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Development of a Practical Orientation Guide with Industrie 4.0 Use Cases for Industrial Manufacturers

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Abstract

Apart from innovators and early adopters, industrial manufacturers are still looking for adequate guidance for the orientation, prioritization, and development of Industrie 4.0 initiatives. Case studies of best practices have proven beneficial for the identification of use cases in manufacturing companies. Therefore, the aim of this paper is to develop an orientation guide for Industrie 4.0 with best practice use cases structured into thematic categories of production system areas. The orientation guide gathers relevant use cases for the adaption in industrial implementations. As a first practical application, the guide will be rolled out in an international study to primarily support regional manufacturing companies from Germany in the development of own Industrie 4.0 use cases. However, the guide is universally applicable to any manufacturing company and provides useful insights for the implementation of Industrie 4.0 use cases globally.

Keywords

Industrie 4.0; Production System; Use Cases; Production Strategy.

1. Introduction

The economy is crossing the threshold of the fourth industrial revolution and digitalization is already influencing the daily lives, economy and workplaces. A wide variety of areas of everyday life are already heavily influenced by information and communications technologies (ICT). Mobile internet, smartphones, cloud and distributed collaboration have led to major changes in the recent years. The widespread entry of ICT into industry is already in full progress, and there is no sign of this development slowing down. It is leading to a reshaping of entire value chains through the multi-layered use of the Internet of Things, mobile networking and flexible robotics. [1–3]

The aim of Industrie 4.0 in Germany is to strategically establish the country as a lead market, including leading technology providers. This offers medium-sized, export-oriented companies in particular from the mechanical engineering sector the potential to position themselves worldwide as pioneers of new, innovative solutions. Driven by the internet, the real and virtual worlds are continuing to grow together into an internet of things, services and people. Industrie 4.0 is an important research stream for the management of growing complexity in socio-technical production systems. [4]

Industry in the region of Baden-Württemberg has already taken up the topic. In particular, large companies are driving forward the digital transformation of their value chains and their range of services. Use cases for artificial intelligence, innovative industrial implementation solutions, new product-service combinations and business models are emerging and some are already in use. [5] In this context, overarching topics such as the creation of standards, IT safety and security, legal framework conditions, labor market trends, qualification measures and the effects on work systems design and work organization are currently being discussed and shaped.

Many companies still find it difficult to relate their own digitized production processes to typical Industrie 4.0 categories. [6] As a practical orientation support for regional companies, which do not yet know exactly whether their implemented solutions are feasible, an orientation guide for Industrie 4.0 best practices is meant to be created.

For the orientation, structuring and localization of these implementation solutions, a systematic guidance is to be developed on the basis of nationally and internationally collected Industrie 4.0 use cases. For this purpose, the *Framework for Cognitive Production Work 4.0* from [7] will be adapted to the practical needs of manufacturing companies in search of innovative implementation cases. The aim is to empower companies to quickly classify their application cases for Industrie 4.0 and at the same time identify gaps in their digitalization portfolio. The orientation guide forms the basis of a comparative study on Industrie 4.0 success factors and best practices.

This paper is structured as follows. Chapter 2 gives an overview of the relevant terminology and existing related works. In chapter 3 the development of the orientation guide is explained with regard to the thematic structure and categories, the application process, and its current limitations and potentials. Chapter 4 provides an outlook on the upcoming research activities and practical application of the orientation guide. The concluding remarks are gathered in chapter 5.

2. Related works

In this chapter the relevant related works for this paper are presented. For this, a definition of the relevant terminology (*Industrie 4.0, digital transformation, use case, Cognitive Production Work 4.0*) is provided in section 2.1. In order to clarify the underlying research framework for the following developments, the specific concepts are briefly explained in section 2.2.

2.1 Terminology

Industrie 4.0 describes the intelligent networking of people, machines and processes in industrial production with the help of information and communications technology (ICT). In this context, Industrie 4.0 is attributed with the change potential of a fourth industrial revolution. The term *digital transformation* in production refers to the implementation process of Industrie 4.0 and consists of the four phases of digitization, virtualization, networking and autonomization. [2,3,8,9] In a recent analysis of influencing factors of the digital transformation on supply chain complexity dimensions, [10] define the most important drivers and enabling technologies for the digital transformation per phase, which are displayed in Figure 1.

Industrie 4.0 technologies are often introduced in a strategic road mapping process with the help of concrete use cases. [11] A *use case* describes an exemplary application of a technology, method or tool. A use case contains concrete technical solutions to problems and also how these solutions can be practically implemented. In the operational context, use cases can be linked to involved actors, business processes and relevant key figures. [12] Use cases can be used to address individual lean and digitalization maturity levels of different plants in a manufacturing enterprise. This enables the benefits of the application to be communicated using practical examples. In addition, use cases can include the estimation and initial calculation of financial and other measurable potentials.

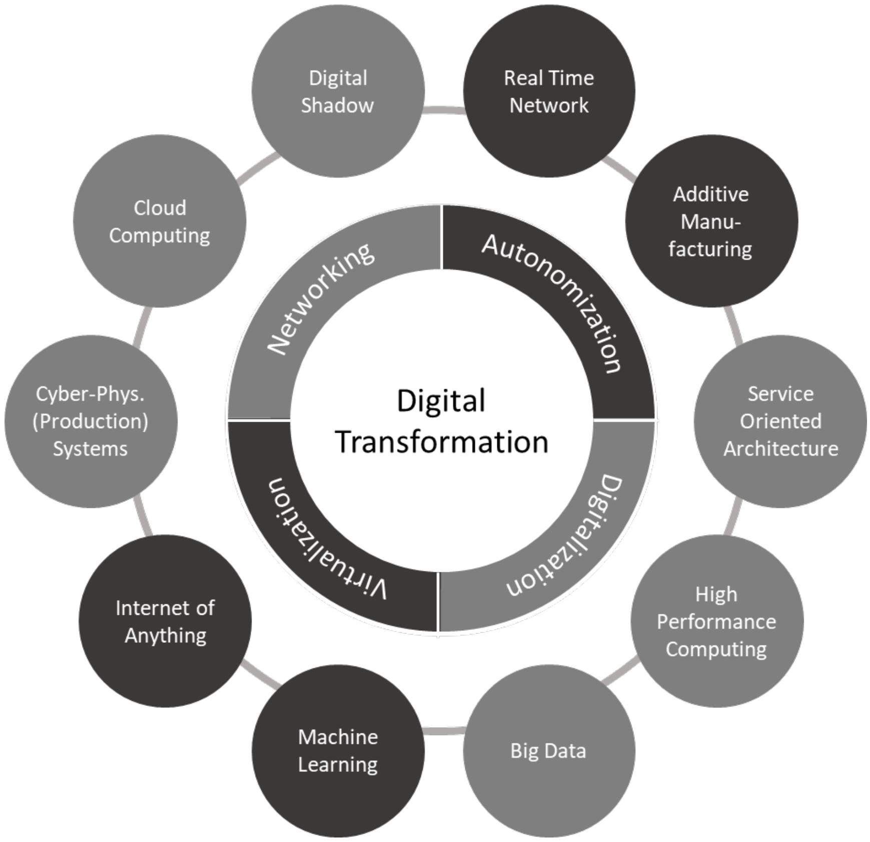

Figure 1: Drivers and enabling technologies for the digital transformation [[10] based on [13]]

Cognitive Production Work 4.0 is defined as follows. Production work describes work within manufacturing processes and will undergo significant change as a result of the use of Industrie 4.0. In terms of growing content, the increasing integration of ICT within work processes will result in a shift from executive activities to more controlling and regulating tasks. At the same time, flexibility requirements in terms of content, time and place will increase. *Cognitive Production Work 4.0* additionally describes the change in production work from physical tasks to more activities that include planning and creative components and, at the same time, support these human cognitive abilities through the use of learning systems based on Industrie 4.0 technologies in production. Production work will continue to change significantly through collaboration with artificial intelligence within work processes and in many cases will mean dynamic handovers between system and human. [14–16]

2.2 Framework for Cognitive Production Work 4.0

Frameworks originate from information systems architecture and deal with the definition and control of logical structures for the integration of components within a system. [17,18] A framework "is a tool which can be used for developing a broad range of different architectures. It describes a method for designing an information system in terms of a set of building blocks, and for showing how the building blocks fit together. It contains a set of tools and provides a common vocabulary. It also includes a list of recommended standards and compliant products that can be used to implement the building blocks." [19] According to [17], frameworks can be characterized by the following features: model characteristics (representation, abbreviation, pragmatism), logical structure, methodical approach, intention/target group. [17]

The *Framework for Cognitive Production Work 4.0* is a development by researchers from the Future Work Lab and has been conceptualized with a domain-specific five-staged development process and according to eleven design principles in [7]. It is set up to serves six distinct aims, including both theoretical and practical elements. [16] The thematic framework elements are structured according to the widely-accepted *Human-*

Technology-Organization (HTO) classification. [20] Following this, the first version of thematic framework elements on two sub-levels and a more complex relation model has been developed in [7]. Figure 2 shows the elements of the first framework level divided into the HTO structure. See [7] and [16] for more details on the framework conceptualization and development as well as the expected benefits of the approach.

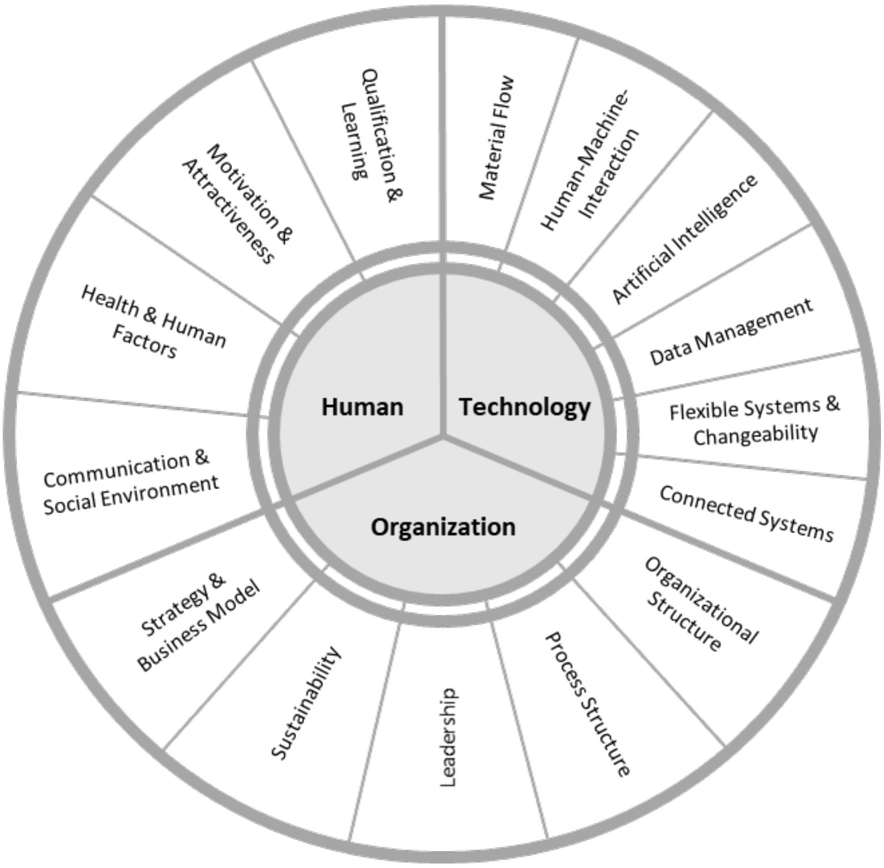

Figure 2: Framework for *Cognitive Production Work 4.0* [16]

The above presented structure of the framework is of mainly theoretical nature. In order to increase the applicability of the framework, the development team initiated multiple activities for practical examples of the application. Typical patterns of manufacturing value streams have been analyzed and transferred into schematic process structure for the direct application in production environments. As a visually supported action for the communication of the framework elements, graphical mood boards for three lead topics of *Cognitive Production Work 4.0* have been developed and communicated to users of the framework. [21] Another practical application of the framework can be observed in the demonstration world of the Future Work Lab. Here, a set of more than 40 use cases has been allocated to seven categories, which form a specific application layer of the framework. The classification approach is laid out in detail in [22]. The seven categories of the application layer are listed below:

- Ergonomics and safety
- Qualification and learning on the job
- Connected manufacturing systems
- Digital assistance
- Human-robot collaboration
- Intelligent machinery and systems
- Virtual engineering and planning [22]

3. Practical orientation guide for Industrie 4.0 best practices

The aim of this paper is to develop a suitable orientation guide for Industrie 4.0 best practices to support industrial companies in the process of their use case implementation. Therefore, the corresponding thematic structure (section 3.1) and process for the use of the orientation guide (section 3.2) are being described in this chapter. The limitations and further potentials are shortly discussed in section 3.3.

3.1 Thematic structure and categories

The thematic structure can be built upon the existing structure of the application layer of the *Framework for Cognitive Production Work 4.0* from 2.2. In order to address the needs of industrial companies, the existing seven categories needed revision for the intended purpose. The revision of the categories included literature analysis, data analysis of existing use case data bases and expert workshops. As a result, eight distinct categories have been identified for the practical orientation guide, which will be explained in subsections of this chapter.

For an intuitive understanding of the thematic fields, exemplary use cases were added to each category. The use cases were analyzed from different Industrie 4.0 data sets, including use cases from European level (*European Factories of the Future Research Association*) [23], German federal level (*Plattform Industrie 4.0*) [24], German regional level (*Allianz Industrie 4.0 Baden-Württemberg*) [25], and the German federal pilot project *Future Work Lab* [26]. Figure 3 shows the resulting composition of categories and exemplary use cases from the Future Work Lab. In the following, each category will be briefly defined and explained with a corresponding example.

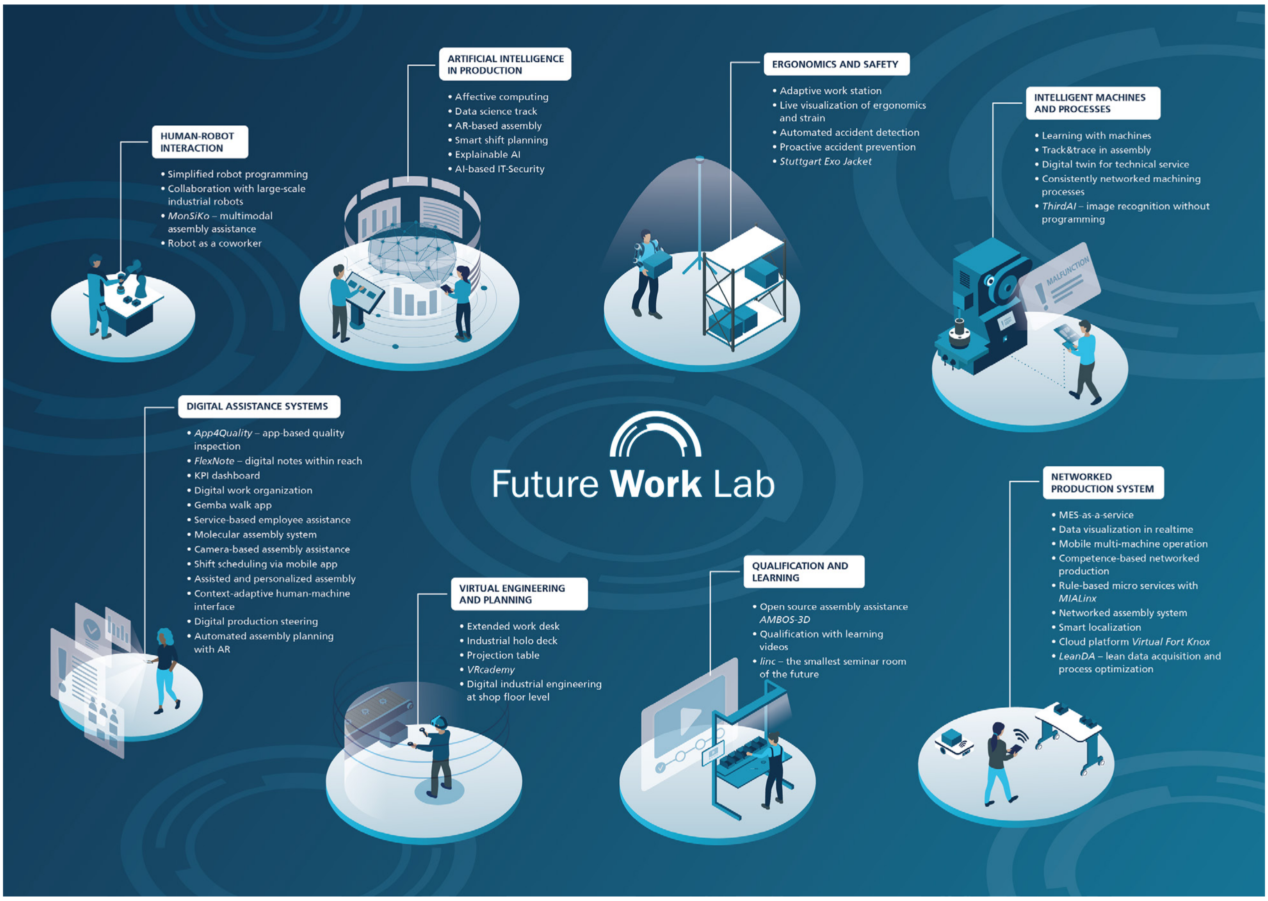

Figure 3: Practical orientation guide for Industrie 4.0 best practices with exemplary use cases from the Future Work Lab
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3.1.1 Human-robot interaction

Many current and future applications in the field of Industrie 4.0 will further reduce the distance (in terms of physical and work-related content) between humans and robots. In many cases, the intention is not to replace human work with technology, but to achieve meaningful cooperation and collaboration between workers and technology in order to enhance human capabilities. Robots are not solely placed in production cells behind fences, but are integrated into collaborative work activities. [27] E.g. sensitive lightweight robots and virtual safety fences enable direct cooperation between humans and robots.

3.1.2 Ergonomics and safety

The reduction of physical strain at work and the increase of occupational safety can be enhanced by intelligent sensor technology and the use of actuators. This category includes the organizational and technologically supported optimization of work task for the benefit of human health. Industrie 4.0 enables multiple innovative solutions based on cyber-physical systems, such as the use of passively or actively driven exo skeletons.

3.1.3 Intelligent machines and processes

Set-up and other activities during machine downtime often take up a lot of time without generating any added value. Intelligent machines can provide relevant data for workers and thus reduce downtime. Legacy machines can be retrofitted and thereby integrated into digital networks of machine parks on cloud platforms. Intelligent solutions combine the connectivity of machines and availability of data into process knowledge based on descriptive, diagnostic, predictive or prescriptive analytics. E.g. a digital twin model can be of such use.

3.1.4 Digital assistance systems

Digital assistance systems are commonly defined as computer-based systems for the support of humans with contextual information during three activities: the perception of information, decision making and the execution of tasks. [28] Humans can be assisted by a wide variety of technological applications. E.g. context information can be supplied via a mobile app, in form of a visualization on a screen or directly at the workplace.

3.1.5 Virtual engineering and planning

In addition to direct activities on the shop floor, engineering and planning are also changing significantly with Industrie 4.0. Virtual systems and tools such as Augmented Reality devices are opening up new possibilities in product development, production planning and many other areas. E.g. physical cardboard engineering can be fully transferred into virtual cardboard engineering with immersive features and underlying process models.

3.1.6 Qualification and learning

Industrie 4.0 technologies enable the integration of learning content directly at the workplace and in relation to individual needs of employees in production. Modular learning content can be provided via digital platforms and consumed independently from rigid structures or limited resources. New forms of qualification methods and tools are assigned to this category, e.g. for life-long learning, re- and upskilling of workers and learning near or on-the-job.

3.1.7 Networked production system

The networking of machines, workstations and tools in production is constantly evolving and offers both productivity and efficiency potential. Along with Industrie 4.0, concepts of networked and interoperable entities such as the *(Industrial) Internet of Things* and *cyber-physical production systems* enable new capabilities within factories. Networked entities also include the potential for the collection, use and analysis of large amounts of data.

3.1.8 Artificial intelligence in production

Artificial intelligence in production has been added as the eighth category in order to address the rapidly growing group of emerging solutions from machine learning algorithms and neural networks based on production data. Use cases vary from typical application fields such as maintenance, logistics, automation technology, quality management and control, product and process development, process planning, and resource planning. With regard to human emotions in production, an exemplary use case from the Future Work Lab is the implementation of affective computing in production, which means that workers' emotions are analyzed for the detection of flow phases and corresponding adaptions in task management. [26]

3.2 Application process

The use of the orientation guide is dependent on the needs of industrial users. For companies in the early orientation phase which have not yet started with the development of a use case, a top-down process is recommended in order to first identify a thematic category of applications and then seek for a suitable solution out of the suggested group of existing use cases. For companies in the use case development or implementation phase, a bottom-up process promises several advantages. Matching the own use case with existing best practices of comparable use cases of the orientation guide allows valuable insights. For example, this concerns technologies used in development and the adaptation of processes in implementation. Both processes are combined in Figure 4.

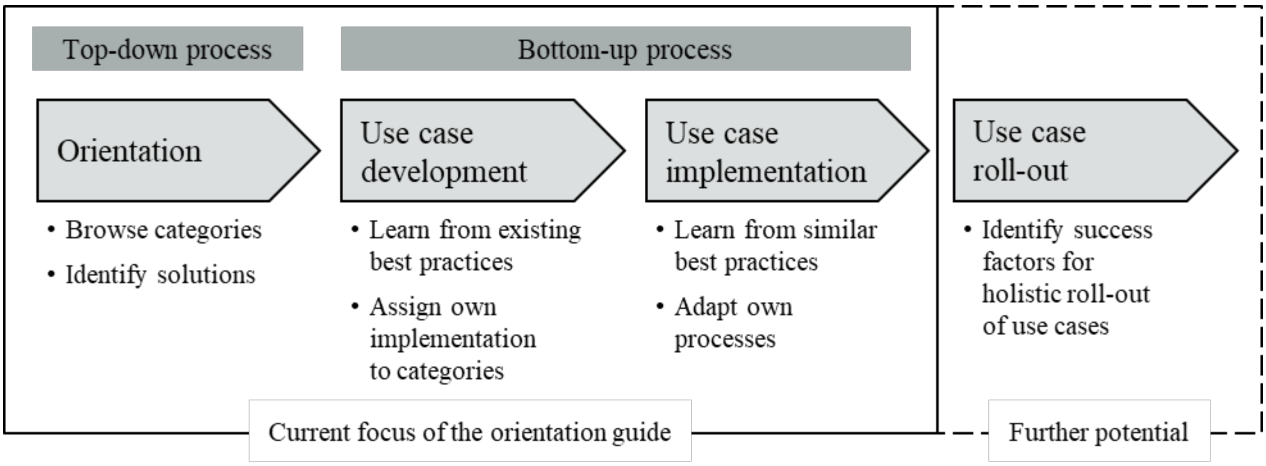

Figure 4: Process for the use of the practical orientation guide for Industrie 4.0 best practices in different phases

3.3 Limitations and potentials

In a first theoretical evaluation, the orientation guide has been found eligible for the thematic categorization of Industrie 4.0 use cases. When tested with new use cases in a practical evaluation, a small fraction of use cases might not be assignable to one of the predefined thematic fields. This limitation is calculated by design, but should not occur often. The orientation guide is expected to be even more valuable to users after further iterations including user feedback. Further potential of the orientation guide could be leveraged by the extension of the guide by integration of pre-developed value stream patterns as well as the expansion of the use case descriptions to include recommendations and success factors for the use case roll-out. However, this extension is planned in a future phase of development. The applicability of the orientation guide is still to be proved in a practical application case, which will be an international study described in the next chapter.

4. Outlook: International study on Industrie 4.0 best practices and success factors

The orientation guide supports its users to get a structured overview of possible Industrie 4.0 use cases and allows to assign own applications to the given thematic categories. The definition of the thematic categories is mainly based on best practices from German industry. In order to include global best practices, an international study on Industrie 4.0 best practices has been planned. This study will analyze best practices of manufacturing companies from seven different nations located in Europe, North America and Asia. Whereas the practical aim of the study is to provide companies from the region of Baden-Württemberg with insights into international best practices and success factors, the scientific aim of the study is also to validate the thematic categories of the orientation guide in an international context.

In order to achieve the aims of the study, a two-stage mixed-methods research design has been set up. The first stage is a standardized online questionnaire and the thematic categories of the orientation guide have been incorporated into the questionnaire. Table 1 gives an overview about the structure and content of the questionnaire. Based on the results of the questionnaire, the second stage of the study consists of expert interviews with representatives of the best practice companies involved. The expert interviews are conceptualized as semi-structured guideline interviews. The study is scheduled to be conducted from May until September 2021. The results will then be published.

Table 1: Structure and content of the questionnaire

Questionnaire section	Content	Exemplary items
Company demographics (3 items)	Brief characterization of companies for comparison	Industry sector; number of employees
General preconditions (16 items)	General preconditions with direct impact on the implementation of Industrie 4.0 use cases	Maturity level of Lean Production; existing infrastructure
Best practice – brief description (4 items)	Short summary of the best practice and assignment to the thematic categories of the orientation guide	Title of best practice; category according to the practical orientation guide
Best practice – situation before implementation (3 items)	Determination of the situation before the best practice was implemented	Know how in the field of Industrie 4.0; amount of implemented Industrie 4.0 use cases
Best practice – implementation phase (9 items)	Data from the implementation phase of the best practice project in order to derive success factors	Costs; external partners
Best practice – organization (5 items)	Analysis of the organizational characteristics of the best practice project	Involved employees/positions; size of the project team
Results (5 items)	Assessment of qualitative and quantitative outcomes of the best practice	Return on investment; quantitative and qualitative outcomes

5. Conclusion

In this paper a useful and practical orientation guide for Industrie 4.0 best practices is presented. The developments are based on a previously published and theoretically proven framework. The orientation guide provides any manufacturing company with suitable categories and a corresponding application process for the establishment of own Industrie 4.0 use cases. Furthermore, the assignment of over 40 use cases to eight thematic categories was successfully performed and proves as a first validation of the structure.

The application of the practical orientation guide for Industrie 4.0 best practices in an international study is already scheduled and prepared. This extensive validation action will generate further insights on the applicability of the structure and show potentials for iterations of the model at the same time.

Acknowledgements

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