.0 Garage**

A large amount of Industry 4.0 projects is characterized by the fact that neither the desired project result nor the approach for achieving it are known at the beginning of the project. The processing of these projects is in a lot of cases not target-oriented and the duration not predictable. To also consider these aspects in the development of innovative Industry 4.0 solutions, the integration of an Industry 4.0 Garage in a company structure makes sense from an organizational point of view.

The Industry 4.0 Garage can be described as a laboratory to assess complex and long-term Industry 4.0 solutions. At least two employees should work in the Industry 4.0 Garage full-time. The necessary employee qualification focuses specifically on technical education. The employed personnel is required to possess an understanding of the application and characteristics of company specific production and processes as well as knowledge about relevant technologies connected to Industry 4.0. The technical equipment includes processing machines for developing, implementing and trying out prospective Industry 4.0 Use Cases, e.g. milling and drilling machinery. The equipment is comparable to workshop equipment, e.g. equipment for working on electronics or hydraulics. Depending on the financial budget, Industry 4.0 Garages also own state-of-the-art technologies such as robotics equipment or 3D printers. The future-oriented equipment enables the Industry 4.0 Garage to research optimization opportunities of Industry 4.0 relevance on its own. Furthermore, the independent endowment empowers the Industry 4.0 Garage to react to top-down assigned topics by the Global Industry 4.0 Manager quickly. The Industry 4.0 Garage is a separate organizational unit whose location is ideally geographically separated from the rest of the company. The general objective is to enable the Industry 4.0 Garage to act as independently as possible from the daily business.

The work structure of the Industry 4.0 Garage is supposed to support the character of working independently as well. Although the Industry 4.0 Garage is subordinate to the Industry 4.0 Global Manager, the employees of the Industry 4.0 Garage report to themselves. Because of the long-term project processing, the Industry 4.0 Garage is obliged to provide status updates to the Global Industry 4.0 Manager.

However, the reporting dates are based on voluntary setting by the Industry 4.0 Garage. The Global Industry 4.0 Manager merely prescribes time periods for the Industry 4.0 Garage within which the reporting must take place. This ensures the least possible organizational constraints for the Industry 4.0 Garage. This degree of
Industrie 4.0: Implement it!

independence aims at supporting the development of complex and visionary ideas in the form of Industry 4.0 solutions.

Various regulating levers can control the intensity of project processing in the Industry 4.0 Garage. If, for example, an Industry 4.0 Use Case or an Industry 4.0 solution is supposed be developed within the Industry 4.0 Garage with high intensity, the Industry 4.0 Steering Committee can enlarge the personnel of the Industry 4.0 Garage with full-time employees from the own company for temporary periods. Furthermore, the Industry 4.0 Garage can be given its own budget responsibility, within which external experts may be temporarily employed for cooperation and consulting purposes. Within a lower priority project, however, the budget responsibility of the Industry 4.0 Garage can be limited and the extent of consulting services focused on internal company employees.

To summarize the depiction of an organizational framework for the implementation of Industry 4.0, the adaptation of the organization is a basic prerequisite for the successful implementation of Industry 4.0 solutions in companies. In its course, it is necessary to create new entities, assign additional functions to existing entities and combine existing organizational structures with new organizational changes.

Innovation environments became standard for large companies in recent years - more than 70% of DAX30 companies have such units

(Schuh et. al. 2017)
Use Case Smart Glasses

In order to develop Industry 4.0 solutions, the employees of the production plants can apply for an Industry 4.0 plant project bottom-up at the Industry 4.0 Steering Committee. In case of a project confirmation and received approval from the plant management, the Industry 4.0 Plant Manager is able to form a temporary Industry 4.0 project team. The target of the project is to develop an Industry 4.0 Use Case for a smart glass application in close collaboration with the employees.

For the composition of the project team, the Industry 4.0 Plant Manager aims towards selecting suitable members. For this project, the selection falls to two machine operators directly affected by the problem, an internal IT expert and a young student trainee currently employed in the company. While the machine operators are essential for validating project results as final users, the IT expert is needed for the project implementation. The student trainee is selected by the Industry 4.0 Plant Manager because he hopes for new university-based research input for the project processing.

The Industry 4.0 Plant Manager classifies the processing intensity as low. The decision is based on the availability of the required hardware on the market. The general capacity approval, however, is justified by the frequency of the occurring problem, the lack of data security of the past application as well as the direct effect of the project on productivity. Due to the low intensity, all involved employees are approved for a maximum of one hour per day for implementing the Industry 4.0 plant project in order to adapt an existing solution from the market to company specific requirements and modify it accordingly. For this purpose, the team receives a separate room to conduct their meetings in. The team members determine the frequency of the meetings themselves. In this Use Case, the team members will meet daily to describe the problem and record the requirements at the beginning. Afterwards, the IT expert supported by the student trainee sets up further meetings with the machine operators in order to validate and optimize intermediate results from the practical application. The team members must report the progress of the project to the Industry 4.0 Plant Manager at the end of each week. If the team needs support or further input from the Industry 4.0 Plant Manager, they contact him in between the reports as well. However, since this is a low-intensity Industry 4.0 plant project, the project team members are not allowed to approach other employees without aligning with the Industry 4.0 Plant Manager first. The purpose of this interface regulation is to prevent the Industry 4.0 plant project to deter more employees from their daily business and hence cause inefficiencies. Due to the low intensity, the Industry 4.0 Plant Manager initially sets the project duration to four weeks.
**Use Case Data Lake**

A Data Lake is needed to realize data availability, their linkage and analysis for correlation in the company. However, building a company-wide Data Lake is expensive. In addition, it is a complex task, which requires a long implementation period. As a result, it is connected to a long-term decision with high financial invest. In order to be able to handle top-down specific Industry 4.0 projects with a high degree of complexity, it makes sense to assign the Industry 4.0 Garage with the development of a company-wide Data Lake. The Industry 4.0 Garage is able to develop this long-term, complex task due to its separation from the operative daily business. Due to the importance of the Industry 4.0 project for the company, the Industry 4.0 Garage receives high budget responsibility. Within the scope of this budget responsibility the integration of an external IT specialist over a period of several months is included. In addition, investments to enable the realization of the required server infrastructure are planned. Due to the high strategic importance of the project, the Industry 4.0 Garage will also receive internal personnel support from two IT experts working with the Industry 4.0 Garage full-time for the duration of the project. Thus, the Global Industry 4.0 Manager gives the project processing of the Industry 4.0 Garage both the capacity and financial scope for action to further focus the implementation of a Data Lake by the Industry 4.0 Garage. Before the start of the project, the Global Industry 4.0 Manager and the members of the Industry 4.0 Garage determine that the team will report the project progress once a month. The members of the Industry 4.0 Garage can ultimately determine the exact time themselves. The mode of cooperation within the Industry 4.0 Garage is determined by the employees themselves. The two full-time employees of the Industry 4.0 Garage decide on the approach and planning of the project processing since both are experienced in processing open-end, complex projects. However, the specific implementation of the defined tasks or sub-projects is being carried out individually and without specific regulations by every respective member of the Industry 4.0 Garage. The conversions within the project are accompanied by a daily exchange of all members in order to make use of synergy effects and solve occurring problems at an early stage. Generally, the employees of the Industry 4.0 Garage are enabled to set up interfaces to other divisions of the company in the interest of the project. Due to the strategic importance of the Data Lake, the Industry 4.0 Garage is therefore allowed to contact any colleague from any department of the manufacturing company if, for instance, information about their activities is needed.
Industry 4.0: Implement it!
Process for the Development and Implementation of Industry 4.0 Use Cases

The target of the entire process is the development and implementation of Industry 4.0 solutions. The funnel-shaped depiction of the implementation process illustrates the approach of the guideline presented at hand. The implementation process consists of individual phases. The initially vague ideas are successively concretized during concept development, elaboration and pilot testing. The developed applications are subsequently rolled out.

Milestones serve as a filter between the individual phases. At the planned milestones, the initial ideas and later developed applications are evaluated in order to identify and improve those applications with the best cost-benefit ratio. First, the current Industry 4.0 maturity level is identified and the strategic goals regarding digital networking are defined. A detailed description of the maturity model will be given later in the study. The step „Awareness“ is being passed through detached from the chronological implementation process. In this stage, employees are enabled to systematically develop ideas for the implementation of Industry 4.0 in the idea generation phase. The step “Awareness” can be repeated later if necessary.
One challenge of the implementation of Industry 4.0 is the great variety of potential applications on the one hand and a lack of awareness for potential solutions among employees on the other hand. In contrast to continuous improvement processes, an Industry 4.0 solution appears to be revolutionary or highly complex which hinders the generation of ideas merely based on the employees’ understanding of the process. Instead, the employee must be informed about the concrete targets and potential applications of Industry 4.0. This requires awareness for Industry 4.0 in all areas and hierarchical levels of a manufacturing company. Adapted to the respective target group, there are various possibilities to carry out this process step.

One way to create awareness is to present existing Industry 4.0 solutions from other plants, companies and industries. Individual cases, reference visits to other plants or companies can supplement the presentation of existing solutions. Another way to create awareness is to conduct internal or external trainings and workshops. They can demonstrate the prerequisites and resulting applications for the implementation of Industry 4.0. In the course of the process, the described training measures can be repeated as often as required.

The Industry 4.0 Plant Manager is responsible for selecting opportunities for creating awareness. His tasks also include the development and implementation of suitable training measures and ensuring knowledge transfers between individual company plants. As a result, employees should be able to generate ideas for the application of Industry 4.0 on their own.

Preparation Phase: Awareness

77% of the companies see the responsibility of focusing digital transformation in companies by the top management (Kienbaum 2017)
Industry 4.0: Implement it!

**Phase 1: Idea Generation**

A variety of good ideas is the prerequisite for the implementation of Industry 4.0. The idea generation is about developing these ideas in high quantity and quality on all hierarchical levels. Three general approaches can be distinguished.

In the top-down approach, the management sets targets for the implementation of Industry 4.0 in order to develop strategically important topics in the company. A characteristic of the top-down approach is the management perspective which has a superordinate understanding of Industry 4.0. Therefore, the management is essentially responsible for generating ideas for an overarching infrastructure in order to create important prerequisites for Industry 4.0. For instance, the continuous networking of IT systems or the development of intelligent service systems can set an important direction for the company. In order to increase the amount of generated ideas, setting a certain number of Industry 4.0 ideas as part of the personal objectives can be useful. The variable salary component can be used to create incentives for management to actively promote their idea generation.

The bottom-up approach stands vis-à-vis to the top-down approach. Unlike the management, the employees of the plant and in the Industry 4.0 Garage have a more operational perspective. That means that the plant employees have a more in-depth understanding of their respective area. Therefore, they know the potentials of individual process steps which Industry 4.0 solutions can address better than the management. A specific innovation bonus – similar to many companies’ usual suggestion system – can provide incentives for employees to increase their amount of generated ideas.

The proactive development of ideas is the task of the Industry 4.0 Plant Manager and can be seen as an additional approach. He must provide additional impulses for idea generation and must develop his own ideas. Various analysis tools are suitable in order to identify potentials in internal processes. Examples of analysis tools are the process analysis, potential analysis, activity structure analysis or the value stream analysis.

![Diagram showing the idea generation and management processes in Industry 4.0](image-url)
To capture and manage a large number of ideas, a unified, company-wide platform for idea management is suggested. All ideas can be put into a standardized profile on this platform. The aim is to enable the provider of an idea to check whether a similar idea has already been saved and whether it can be linked with the own. The Global Industry 4.0 Manager takes on the overall responsibility for the platform.

The result of phase 1 is the best possible amount of generated ideas in all areas and hierarchical levels of the manufacturing company, documented in the central idea management platform.

**Milestone: Idea Filtering**

After the idea generation, a first evaluation of ideas takes place. Idea filtering as well as all subsequent phases and milestones are carried out for each individual idea. This milestone classifies the idea within the Industry 4.0 maturity model and compares it with the company's targets. If the idea corresponds with the targets, it is pursued further. Otherwise, the idea will not be processed any further and merely be documented in the idea management platform. The detailed approach for classifying an idea within the Industry 4.0 maturity model is described in the chapter "Industry 4.0 maturity model". A further part of the evaluation is the assignment of an intensity level. This indicates how intensively and in what amount of time the idea should be developed. Furthermore, the complexity and type of processing, in the Industry 4.0 Garage or in the plant, is decided upon. The intensity level of an idea has an influence on the working mode which is described in the following. The Industry 4.0 Steering Committee determines the intensity level.

**Phase 2: Concept Development**

The aim of this step is to detail the selected ideas in order to be able to carry out a first quantitative evaluation of the developed concepts. For this evaluation, it is necessary to define uniform requirements for the concepts in order to ensure comparability. The definition of the following steps can be derived from the intensity level set in the previous milestone.

Before concept development can begin, it is crucial to identify the executing team. Depending on the idea, it is necessary to decide on required competencies and roles. An additional determining factor in team building is the availability of employees since a release of resources can potentially lead to long waiting times. If an idea is supposed to be worked out without a great delay, it can make sense to assign the concept development to the Industry 4.0 Garage.

After team building and the decision whether the concept should be developed in the plant or in the Industry 4.0 Garage, the working phase starts. Depending on the chosen intensity and complexity of the Industry 4.0 solution, different working modes are available.

**Full-time Processing by the Industry 4.0 Garage**

If an Industry 4.0 solution is to be developed with very high intensity and complexity, it makes sense to assign the Industry 4.0 Garage with the concept development. Within 2-3 days, the idea can be developed into a concept by the corresponding experts in full time.

**Full-time Processing by the Plant**

If the ideas are less complex, plant employees can also develop concepts. If the intensity is high, the concept development should be carried out full-time. In this working mode, full-day workshops moderated by the Industry 4.0 Plant Manager can be conducted to
develop a concept within 2-3 days.

**Part-time Processing by the Plant**

If there are not enough employees available for full-time processing or the development of the idea can be executed with a lower intensity, part-time processing can be chosen as working mode. In this case, the employees spend part of their working time (e.g. 10-20 %) on the development of Industry 4.0 solutions in addition to the operative day-to-day business. The concept development requires longer time and can only be completed after 4-6 weeks. The three described working modes represent exemplary forms of cooperation. In company practice, an individual working mode which combines these approaches is also possible. Depending on the project, it can be advantageous to involve future users during the concept development phase. However, since the concept development is about creating a quantitatively assessable concept of an idea without developing the user interfaces, the complete integration of a user into the project work is not necessarily required yet.

The result of Phase 2 is a developed concept that integrates all information for a quantitative cost-benefit assessment. The main contents of the concept are a short description of the problem which should be managed by the suggested Industry 4.0 solution and the expected result. In addition, the work steps required for implementation are described including a rough cost and effort estimation as well as a description of the concrete benefits of the application.

**Milestone: Cost-Benefit Assessment**

With this milestone, the concept is evaluated from a business perspective and a cost-benefit assessment is carried out. The further development of a cost-intensive idea which offers no economic advantages can thus be avoided at an early stage. The Industry 4.0 Steering Committee is responsible for the evaluation and subsequent approval. The procedure of selecting Industry 4.0 solutions that should be further developed is described in detail in the chapter „Quantitative Assessment of Industry 4.0 Use Cases“.
Phase 3: Elaboration

The target of the elaboration phase is the development and prototypical implementation of an Industry 4.0 solution to be piloted. The team which has already developed the concept continues to work together in this phase and provides a significant part of the necessary work. The advantage of this consecutive working method is that an expensive transfer of the already gathered knowledge can be avoided. In addition, the team can include findings gained during concept development for a concrete implementation. Similar to the procedure during the concept development phase, a suitable working mode is selected depending on the required intensity. The choice of the optimal working mode plays a greater role in the elaboration phase than during the more abstract concept development, because the elaboration phase is usually more complex and time-consuming. The early involvement of a future user can also have a considerable influence on the final result and prevents subsequent iteration loops.

If the intensive involvement of a user in the project team makes sense, the development should be carried out internally in the plant. If the intensity is low, flexible working modes can be used equivalently to the concept development phase. An important advantage of developing the concept on a part-time basis is the involvement of plant employees while continuing operational activities at the same time. The application of such part-time models can lead to longer processing times. Additionally, this form of elaboration only achieves a comparable quality of content in exceptional cases. Hence, full-time processing makes sense for the elaboration of complex and more extensive applications. Similar to the concept development phase, the necessary coordination must be ensured in order to involve a sufficient number of released employees. In the case of full-time processing, plant employees can achieve rapid interdisciplinary work progress in iterative sprints. The use of the so-called Scrum approach is recommended. If the project cannot be processed in the plant, the Industry 4.0 Garage is integrated into the project. Since the Industry 4.0 Garage is less close to plant processes, a plant-specific adaptation of the Industry 4.0 solution is potentially necessary at the end.

<table>
<thead>
<tr>
<th>Working mode</th>
<th>+</th>
<th>—</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industry 4.0 Garage full-time</strong></td>
<td>High competency</td>
<td>Lower involvement of users possible</td>
</tr>
<tr>
<td></td>
<td>Fast processing</td>
<td>Potentially reduced practicability</td>
</tr>
<tr>
<td></td>
<td>No need for other capacities</td>
<td></td>
</tr>
<tr>
<td><strong>Plant employees full-time</strong></td>
<td>Fast processing</td>
<td>Necessary release of employees</td>
</tr>
<tr>
<td></td>
<td>Users and experts in one team</td>
<td>Conflict with the operative daily business</td>
</tr>
<tr>
<td></td>
<td>Sprint (1 week)</td>
<td>Potential waiting time until start of processing</td>
</tr>
<tr>
<td></td>
<td>Kick-off</td>
<td></td>
</tr>
<tr>
<td><strong>Plant employees part-time</strong></td>
<td>Active involvement of employees beside their operative daily business (e.g. 70-20-10 rule)</td>
<td>Long processing time</td>
</tr>
<tr>
<td></td>
<td>Users and experts in one team</td>
<td>High demands regarding employee’s time management</td>
</tr>
<tr>
<td></td>
<td>Industry 4.0 application</td>
<td>Potentially lower depth of content</td>
</tr>
<tr>
<td></td>
<td>Kick-off</td>
<td></td>
</tr>
</tbody>
</table>

6% of the companies have created a new role for digital topics (Kienbaum 2017)
Before pilot testing, the Industry 4.0 Steering Committee evaluates the Industry 4.0 solution retrospectively. The evaluation is analogous to the milestone of cost-benefit assessment. The renewed quantitative evaluation is much more valid at this time. The application is evaluated in terms of practicability and a decision about the start of pilot testing is taken. In case of an approval for pilot testing, the Industry 4.0 Steering Committee selects a plant for the pilot project. If the Industry 4.0 solution is not approved for pilot testing, the application will be optimized due to renewed processing of the elaboration phase. In case the developed Industry 4.0 solution cannot bring the expected benefit, or the effort exceeds the benefit significantly, the elaboration of the Industry 4.0 solution can be stopped at this milestone.

The developed and prototypically implemented Industry 4.0 solution is tested on the selected plant. In most cases it makes sense to choose one lead plant for Industry 4.0 pilots. In this lead plant, all Industry 4.0 solutions are tested before being rolled out to other plants. This way, extensive experience regarding the implementation of Industry 4.0 solutions can be built up at the lead plant. Application-specific advantages, which other plants might offer in individual cases, e.g. regarding the used processes or manufacturing technologies, cannot be fully exploited by the lead plant. Therefore, the Industry 4.0 Steering Committee has to determine the plant for pilot testing in some cases.

The integration of the pilot application also requires users to be familiar with the new application. Training can be a suitable approach depending on the complexity. It is important that this step of qualification is evaluated thoroughly and documented for a subsequent roll-out. Thereafter, the pilot application is integrated into the ongoing processes. Regular feedback from the users is particularly important in this context in order to optimize the pilot as well as the integration process for the subsequent roll-out.

**Milestone: Pilot Testing Release**

**Phase 4: Pilot Testing**
The pilot testing phase must be concluded with a comprehensive revision which bundles all findings from the training and integration process. In order to support pilot testing, it is necessary to specifically create an implementation team for the respective Industry 4.0 solution. The implementation team consists of employees who have developed the Industry 4.0 solution as well as those who are responsible for the area where the Industry 4.0 solution will be implemented. The team should also significantly support the subsequent roll-out and use findings from pilot testing for this.

Milestone: Roll-out Release

After the pilot testing phase, the implementation success of the Industry 4.0 solution is to be evaluated. For this purpose, the experience gained from pilot testing is compared with the previously performed cost-benefit assessment in analogy to the pilot testing release. A meeting of the Industry 4.0 Steering Committee decides whether the desired added value has been achieved through the implementation or whether the Industry 4.0 solution needs to be optimized in further elaboration. If further optimization of the application is not necessary and the cost-benefit assessment of the pilot is positive, the implementation of the Industry 4.0 solution takes place in the form of a roll-out in other plants. Equivalent to the pilot testing release, the roll-out of the Industry 4.0 solution can also be rejected in individual cases due to a negative cost-benefit ratio at this point.
**Phase 5: Roll-out**

The roll-out throughout the company happens equivalently to phase 4. The relevant steps are the initial installation of the Industry 4.0 solution in further plants, the qualification of employees and the integration of the Industry 4.0 solution into the daily operational business. The implementation of identified further improvements to the process from the pilot phase is crucial for an optimized introduction. Further optimization measures can be identified during the implementation of the Industry 4.0 solution in individual plants due to slightly different individual conditions. Therefore, a further, plant-specific improvement of the Industry 4.0 solution is necessary. The definition of a responsible person on-site in each plant who coordinates the local integration process is essential. This task is performed by the local Industry 4.0 Plant Manager.

### Milestone: Project Success Evaluation

After finishing the roll-out, a revision is carried out in order to bundle and safeguard experience, similar to the end of pilot testing. In this context, the final success of the implementation of the Industry 4.0 solution is evaluated. The evaluation is carried out by means of specific process key figures that represent the benefits of the Industry 4.0 solution in a quantified manner. In addition, the current degree of implementation of Industry 4.0 is updated in the maturity model after each implemented roll-out of an Industry 4.0 solution. Experiences from the development of the solution will be analyzed and documented in a project retrospective to utilize for the further implementation of Industry 4.0. Within half-annual or annual intervals, the future objective is updated in the maturity model analogous to the Industry 4.0 maturity determination milestone.

<table>
<thead>
<tr>
<th>Global implementation</th>
<th>Training of employees</th>
<th>Integration of the Industry 4.0 application</th>
<th>Exploitation of the Industry 4.0 application</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Global implementation" /></td>
<td><img src="image2.png" alt="Training of employees" /></td>
<td><img src="image3.png" alt="Integration of the Industry 4.0 application" /></td>
<td><img src="image4.png" alt="Exploitation of the Industry 4.0 application" /></td>
</tr>
</tbody>
</table>
Use Case Smart Glasses

In the preparation phase “Awareness”, a Smart Glasses application is demonstrated during the presentation of existing Use Cases in other companies. The Smart Glasses are a pair of glasses that transmit a video signal and display information in the wearer’s field of vision in real-time. An employee from the service department recognizes the potential for carrying out assembly work during remote maintenance. He submits it to the idea management platform. The Industry 4.0 Steering Committee decides on this Use Case at the next meeting and classifies it within the maturity model. The idea is determined to be less complex and should only be pursued with low intensity since the glasses and the required hardware are already available on the market. The other tasks can be carried out in the plant in a part-time working mode. The corresponding employees should use 15% of their working hours for the concept development as well as for the elaboration of the Industry 4.0 solution. During the concept development phase further development steps, the benefit of the Industry 4.0 solution and necessary expenses are defined. In the cost-benefit assessment, the Industry 4.0 Steering Committee compares the expected efficiency gains to the costs and calculates an amortization period of six months. Since the determined limit for the amortization period of this Use Case is set at three years, the Industry 4.0 Steering Committee decides to continue the development of the project. The main task of the next phase is the development of suitable interfaces in order to efficiently arrange the cooperation between an expert at a desk and a technician on-site. The development of a tablet application for the expert makes sense in this case as the touch screen is easily usable to interact with the video signal of the technician. After the release, pilot testing takes place at two plants so that remote maintenance using Smart Glasses can be tested in real conditions. The company’s headquarter in Germany which is the preferred selection as lead plant for the implementation of Industry 4.0 solutions is one of the two plants. In addition, a manufacturing plant in Asia is selected for pilot testing of the Use Case. The mechanics wearing Smart Glasses are guided from the lead plant. The pilot phase shows that the experts and specialists on-site can be trained without great effort due to the intuitive system used and the desired increases in efficiency are achieved. After the implementation of smaller improvement measures which are derived from pilot testing, the global roll-out takes place. In this phase, the Industry 4.0 solution is implemented in all production plants and all affected personnel is qualified in the process.
Use Case Data Lake

In a presentation about the „Internet of Production“ some requirements for Industry 4.0 are shown to the management. Among other findings, it is recognized that the availability of data as well as data consistency („single source of truth“) must be increased along the entire process chain. The idea of a uniform data platform such as a so-called Data Lake is put into idea management and checked for overlaps with other ideas. Since there are none, the idea is submitted to the Industry 4.0 Steering Committee. The structure of a Data Lake becomes clear when it is classified within the maturity model and leads the Industry 4.0 Steering Committee to decide for developing the idea. The development of a Data Lake requires a high degree of IT know-how and is considered to be very costly, so that concept development and elaboration are supposed to take place with high intensity. The Industry 4.0 Garage is the ideal place for continuing the idea. Also, the user interface is limited in this Use Case. Merely the definition of requirements for the Data Lake is to be conducted in coordination with the plants. The team designs a concept in which the expected effort and benefits are quantified. Since a Data Lake has no direct monetary advantages on its own, the decision for its development is of a strategic nature. The relevance of the Data Lake for numerous other Industry 4.0 solutions plays a decisive role. After deciding to continue the development of the project, the concept is elaborated. That also takes place in the Industry 4.0 Garage to make use of synergy effects from assigning the same team. After the pilot testing release, implementation is initiated at the Industry 4.0 lead plant in Germany. This is where the Industry 4.0 Garage to accompany the pilot testing is located and where the central IT department of the company has its headquarter. Since the Data Lake itself has hardly any interfaces with users on the shop floor, the learning process only plays a subordinate role and primarily serves to build acceptance and understanding for pilot testing. In the specific case of the Data Lake the quality and relevance of the collected data and its sources can be assessed. In the course of pilot testing some optimization measures are still open to be implemented. Thereafter, the global roll-out is conducted. Plant-specific conditions are considered, and in-house IT staff is trained in order to carry out the continuous expansion of the Data Lake independently.
Industry 4.0 Maturity Model for Target Determination and Idea Filtering

In the practical corporate world, the implementation of Industry 4.0 is treated as a rough indication of direction in many cases, yet sometimes as an obligatory strategic initiative. Only in the rarest of cases clear, structured and, above all, realistic targets are set. Basis for the successful implementation of Industry 4.0 is the structured analysis of the status quo for the respective company in individual fields of action of Industry 4.0 along the entire value chain. The instruments to determine the status quo are Industry 4.0 maturity models. In literature and practice numerous maturity models of varying extent and level of detail can be found. Within this study, an Industry 4.0 maturity model will be created which is universally applicable to all companies of the manufacturing industry. Based on the determined maturity level, concrete and realistic objectives can be identified which are aimed to be achieved within a defined period. In addition to the initial application of the maturity assessment for the analysis of the entire company, the evaluation of individual, yet to be implemented Industry 4.0 Use Cases enables the definition of implementation requirements. This procedure ensures the continuous and target-oriented implementation of Industry 4.0. In the following, the maturity model itself and the procedure for its application is described.

Approach for the Determination of the Industry 4.0 Maturity Level

The maturity model for evaluating the implementation status of Industry 4.0 is applied to two steps of the implementation process, whereby three functions are fulfilled that have to be differentiated from each other. First of all, an initial Industry 4.0 maturity level is determined as the starting point of the implementation process. On the one hand, this aims to determine the status quo and, on the other hand, provides the basis for the definition of concrete goals and specifications for the further implementation of Industry 4.0. These two functions are carried out by the Industry 4.0 Steering Committee in order to achieve a consistent application of the maturity level in the entire company. In doing so, both the evaluation of the status quo as well as the target definition for individual locations or production plants can be carried out individually. Further detailing of the evaluation is also possible. Another application of the Industry 4.0 maturity model takes place at the milestone of idea filtering. Individual Industry 4.0 solutions developed by employees on the operational level are reviewed regarding their contribution to the further implementation of Industry 4.0 and classified within the maturity model. Practicing this third function enables the Industry 4.0 Steering Committee to control the implementation process by identifying those solutions which serve to achieve the initially defined goals. In the following, the structure of the Industry 4.0 maturity model and the functions fulfilled by it are explained in greater detail.

The maturity model evaluates the implementation of Industry 4.0 in manufacturing companies in six stages. Each stage represents a step on the path to the full implementation of Industry 4.0. This includes both the evaluation of implementation prerequisites as well as the actual implementation of Industry 4.0 within the company. The following illustration gives an overview of the Industry 4.0 maturity model.

The stages “computerization” and “digital networking” form the basis for the implementation of Industry 4.0. Here, the term computerization denotes the use of digital systems instead of analogue solutions. The linkage of individual digital systems for the

22 % of interviewed mid-sized companies have formulated clear targets in the context of Industry 4.0
(Deloitte 2016)
realization of an exchange of information leads to the achievement of the digital networking stage. Without company-wide digital management and the use of information, an implementation of Industry 4.0 is not possible. The first stage of implementation of Industry 4.0 based on computerization and digital networking of production is the visualization of relevant processes. With the support of sensor and transmission technology, visibility of conditions and processes is created at this stage by realizing a digital collection of information for all the processes of product creation as well as for product information along the product life cycle. The second stage is the attainment of transparency over all the causes of the previously only visualized conditions and processes. This is achieved by the identification of cause-effect relationships which enable an understanding about production engineering processes and their background. This is followed by the third stage on the Industry 4.0 development pathway - the forecast. Based on the identified cause-effect relationships the company will be able to forecast future conditions and rate the respective probability of occurrence at this stage. As a result, the company is able to anticipate predicted events. The ability to evaluate data, the understanding of cause-effect relationships in production and the possibility to predict future conditions are prerequisites for achieving the fourth and last stage of the maturity model of Industry 4.0 – adaptability. Self-optimizing processes enable company systems to record data in real time, interpret this data and take appropriate measures automatically. The task of employees thus shifts towards monitoring and further developing a company’s systems.
Industry 4.0 maturity evaluation takes place in various corporate functions along the value chain of manufacturing companies. Additionally, supportive functions such as corporate management, human resources or controlling are considered. This is used to structure the evaluation of the status quo carried out by the Industry 4.0 Steering Committee. Executing only a global evaluation of the implementation status of Industry 4.0 is insufficient for the depiction of the complexity of a manufacturing company. In addition, this detailing of the evaluation is indispensable for the other two functions of the Industry 4.0 maturity model, the definition of objectives and the filtering of ideas.

A collection of defined Industry 4.0 maturity characteristics in individual corporate functions can be found in the appendix. After the Industry 4.0 implementation level of the individual corporate functions are determined, the target determination can be defined. Although the real objective is to achieve the complete implementation of Industry 4.0 across all corporate functions, a successful implementation requires the structuring and prioritization of necessary sub-steps in the process of the implementation of Industry 4.0. To achieve this, the Industry 4.0 Steering Committee determines concrete implementation targets and specifications that define in which corporate functions the implementation of Industry 4.0 should be accelerated. These goals will be derived, for instance, from the corporate strategy or from identified weaknesses of the value chain. The result of the target definition serves as the input for idea filtering. Industry 4.0 solutions are analyzed regarding their effect on the implementation level of Industry 4.0 in the individual corporate functions by the Industry 4.0 Steering Committee. If this analysis concludes that the achievement of the defined goals coincides sufficiently with the investigated approach, this approach is further pursued. To check the effectiveness of the implemented solutions regarding the Industry 4.0 maturity level, the evaluation of the status quo needs to be updated in regular intervals.

In addition to the Industry 4.0 maturity model, this study presents an approach to the systematic identification of requirements for the implementation of certain Industry 4.0 solutions. This serves as input for the cost-benefit assessment in the next step of the implementation process. The approach is derived from the model of the „Internet of Production” developed by the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University. The approach to determining the implementation requirements has a multi-level structure. The target, the highest level, is the realization of a data-driven decision. The necessary conditions are symbolized by the remaining steps. On the lowest level, potentially required raw data for the implementation of Industry 4.0 solutions can be found as well as the corresponding systems in which this data is usually present. With the help of a so-called middleware solution the gathered data can be aggregated and synchronized in the adjacent higher level to become usable in a consolidated manner. Subsequently, the aggregated and synchronized data is stored and managed centrally in order to ensure its direct and complete availability for further use. The information is used multimodally supported by methods of data analytics or the digital shadow. The gained data can therefore be used for data-supported decision making.

**2.62 Bn. €**

will be invested in Industry 4.0 projects by German companies in 2020

*(Statista 2018)*
According to the described procedure, for every Industry 4.0 solution that has passed idea filtering, an individual examination is necessary to identify the raw data required and the software solutions in which this data is available. Subsequently, it is evaluated whether and in which scope an aggregation and synchronization of the existing information is necessary and which analysis methods are required for the implementation of the examined solution. Finally, a comparison with the status quo is made regarding the identified prerequisites for the implementation in the company. This way, the necessary effort for the implementation can be determined and necessary measures can be pointed out.
The evaluation and target definition carried out by the Industry 4.0 Steering Committee is depicted in the following figure. The determination of the maturity level has shown that only for the company functions supply chain management and procurement as well as marketing and sales a successful implementation of Industry 4.0 has been accomplished. In supply chain management, solutions have been implemented that allow a general prediction of order changes and, consequently, enable an early reaction by the supply chain management. In marketing and sales, a visualization of current sales figures as well as sales development is implemented. Only in product development and production, both levels of enabling fundamentals, computerization and digital networking, are implemented. In other corporate functions, digital systems are used, but merely as singular solutions without systematic digital networking. Bidirectional exchange of information is not possible. Based on an evaluation of the resulting optimization potential, the Industry 4.0 Steering Committee decided that especially in product development, production planning and scheduling as well as logistics and production, the implementation of Industry 4.0 solutions should be targeted. In logistics and production, the stage of transparency is targeted whereas in product development and production planning and scheduling, only the visualization stage is set to be targeted. The set targets are to be achieved within the next six months by taking suitable implementation measures.

After determining the status quo and defining the targets for the Industry 4.0 implementation in the first step of the Industry 4.0 implementation process, the step of idea filtering is conducted by analyzing Use Cases and classifying those within the Industry 4.0 maturity model.

The Use Case for Smart Glasses contains the digital support of assembly and maintenance tasks as well as repair processes in production. According to the classification within the Industry 4.0 maturity model, the implementation leads to an optimized
coordination of production processes by visualizing information regarding current conditions for the employees. As a result, the use of Smart Glasses contributes to achieve visualization as a partial step towards the desired stage of transparency. For this reason, the Industry 4.0 Steering Committee decides for a further pursuit of the Use Case.

A Data Lake represents a central collection point for company data. Therefore, the sole implementation of a company-wide Data Lake does not imply the realization of Industry 4.0. However, it is a basis for the implementation of Industry 4.0 solutions since the information required by other solutions is made available centrally. Therefore, digital networking is achieved in all corporate functions by implementing the Use Case. Since it provides a basis for all further implementation activities and directly supports the objectives set in production planning and scheduling as well as logistics, the Industry 4.0 Steering Committee decides for the continuance of concept development.

In addition to the classification within the Industry 4.0 maturity model, the Use Cases are analyzed regarding their prerequisites for implementing them in the company. This serves as input for the cost-benefit assessment in the next step of the implementation process.

**Use Case Smart Glasses**

To support assembly and repair processes with the use of Smart Glasses, product and CAD data as well as machine and feedback data is required to provide corresponding information to employees. In the respective Use Case, product and CAD data are stored in corresponding software solutions throughout the company. However, machine or feedback data from production is not gathered yet. Additionally, neither a middleware solution for the aggregation and synchronization of data nor central data management for providing the required information to the Smart Glasses application exist. Applications of data analytics or a digital shadow are not required in the present case. The implementation of a data-driven decision is also not necessary for the implementation of the Use Case. The results from the analysis are presented in the following figure.
To implement a company-wide Data Lake, the collection of all available data in various corporate functions along the value chain is necessary. As a result, all data is determined to be prerequisite for implementation of the Data Lake all data is required. The collected data is aggregated and synchronized using a suitable middleware solution before making it available in a central data management system. Currently, product, CAD, process and test data is already usable via corresponding software solutions in the company. However, simulation, machine, feedback and customer data are not collected systematically. Also, there is neither a middleware solution nor a central data management system. The mentioned systems and means of data collection are to be realized before implementing the Use Case. The following figure gives an overview of the analysis of required prerequisites.
Industry 4.0: Implement it!
Quantitative Assessment of Industry 4.0 Use Cases

Introduction and Target Vision

The cost-benefit assessment is often one of the central difficulties that companies are confronted with regarding Industry 4.0. Often, it is unclear how innovative Industry 4.0 solutions affect revenues and costs in short, medium or long term. This increases the difficulty for companies to make a fact-based investment decision. Although not an end in itself, Industry 4.0 must be implemented with a comprehensive cost-benefit assessment. However, the extensive technological opportunities along the entire value chain of a company demand for a selection and prioritization of potential Use Cases due to limited financial resources. Therefore, the following chapter addresses the milestone of conducting a cost-benefit assessment within the implementation process of Use Cases.

To this end, a three-stage evaluation of the Use Cases, which, in addition to quantifiable revenues and costs, also considers „soft“ factors such as increased transparency, ergonomic design or decision support of the employees. This allows well-founded decision making based on objective criteria. Therefore, the decision is not only made comprehensibly, but also independently.

The preliminary assessment aims at reviewing whether the Use Case concepts are complete. For the subsequent monetary assessment, a static or dynamic amortization calculation is applied depending on the investment volume and the required accuracy of the monetary assessment. For equivalent amortization periods of competing solutions,
the amortization calculation can be supplemented by a capital value calculation. The evaluation of non-monetary aspects is recommended to be conducted based on a benefit analysis. Beneficial aspects of an Industry 4.0 Use Case which cannot be evaluated monetarily or only with very high expenditure are assessed systematically. To carry out the monetary and non-monetary assessment, potential evaluation criteria are named. The described process is centrally carried out by the Global Industry 4.0 Manager.

### Preliminary Assessment

The objective of the preliminary assessment of a Use Case is to ensure the completeness and validity of relevant information prior to its evaluation. For this, five central prerequisites need to be fulfilled:

- The concept is sufficiently specified
- Relevant (preliminary) information is available and validated
- The novelty of the Use Case is ensured
- The basic temporal and financial conditions are feasible
- Contact persons for inquiries are defined

First of all, the project needs to be sufficiently specified in the course of concept development. This includes, besides the short description of the problem, a detailed description of the Use Case and the underlying solution concept. Beyond that, a first qualitative estimation of the expected benefits as well as a rough assessment of the project duration and costs should be present. If there is information that could contribute to detailing the Use Case, e.g. in the form of external offers or feasibility studies, these should be attached to the project description as well. Also, it should be ensured that equivalent Use Cases have not been piloted or implemented in the company yet. If that is the case, the results and experiences of previous Use Cases can be used. Furthermore, the temporal and financial feasibility of all requirements should be taken into account, if estimations are possible. Lastly, contact persons need to be defined so that the evaluating entities of the Industry 4.0 Steering Committee can follow up with questions regarding the solution and associated costs or benefits. If all prerequisites are fulfilled, the monetary assessment can be conducted.

18 % of interviewed mid-sized companies use key figures and indicators to review Industry 4.0 projects (Deloitte 2016)
Monetary Assessment of Use Cases

Investment alternatives or Use Cases can be assessed regarding their financial cost-benefit ratio using different methods. Further methods exist in addition to a simple cost or profit comparison, e.g. the average return method, the capital value method or the asset end-value method. The disadvantage of most of these methods lies either in their simplicity of only quantifying efforts or benefits, or in requiring a fixed observation period. Establishing such a fixed period can be difficult in evaluating new technologies and Use Cases for two reasons. Firstly, different capital goods have diverging depreciation periods sometimes. Secondly, estimating the period of use can be difficult. Hence, the amortization period (return on investment - ROI) is selected as the key performance indicator in the financial evaluation of Use Cases within this study. In addition to depicting the amortization period, the amortization period also represents the risk of an investment. The higher the amortization period, the higher the uncertainty of an investment.

The amortization period can be calculated statically or dynamically depending on accuracy requirements. The static method should be applied to less financially comprehensive or to easily evaluable Use Cases due to its simplicity. The dynamic amortization calculation is more accurate but also requires detailed information as well as a greater calculation effort. While the static amortization calculation does not differentiate between reflows of individual periods and discount factors are not considered, both the periodic differentiation and the calculation of interest are part of the dynamic amortization calculation. To ensure the comparability of individual Use Cases, the same type of amortization calculation should be applied to all considered Use Cases. Hence, the selected method needs to be initially defined in a company. Subsequently, the relevant calculation variables for quantifying future benefits are defined in the form of additional turnover or saved costs.

Static Amortization Calculation

For the static amortization calculation, there is no distinction between the observation periods. Instead, a hypothetical average period is used as basis for the calculation. The incoming and outgoing payments are assumed to be the same during future periods. The amortization period is calculated as follows:

\[ \text{amortization period} = \frac{\text{employed capital}}{\text{average returns}} \]

For the static amortization calculation, there is no distinction between the observation periods. Instead, a hypothetical average period is used as basis for the calculation. The incoming and outgoing payments are assumed to be the same during future periods. The amortization period is calculated as follows:

\[ \text{employed capital} = \text{acquisition cost} - \text{liquidation proceeds} \]

The average return flow is calculated based on incoming and outgoing payments (cash flow calculation). These can be calculated as follows:

\[ \text{average returns} = \text{incoming payments} - \text{outgoing payments} \]

A Use Case is called relatively advantageous if it shows a shorter amortization period compared to other investment alternatives. It is called absolutely advantageous if the amortization period falls below a company’s set period for an investment.
Dynamic Amortization Calculation

Contrary to the static amortization calculation, no average payments are considered. In each period $t$ individual net payments $N_t$, i.e. incoming and outgoing payments, incur which can differ from period to period. Determining these net payments works similarly to the formula presented beforehand.

Period $t = 0$ represents the point in time that the investment asset is being procured. Therefore, the investment costs are a net payment with negative value. For further net payments in the following periods, the so-called time preference is also taken into account mathematically. This means that the cash value $W_1$ of a payment $N$ at the point in time $t_1$ is different from the cash value $W_2$ of the same payment $N$ at another point in time $t_2 \neq t_1$. To ensure comparability of payments from different periods, they are transformed and discounted to the point in time $t = 0$ using the following formula:

$$W_t = N_t \cdot (1+i)^{-t}$$

The term $(1 + i)^{-t}$ represents the so-called discount factor to calculate the value of a payment $N_t$ at the point in time $t = 0$. For the dynamic amortization calculation, the interest rate $i$ is assumed to be a constant value in all periods. To calculate the dynamic amortization period of an investment alternative, the cash values of all periods are accumulated step by step. Therefore, a systematic assessment of which period $t^*$ reaches a positive, cumulated cash value $kW_t$ is enabled. That is calculated using the following formula:

$$kW_t = \sum_{t=0}^{t} N_t \cdot (1+i)^{-t}$$

By means of linear interpolation between the previous period $t^*$ with negative cash value and the first positive period $t^*+1$, the exact amortization period $AT_c$ can be determined:

Formula:

$$AT_c \approx t^* + \frac{kW_{t^*}}{kW_t - kW_{t+1}}$$

Calculation Parameters for Benefits Assessment

Once the calculation method has been established, there often is a difficulty in holistically quantifying the aforementioned net payments and hence the additional benefit generated by a Use Case. These net payments are required to quickly amortize costs incurred by a Use Case. There are two control variables available to positively influence the average returns $N$ (see above). According to the formula, by implementing a Use Case, incoming payments in the form of additional revenues can be generated. That effect is achieved by, for instance, the earlier introduction of new products and the associated realization of so-called monopoly annuities. Furthermore, implementing a Use Case can cause outgoing payments (costs) to be saved in the value creation process and initial capital expenditure thus justified.

For a comprehensive approach, compiling a list of all relevant influencing variables is necessary. Influencing variables that do not significantly impact the cash flow of a Use Case can be neglected in order to minimize efforts. To consider potential influencing variables with regard to increasing revenues and with regard to cost reduction, there are corresponding tables referenced in the appendix. Influencing variables along the corporate functions of the maturity model are compiled there exemplarily as well as corresponding formulas. Users need to evaluate relevant items regarding their increase in revenues or reduction of costs and determine their balance based on the given formulas.

Securing Assessment in Case of Equivalent Amortization Periods

With a high number of evaluated Use Cases, there is the possibility that some applications show a similar amortization period. In order to assure the financial benefit of a Use Case compared to others, an additional assessment by means of a capital value calculation is recommended. It evaluates the financial
benefits after the amortization period has elapsed and compares the long-term monetary benefits of different investments. As a formula, the cash value $kW_t$ can also be used on the condition that a uniform, predefined observation period $t$ is established.

**Non-monetary Assessment of Use Cases**

The exclusive monetary evaluation of Use Cases is not effective. To also consider non-monetary aspects for the evaluation of Use Cases, a benefit analysis should be applied. Based on the benefit analysis, non-monetary aspects of Use Cases are made quantifiable. To this end, four steps are explained in the following.

**Determination of Target Criteria**

Corresponding with the maturity model, target criteria from the departments of marketing and sales, product development, supply chain management and procurement, production planning and scheduling, logistics, production, quality management and supporting functions are relevant to the implementation of Industry 4.0 in the company. In addition, superordinate criteria are to be considered which do not occur in the maturity model but are of great importance to the evaluation of benefits of an Industry 4.0 Use Case nevertheless. These need to be specified once for a defined period. It is reasonable to define those criteria in the course of a (re-)evaluation of the maturity level. It should be considered that the benefit of a Use Case correlates significantly with the choice and weighting of the target criteria. To ensure comparability, competing Use Cases should therefore be evaluated with equivalent target criteria and consistent weighting. Hence, the target criteria should be selected in a way that they especially cover areas in which the company has identified weaknesses and/or seeks to improve.

**Due to Industry 4.0, an increase of company productivity of up to 40% is expected**

*(Behrendt et. al. 2017)*

<table>
<thead>
<tr>
<th>Superordinate criteria</th>
<th>Marketing &amp; sales</th>
<th>Product development</th>
<th>Supply chain management &amp; procurement</th>
<th>Production planning &amp; scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data availability and quality</td>
<td>Market and customer awareness</td>
<td>Degree of innovation</td>
<td>Supplier base and performance capability awareness</td>
<td>Flexibility</td>
</tr>
<tr>
<td>Knowledge acquisition and transfer</td>
<td>Offering speed</td>
<td>Requirement fit (awareness of customer requirements)</td>
<td>Demand equalization</td>
<td>Adaptability</td>
</tr>
<tr>
<td>Information transparency and actuality</td>
<td></td>
<td>Production orientation</td>
<td></td>
<td>Lead time</td>
</tr>
<tr>
<td>Time to market</td>
<td></td>
<td></td>
<td></td>
<td>Punctuality</td>
</tr>
</tbody>
</table>
With the use of many criteria, the accuracy of results and benefits increase, but the effort does as well. Accordingly, the selection of criteria should be examined critically. Areas with a high potential for improvement should be evaluated by more criteria to reflect their importance — areas in which there is little potential for improvement should hence be evaluated with correspondingly less.

**Weighting of the Target Criteria**

The second step weights the selected target criteria by putting the criteria in relation to each other. For this purpose, the method of pairwise comparison is used. In pairwise comparison, each criterion is compared with each other one by one to assign individual weightings. For example, first criterion 1 is compared to the criteria 2 to 5 and points are assigned to the corresponding cells of the table. The following rules apply:

- 2 points: The criterion in the row is more important than the criterion in the column
- 1 point: The criterion in the row is just as important as the criterion in the column
- 0 points: The criterion in the row is less important than the criterion in the column

The weighting of the criteria is evaluated based on the maturity model. In the maturity model, improvement potentials are defined.
in various areas based on the target-actual comparison. From the target-actual comparison, so-called deltas are derived which represent the need for action to move from the actual to the target state. The target criteria are rated in a way that the target criteria that show a large delta are rated as very important and, accordingly, criteria which show a small delta are less important in the pairwise comparison. This ensures the weighting of the criteria to be adapted to the needs for action from the maturity model. After completing the weighting, the points of the individual criteria are summed up. If a criterion has a sum of zero points, one point is added to each criterion so that all the selected target criteria are being considered in the following analysis. Finally, the relative weightings of all criteria are determined. The relative weightings \( g_i \) of criterion \( i \) are calculated from the ratio of the points of the criterion \( K_i \) to the number of all assigned points \( \sum K_i \), whereby \( n \) is the number of the selected criteria. This results in the following formula:

\[
g_i = \frac{K_i}{\sum_{i=1}^{n} K_i}
\]

**Determination of Partial Utility Values**

The determination of partial utility values of the Use Cases is carried out in two steps. First, the characteristic values or the target achievement values of the individual Use Cases are determined based on the various target criteria. Nominal, ordinal and cardinal scales can be applied to this end. In technical areas, the alternative with best target achievement in a target criterion is used as a benchmark for the assessment. The determined target achievement values are thereafter transformed into the partial utility value \( n_{i,r} \). Usually a cardinal, partial utility value scale of 1 to 5 is used uniformly.

For further clarification, the definition of potential characteristics in the respective target achievement value is possible and recommended to objectify the assessment.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target criterion very poorly fulfilled</td>
<td>Target criterion poorly fulfilled</td>
<td>Target criterion moderately fulfilled</td>
<td>Target criterion highly fulfilled</td>
<td>Target criterion very highly fulfilled</td>
</tr>
</tbody>
</table>

**Determination of the Utility Value**

The utility value \( N_{UC,r} \) of a Use Case \( r \) is determined by summing up its partial utility values \( n_{i,r} \), multiplied by the corresponding weightings \( g_i \). The utility value of all Use Cases can be determined this way and subsequently compared with each other in terms of their non-monetary benefits. Through this method, among other uses, the formation of a ranking of Use Cases is possible.
Industry 4.0: Implement it!

**Graphic Summary and Decision**

For decision making, a portfolio matrix which visualizes the different investment alternatives with regard to their monetary and non-monetary benefits is used. In addition to the amortization period on the x-axis and the utility value on the y-axis, a third dimension can be established. Various figures, e.g. the qualitative representation of the investment volume can be depicted to highlight the impact of a Use Case on a limited investment budget. Thereby, the severity of the financial risk that accompanies a Use Case (regardless of the calculated amortization period) can be determined. Alternatively, the cash value of an investment (see monetary assessment) can be represented as a third dimension to increase the financial information value beyond the results of an amortization calculation.

An exemplary portfolio matrix is depicted below. As a third dimension, the investment volume is depicted. For deriving a decision based on the portfolio matrix, a so-called indifference line can be integrated in the matrix. The indifference line describes how much additional, non-monetary benefit a Use Case must have to compensate for a worse amortization period in terms of overall utility. The same mechanism applies the other way around. By turning the line around the axis cross, a tendency for a more qualitative or quantitative evaluation can be achieved. Additionally, a first indication regarding the degree to which the requirements are met can be achieved by sketching trend zones within the portfolio matrix. Use Cases in the upper left section generally show better ratings regarding target achievement than those displayed in the lower right corner.

To decide on Use Cases to be realized, the benefit of the available investment budget needs to be optimized in the best possible way. The following graphical solution is applied: Each Use Case is horizontally and vertically connected to the indifference line (black dashed lines). For Use Cases above the indifference line, the order of Use Cases to be implemented applies in descending order of the distance from the intersection points to the indifference line. Use Cases are approved until the available budget is exhausted. Should there be available budget after the aforementioned Use Cases are approved, Use Cases below the indifference line can be selected as well. Below the indifference line, the Use Cases are sorted in descending order starting with the shortest distance of the intersection points from the indifference line.
In the illustration it is visible that not all Use Cases are able to meet the set target regarding their amortization period. Use Cases in the red area below the indifference line are not approved because their amortization period is higher than the period defined by the company. Use Cases that are located above the indifference line can be carried out under certain circumstances. In these cases, a very high utility value (above the indifference line) justifies a potentially positive investment decision. This procedure is based on some Use Cases not meeting financial targets but are being elementary prerequisites for the implementation of future Use Cases and are rated accordingly regarding their utility value. Hence, an investment decision can also be realized with a correspondingly high utility value and therefore does not need to be excluded by standard. In the example below, Use Case G is preferred to Use Case F for the reason that Use Case G has a higher overall benefit according to the indifference line and, in contrast to Use Case F, will still be taken into account when distributing the overall budget.
The company has decided to apply the more precise, dynamic amortization calculation method. The calculated interest rate is set to 10% for all Use Cases. The target criteria and their weighting are determined based on the determined maturity level.

**Use Case Smart Glasses**

The proposal to implement a Smart Glasses application has gone through all previous process steps and has been detailed in the course of concept development. The preliminary check shows that all relevant information has been collected. The degree of novelty is guaranteed and both the temporal and the financial frame can be implemented as well as a contact for further inquiries named. Accordingly, the assessment of the monetary and non-monetary aspects can be initiated.

On the side of the monetary benefits the calculation particularly takes the aspects in the area of production into account. Through simplified repair processes of a plant stationed abroad, not only the downtime can be reduced, but personnel and travel expenses saved. Moreover, the company generated less revenue due to delayed repairs despite short-term outsourcing for compensating machinery failures beforehand. Lastly, set-up times are reduced and unproductive waiting times decreased. After including all factors, the Use Case amortizes itself after about half a year.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cost type</th>
<th>Measured value</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Investment costs</td>
<td></td>
<td>-27,000.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>System care</td>
<td>License costs</td>
<td>-</td>
<td>1,100.00</td>
<td>1,100.00</td>
<td>1,100.00</td>
<td>1,100.00</td>
<td>1,100.00</td>
<td>1,100.00</td>
<td>1,100.00</td>
</tr>
<tr>
<td>Benefit</td>
<td></td>
<td></td>
<td>32,200.00</td>
<td>32,200.00</td>
<td>32,200.00</td>
<td>32,200.00</td>
<td>32,200.00</td>
<td>32,200.00</td>
<td>32,200.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Opportunity costs (Revenue)</td>
<td></td>
<td>2,600.00</td>
<td>2,600.00</td>
<td>2,600.00</td>
<td>2,600.00</td>
<td>2,600.00</td>
<td>2,600.00</td>
<td>2,600.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Savings maintenance costs (incl. travel cost)</td>
<td></td>
<td>2,200.00</td>
<td>2,200.00</td>
<td>2,200.00</td>
<td>2,200.00</td>
<td>2,200.00</td>
<td>2,200.00</td>
<td>2,200.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Savings set-up time</td>
<td></td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Savings waiting time</td>
<td></td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td>15,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Savings short-term outsourcing</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Result</td>
<td>Balance</td>
<td></td>
<td>-27,000.00</td>
<td>57,900.00</td>
<td>57,900.00</td>
<td>57,900.00</td>
<td>57,900.00</td>
<td>57,900.00</td>
<td>57,900.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cash value</td>
<td></td>
<td>-27,000.00</td>
<td>52,636.36</td>
<td>47,855.24</td>
<td>43,501.13</td>
<td>39,546.48</td>
<td>35,951.34</td>
<td>32,683.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aggregated cash value</td>
<td></td>
<td>-27,000.00</td>
<td>25,636.36</td>
<td>73,487.60</td>
<td>116,988.73</td>
<td>156,535.21</td>
<td>192,486.55</td>
<td>225,169.59</td>
<td></td>
</tr>
</tbody>
</table>

**Exemplary Application of Use Cases**
The monetary assessment is followed by the assessment of non-monetary benefits. The relevant criteria are initially selected and weighted for all Use Cases based on the maturity level evaluation of the company. Due to the low maturity level and the specified target characteristics set by the company, the areas of product development, production planning and scheduling, logistics and production as well as quality management are specifically focused on. By addressing the areas, a large benefit is generated which is subsequently highly weighted. As the company already has a very high maturity level in supply chain management and procurement as well as in marketing and sales, no criteria for assessing those aspects are taken into account. All in all, the Industry 4.0 Steering Committee defines the following criteria for the benefit analysis:

<table>
<thead>
<tr>
<th>Superordinate Criteria</th>
<th>Product development</th>
<th>Production planning &amp; scheduling</th>
<th>Logistics</th>
<th>Production</th>
<th>Quality management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information transparency and actuality</td>
<td>Production orientation</td>
<td>Flexibility</td>
<td>Material flow optimization</td>
<td>Process reliability</td>
<td>Cause identification</td>
</tr>
<tr>
<td>Knowledge acquisition and transfer</td>
<td></td>
<td>Cycle time</td>
<td></td>
<td>Ergonomics</td>
<td></td>
</tr>
</tbody>
</table>

The weighting, based on the maturity level, receives the following result:

<table>
<thead>
<tr>
<th>Group</th>
<th>Criterion</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superordinate criteria</td>
<td>Information transparency and actuality</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Knowledge acquisition and transfer</td>
<td>0.5</td>
</tr>
<tr>
<td>Product development</td>
<td>Production orientation</td>
<td>0.20</td>
</tr>
<tr>
<td>Production planning &amp; scheduling</td>
<td>Flexibility</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Cycle time</td>
<td>0.15</td>
</tr>
<tr>
<td>Logistics</td>
<td>Material flow optimization</td>
<td>0.21</td>
</tr>
<tr>
<td>Production</td>
<td>Process reliability</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Ergonomics</td>
<td>0.05</td>
</tr>
<tr>
<td>Quality management</td>
<td>Cause identification</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Subsequently, the fulfilment of the criteria as well as the total benefit is calculated. The Smart Glasses increase both process reliability and ergonomics in the area of production. Process reliability can be achieved very highly, whereas ergonomics is evaluated moderately due to the low level of long-term wearing comfort. In addition, Smart Glasses fulfill the superordinate criteria of information transparency and actuality moderately. 
as well as the acquisition and transfer of knowledge very highly. All other criteria are fulfilled very poorly. This results in a utility value of 2.44 for the Use Case Smart Glasses. Before the Use Case is classified within the portfolio matrix, the company-wide Data Lake is evaluated.

**Use Case Data Lake**

For the Use Case Data Lake, all relevant information is available so that the preliminary examination is passed without any necessary changes. Regarding the monetary assessment, the company has difficulties in obtaining a directly measurable benefit. To be able to make a statement about economic efficiency possible Use Cases based on a Data Lake are considered as well. It is assumed that these are mainly found in the areas of quality management, logistics and production. However, these will only be available approximately one year after implementing the Data Lake. After intensive considerations with employees involved in the Use Case, the following chart is created by the Global Industry 4.0 Manager:

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cost type</th>
<th>Measured value</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Investment costs</td>
<td>Investment costs</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>System care</td>
<td>Maintenance costs</td>
<td>-</td>
</tr>
<tr>
<td>Quality costs</td>
<td>Reduction failure and rework costs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction inspection costs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production</td>
<td>Reduction set-up time</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction maintenance costs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction outsourcing cost</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Increased utilization rate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Logistics</td>
<td>Reduction search effort</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction transport times</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction confirmation costs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduction current assets</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Result</td>
<td>Balance</td>
<td>-275,000.00</td>
<td>-7,500.00</td>
</tr>
<tr>
<td></td>
<td>Cash value</td>
<td>-275,000.00</td>
<td>-6,818.18</td>
</tr>
<tr>
<td></td>
<td>Aggregated cash value</td>
<td>-275,000.00</td>
<td>281,818.18</td>
</tr>
</tbody>
</table>
The company determines an amortization period of about 6.8 years. This lies far above the usual target value of 3 years set by the company. For non-monetary benefits, the criteria defined in the course of the Smart Glasses application are used to ensure the comparability of the utility value.

In particular, the Data Lake creates benefits in production planning and scheduling, logistics, quality management as well as in supporting areas (see section “maturity model”). In addition, superordinate criteria are fulfilled as well. The evaluation of the superordinate criteria shows that the transparency of information is significantly improved by a Data Lake and, accordingly, is fulfilled very highly. Production planning and scheduling, logistics, production and quality management can also be improved further by corresponding applications. However, this will only take place mid-term. Accordingly, the Data Lake is only given a moderate fulfillment value in these fields. All other criteria are fulfilled very poorly. Thus, the result for the Data Lake is a total utility value of 3.10.

**Final Evaluation**

A transfer of both Industry 4.0 Use Cases into the portfolio matrix is shown below. In total, a maximum utility value of 5 can be achieved. In addition, the company aims for an amortization period of less than three years. The monetary benefit is weighted with 30 % in the portfolio matrix while the non-monetary benefit is credited 70 %.

Due to the graphically determined longer intersection point distance of the Smart Glasses Use Case, it is prioritized in the company. Due to a sufficient budget and the fulfillment of various framework conditions the Data Lake is also approved to be implemented. The example shows that by determining the monetary and non-monetary benefits, a decision can be determined objectively. Thus, companies are enabled to evaluate Use Cases based on defined criteria and implement them according to their benefit.
Industry 4.0: Implement it!
Summary and Outlook

There hardly is a topic which has been put as much into strategic focus of German companies in recent years as Industry 4.0. The real-time capable digital networking of people, machines, objects and ICT systems enables the optimization of production processes, products and services. Despite visibly large efforts and, in some cases, high capital investment, the number of success stories is rather small. For instance, there is a large number of pilot projects and prototypical applications, but the expected high benefit from the overall company perspective has failed to materialize so far. One of the main reasons is the lack of structured implementation concepts. This study presents a concrete guideline which describes the procedure for a successful implementation of Industry 4.0 in companies. This guideline provides necessary organizational requirements and a six-step procedure for implementation.

A central element of the organizational structure that is to be created is the Industry 4.0 Steering Committee. It is the central point of contact for top management and serves as a controlling and coordinating function for the implementation of Industry 4.0. It consists of a company-wide responsible Industry 4.0 Manager and several experts from different specialist areas. The implementation of Industry 4.0 projects is conducted either on the shop floor in project teams or in an independent organizational unit, the Industry 4.0 Garage.

The procedure for the implementation of Industry 4.0 projects is described in detailed sub-steps in the guideline. Initially unspecific ideas are successively concretized and exemplarily implemented inside a company. The starting point is the determination of the current Industry 4.0 maturity level of a company. That enables a target-oriented selection of Use Cases which are to be implemented and subsequently evaluated in detail regarding their cost-benefit ratio. After a successful pilot testing phase of the Industry 4.0 Use Cases, a roll-out throughout the company is carried out.

The implementation of the guideline presented in this study enables companies to realize the potentials of Industry 4.0 to their full extent. It is essential for the success of an implementation of Industry 4.0 to maintain a holistic and structured approach towards the implementation. The practical introduction of the described concept requires an adaptation to the individual needs of a company. It needs to be evaluated to what extent resources are provided for the implementation of Industry 4.0 and which employees are worth considering for different newly created roles in question at this point. The selection of appropriate employees based on professional and personal suitability strongly contributes to the success of the concept. To anchor the concept into the everyday work processes of a company, trainings are required for the employees. Ideally, they raise motivation for adopting the new approach by setting corresponding impulses. It is recommended to test initial changes for the introduction of the concept in pilot areas such as individual departments or plants as well as in selected pilot projects. The step-by-step roll-out ensures that the potentials of Industry 4.0 contribute to increasing efficiency and productivity of production processes throughout the company as well as in a sustainable and comprehensive manner.
### Industry 4.0 Maturity Model – Structure and Explanations

#### Adaptability
- How can an automatic reaction take place?
  - "Self-optimization"
- • Autonomous decision making
- • Independent optimization of systems

#### Forecast
- What will happen?
  - "Be prepared"
- • Evaluation of the probability of occurrence of various events
- • Early detection of events

#### Transparency
- Why does it happen?
  - "Understanding"
- • Semantic linking of the data of a system
- • Achieving an understanding of cause-effect relationships

#### Visualization
- What happens?
  - "See"
- • Visualization of company processes and events
- • Representation of the status quo of states, processes and events

#### Digital networking
- Who with whom?
  - "Connect"
- • Targeted data exchange and communication in business processes
- • Representation of the status quo of states, processes and events

#### Computer-ization
- Do what basis?
  - "Digitize"
- • Active recording and storage of data in the corporate context
- • Use of digital systems in management, business and supporting processes

### Industry 4.0 Maturity Model – Marketing & Sales

#### Adaptability
- How can an automatic reaction take place?
  - "Self-optimization"
- • Autonomous decision making in the event of market shifts
- • Independent implementation of price and sales volume adjustments

#### Forecast
- What will happen?
  - "Be prepared"
- • Evaluation of the probability of occurrence of market developments
- • Early detection of changes in sales figures on the basis of historical value

#### Transparency
- Why does it happen?
  - "Understanding"
- • Semantic linking of sales events and market developments
- • Logical linkage of sales events with data from product development and quality management

#### Visualization
- What happens?
  - "See"
- • Display of current sales figures
- • Presentation of the status quo of sales developments

#### Digital networking
- Who with whom?
  - "Connect"
- • Consolidation of sales and customer data
- • Development of interfaces for interaction with customers

#### Computer-ization
- Do what basis?
  - "Digitize"
- • Active recording and storage of sales developments
- • Use of digital systems in distribution
Industry 4.0 Maturity Model – Product Development

Adaptability
How can an automatic reaction take place?
“Self-optimization”
- Autonomous decision making on development targets for specific changes and developments in the market
- Proactive, time- and task-specific provision of relevant information in product development

Forecast
What will happen?
“Be prepared”
- Forecasting the probability of occurrence for product developments
- Early recognition of market potential

Transparency
Why does it happen?
“Understanding”
- Semantic linking of product specifications and market requirements
- Identification of cause-effect relationships for the determination of product requirements

Visualization
What happens?
“See”
- Identification of market developments
- Presentation of the status quo of business as well as product ideas and market potentials

Digital networking
Who with whom?
“Connect”
- Consolidation of product development information, corporate strategy, market research and resource management

Computerization
On what basis?
“Digitize”
- Recording of development-relevant data
- Use of digital systems in product development

Industry 4.0 Maturity Model – Supply Chain Management & Procurement

Adaptability
How can an automatic reaction take place?
“Self-optimization”
- Autonomous decision making and processing in the case of shortfall and exceedance of capacity limits
- Independent implementation of optimization measures for order changes

Forecast
What will happen?
“Be prepared”
- Evaluation of the probability of occurrence of order changes based on the behavior of value creation partners
- Early detection of changes in the order situation

Transparency
Why does it happen?
“Understanding”
- Linking of information for the evaluation of value added partners and procurement processes
- Identification of cause-effect relationships between good control and order situation

Visualization
What happens?
“See”
- Showing the status quo of current processes in the supply chain
- Representation of the interaction with value creation partners

Digital networking
Who with whom?
“Connect”
- Exchange of information between value creation partners in the procurement process
- Establishment of internal and external company interfaces

Computerization
On what basis?
“Digitize”
- Active recording and storage of supply chain data
- Use of digital systems to manage the supply chain
### Industry 4.0 Maturity Model – Production Planning & Scheduling

<table>
<thead>
<tr>
<th>Adaptability</th>
<th>How can an automatic reaction take place?</th>
<th>“Self-optimization”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Autonomous decision making for proactive planning adjustments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Independent optimization of production planning and scheduling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forecast</th>
<th>What will happen?</th>
<th>“Be prepared”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evaluation of the probability of occurrence of production events on the basis of current data and historical data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early detection of critical orders</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transparency</th>
<th>Why does it happen?</th>
<th>“Understanding”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Semantic linking of the actual production data with the short-, mid- and long-term production planning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identification of cause-effect relationships of planning parameters and regularities through analysis of production data</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Visualization</th>
<th>What happens?</th>
<th>“See”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Display of production processes and events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Representation of the status quo of status relevant to production</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digital networking</th>
<th>Who with whom?</th>
<th>“Connect”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combination of several digital systems in the production process for planning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Development of company interfaces for all entities involved in the value creation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computerization</th>
<th>On what basis?</th>
<th>“Digitize”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active recording and storage of order data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use of digital systems in planning</td>
<td></td>
</tr>
</tbody>
</table>

### Industry 4.0 Maturity Model – Logistics

<table>
<thead>
<tr>
<th>Adaptability</th>
<th>How can an automatic reaction take place?</th>
<th>“Self-optimization”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Autonomous decision making in case of the necessity to change the movements of goods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Independent optimization of the movements of goods on the basis of data analysis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forecast</th>
<th>What will happen?</th>
<th>“Be prepared”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evaluation of the probability of occurrence of changes in goods and information flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early detection of logistical bottlenecks</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transparency</th>
<th>Why does it happen?</th>
<th>“Understanding”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Semantic linking of data from logistics processes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Achieving an understanding of cause-effect relationships within flows of goods and information</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Visualization</th>
<th>What happens?</th>
<th>“See”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Display of goods movements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Display of the current stock</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digital networking</th>
<th>Who with whom?</th>
<th>“Connect”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consolidation of internal and external logistics processes for the supply of locations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Establishment of interfaces between internal and external logistics entities involved in logistics processes</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computerization</th>
<th>On what basis?</th>
<th>“Digitize”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active recording of data on goods and information movements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use of digital systems in logistics</td>
<td></td>
</tr>
</tbody>
</table>
Industry 4.0: Implement it!

Industry 4.0 Maturity Model – Production

Adaptability
How can an automatic reaction take place?
“Self-optimization”
- Autonomous decision making for product-specific changes in the manufacturing process
- Independent optimization of manufacturing processes

Forecast
What will happen?
“Be prepared”
- Evaluation of the probability of occurrence of various scenarios in production
- Early detection of upcoming changes in the manufacturing process

Transparency
Why does it happen?
“Understanding”
- Achieving an understanding of cause-effect relationships in production
- Definition of a cross-departmental information logistics system for the departments involved in manufacturing

Visualization
What happens?
“See”
- Display of the current production status
- Creation of transparency in relation to logistics and manufacturing processes

Digital networking
Who with whom?
“Connect”
- Consolidation of information from different departments involved in the manufacturing process
- Establishment of interfaces for interaction with upstream and downstream processes

Computerization
On what basis?
“Digitize”
- Active recording of process, machine and product data in a single digital system
- Use of digital systems in manufacturing

Industry 4.0 Maturity Model – Quality Management

Adaptability
How can an automatic reaction take place?
“Self-optimization”
- Autonomous decision making for quality improvement
- Independent implementation of optimization measures

Forecast
What will happen?
“Be prepared”
- Evaluation of the probability of occurrence of potential changes in quality
- Early detection of process and product inaccuracies

Transparency
Why does it happen?
“Understanding”
- Semantic linking of quality management data
- Creation of cause and effect relationships between quality changes and the production process

Visualization
What happens?
“See”
- Showing company-wide quality data which are relevant for end and intermediate products
- Presentation of the status quo of qualitative product and production characteristics

Digital networking
Who with whom?
“Connect”
- Consolidation of quality management data with production and sales
- Development of interfaces between production and quality management

Computerization
On what basis?
“Digitize”
- Active recording of quality-relevant data of manufactured products
- Use of digital systems in quality management
### Industry 4.0 Maturity Model – Supporting Functions, Example: Controlling

| Adaptability | How can an automatic reaction take place? | • Autonomous decision making in the event of discrepancies between financial planning and company results  
• Independent implementation of optimizations regarding company parameters for managing the financial results of the company |
| Forecast | What will happen? | • Evaluation of the probability of occurrence of various company results  
• Early recognition of changes in financial key figures on the basis of historical values |
| Transparency | Why does it happen? | • Semantic linking of company results and financial performance planning  
• Identification of cause-effect relationships between financial planning and business development |
| Visualization | What happens? | • Highlighting business processes and events with a focus on finances  
• Presentation of current financial and productivity key figures |
| Digital networking | Who with whom? | • Consolidation of data from controlling and other relevant company departments  
• Development of company interfaces with controlling |
| Computerization | On what basis? | • Active recording of controlling-relevant data  
• Use of digital systems in controlling |
### Quantification of Industry 4.0 Use Cases – Superordinate Target Criteria

<table>
<thead>
<tr>
<th>Increase in revenue</th>
<th>Company-wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase of (machine) utilization rate</td>
<td>LR</td>
</tr>
<tr>
<td>Increase in product sales</td>
<td>LR</td>
</tr>
<tr>
<td>Requirement conformity</td>
<td>LR</td>
</tr>
<tr>
<td>Increase in market price</td>
<td>LR</td>
</tr>
<tr>
<td>Customization</td>
<td>LR</td>
</tr>
<tr>
<td>Shorter time-to-market</td>
<td>LR</td>
</tr>
<tr>
<td>Increase in quality</td>
<td>LR</td>
</tr>
<tr>
<td>Increase in product innovation and differentiation</td>
<td>LR</td>
</tr>
<tr>
<td>Improvement of adherence to delivery dates</td>
<td>LR</td>
</tr>
<tr>
<td>Information procurement effort</td>
<td>PC</td>
</tr>
<tr>
<td>Maintenance expenditure</td>
<td>PC, OC, MC</td>
</tr>
<tr>
<td>Data maintenance expenditure</td>
<td>PC</td>
</tr>
<tr>
<td>Contractual penalties (for delay)</td>
<td>CP</td>
</tr>
<tr>
<td>Coordination effort</td>
<td>PC</td>
</tr>
<tr>
<td>Data preparation and analysis effort</td>
<td>PC</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>LR</td>
</tr>
<tr>
<td>Administration effort (paper, printer, …)</td>
<td>MC</td>
</tr>
<tr>
<td>Search effort</td>
<td>PC</td>
</tr>
<tr>
<td>Error analysis effort</td>
<td>PC</td>
</tr>
<tr>
<td>Waiting and lay times</td>
<td>PC, MAC</td>
</tr>
</tbody>
</table>
Quantification of Industry 4.0 Use Cases — Department-specific Target Criteria

<table>
<thead>
<tr>
<th>Product development</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost saving</strong></td>
<td><strong>Potential</strong></td>
</tr>
<tr>
<td></td>
<td>Engineering and design expenses</td>
</tr>
<tr>
<td></td>
<td>Creation of prototype parts</td>
</tr>
<tr>
<td></td>
<td>Change effort and iteration loops</td>
</tr>
<tr>
<td></td>
<td>Optimization of production suitability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supply chain management &amp; procurement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost saving</strong></td>
<td><strong>Potential</strong></td>
</tr>
<tr>
<td></td>
<td>Initiation and processing costs</td>
</tr>
<tr>
<td></td>
<td>Additional costs due to small supplier width</td>
</tr>
<tr>
<td></td>
<td>Supplier support expenditure (acquisition, auditing, …)</td>
</tr>
<tr>
<td></td>
<td>Shipping costs</td>
</tr>
<tr>
<td></td>
<td>Cost potentials through outsourcing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supporting functions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost saving</strong></td>
<td><strong>Potential</strong></td>
</tr>
<tr>
<td></td>
<td>Expenses for human resources</td>
</tr>
<tr>
<td></td>
<td>Reporting efforts</td>
</tr>
<tr>
<td></td>
<td>Post calculation</td>
</tr>
</tbody>
</table>
### Industry 4.0: Implement it!

#### Production planning & scheduling

<table>
<thead>
<tr>
<th>Potential</th>
<th>Revenue/cost type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current assets</td>
<td>CC</td>
</tr>
<tr>
<td>Planning and scheduling expenses</td>
<td>PC</td>
</tr>
<tr>
<td>Needs assessment</td>
<td>PC</td>
</tr>
</tbody>
</table>

#### Logistics

<table>
<thead>
<tr>
<th>Potential</th>
<th>Revenue/cost type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation costs</td>
<td>PC</td>
</tr>
<tr>
<td>Material provision expenditure</td>
<td>PC</td>
</tr>
<tr>
<td>Inspection effort</td>
<td>PC</td>
</tr>
<tr>
<td>Inventory booking effort</td>
<td>PC</td>
</tr>
<tr>
<td>Packaging effort</td>
<td>PC, MC</td>
</tr>
<tr>
<td>Storage costs</td>
<td>PC, CC, SC</td>
</tr>
<tr>
<td>Inventory risks</td>
<td>IR</td>
</tr>
</tbody>
</table>

#### Production

<table>
<thead>
<tr>
<th>Potential</th>
<th>Revenue/cost type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set-up costs</td>
<td>PC, MAC</td>
</tr>
<tr>
<td>Repair and maintenance costs</td>
<td>PC, TC, MC, MAC</td>
</tr>
<tr>
<td>Machine support expenditure</td>
<td>PC</td>
</tr>
<tr>
<td>Feedback effort</td>
<td>PC</td>
</tr>
</tbody>
</table>
### Quality management

<table>
<thead>
<tr>
<th>Potential</th>
<th>Revenue/cost type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection effort</td>
<td>PC</td>
</tr>
<tr>
<td>Troubleshooting effort</td>
<td>PC, MC, OC</td>
</tr>
<tr>
<td>Recall effort</td>
<td>PC, CP</td>
</tr>
</tbody>
</table>

### Marketing & sales

<table>
<thead>
<tr>
<th>Potential</th>
<th>Revenue/cost type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition effort</td>
<td>PC, TC</td>
</tr>
<tr>
<td>Sales expenditure</td>
<td>PC, TC</td>
</tr>
<tr>
<td>Market expansion effort</td>
<td>PC, TC</td>
</tr>
<tr>
<td>Distribution expenditure</td>
<td>PC, OC</td>
</tr>
<tr>
<td>Calculation effort</td>
<td>PC</td>
</tr>
</tbody>
</table>

### Index

<table>
<thead>
<tr>
<th>Index</th>
<th>Cost type</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC</td>
<td>Machine costs</td>
<td>$\text{MAC} = \sum_{i=1}^{n} \text{hourly machine rate}_i \times \text{additional hours possible}_i$</td>
</tr>
<tr>
<td>PC</td>
<td>Personnel costs</td>
<td>$\text{PC} = \sum_{i=1}^{n} \text{hourly personal rate}_i \times \text{saved hours}_i$</td>
</tr>
<tr>
<td>OC</td>
<td>Outsourcing costs</td>
<td>$\text{OC} = \sum_{i=1}^{n} \text{outsourcing cost}_i$</td>
</tr>
<tr>
<td>MC</td>
<td>Material costs</td>
<td>$\text{MC} = \sum_{i=1}^{n} \text{direct material cost}_i + \text{share of indirect material cost}_i$</td>
</tr>
<tr>
<td>LR</td>
<td>Lost revenues</td>
<td>$\text{LR} = \sum_{i=1}^{n} \text{share of unsold or additionally sold products}_i \times \text{market price}_i$</td>
</tr>
<tr>
<td>CP</td>
<td>Contractual penalties</td>
<td>individually agreed</td>
</tr>
<tr>
<td>TC</td>
<td>Travel costs</td>
<td>$\text{TC} = \sum_{i=1}^{n} \text{travel cost}_i$</td>
</tr>
<tr>
<td>CC</td>
<td>Capital costs</td>
<td>$\text{CC} = \left( \frac{\text{E}}{\text{V}} \right) \times \text{ke} + \left( \frac{\text{F}}{\text{V}} \right) \times \text{kF} \times (1 - \text{sc})$</td>
</tr>
</tbody>
</table>

with $E = \text{equity capital}; F = \text{market value of debt capital}; V = \text{total company value}; \text{ke} = \text{interest rate of equity investors}; \text{sc} = \text{tax benefit of debt capital costs}$

| SC    | Storage costs      | $\text{SC} = \sum_{i=1}^{n} \text{storage cost rate}_i \times \text{required storage space}_i$ |
| IR    | Inventory risks    | $\text{IR} = \sum_{i=1}^{n} \text{Value of good}_i \times \text{risk of default}_i$ |
| EC    | Energy consumption | $\text{EC} = \sum_{i=1}^{n} \text{energy consumption}_i \times \text{energy cost}_i$ |
Bibliography

Behrendt et. al. 2017:

Deloitte 2016:

E&Y 2017:

Kienbaum 2017:

McKinsey 2016:
McKinsey & Company, Inc.: Industry 4.0 after the initial hype: Where manufacturers are finding value and how they can best capture it, 2016. https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/getting%20the%20most%20out%20of%20industry%204%20/mckinsey_industry_40_2016.ashx

PwC 2016:

Schuh et. al. 2017:

Statista 2018:
Industry 4.0: Implement it!
Authors

Prof. Dr. Günther Schuh
Holder of the Chair for Production Engineering
Laboratory for Machine Tools and Production Engineering (WZL)

Prof. Dr. Wolfgang Boos
Executive Chief Engineer
Laboratory for Machine Tools and Production Engineering (WZL)

Christoph Kelzenberg
Head of Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)

Johan de Lange
Group Leader Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)

Felix Stracke
Research Associate Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)

Jens Helbig
Research Associate Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)

Julian Boshof
Research Associate Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)

Christoph Ebbecke
Research Associate Department Business Development
Laboratory for Machine Tools and Production Engineering (WZL)
Industry 4.0: Implement it!