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Cost estimation approach of a digital twin implementation in industry

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Abstract

In the context of Industry 4.0, the concept of the digital twin provides an approach, which supports companies by finding solutions for complex problems. Due to the novelty of the technology, companies face certain issues regarding the implementation, like the uncertainty of the arising costs. By introducing a methodology in this publication, an estimation approach for the costs of a digital twin implementation is expounded. Through the assessment of the actual digitization level of a company previous relevant achievements are considered in the cost estimation. Furthermore, the methodology is implemented in an Excel tool and validated within an industry use-case.

Keywords: Digital twin; Digital twin implementation; Cost estimation; Industry 4.0; Cyber physical system

1. Introduction

Today, manufacturing companies are challenged on the one hand with a stronger responsibility towards the environment and on the other hand with an intensified market competition [1,2]. Customers expect a transparent and efficient use of natural resources and at the same time the demand for individual products is increasing [3,4]. In addition, companies must optimise their business processes due to increased price pressure to raise cost efficiency [5].
In order to address these challenges and the increasing complexity, the use of new concepts and technologies can be considered. In particular, the concept of Industry 4.0, which describes the intelligent networking throughout the complete supply chain, represents a great potential for companies [6]. In this context, the digital twin (DT) is growing in importance. Especially because of advances in data acquisition, data processing technology as well as simulation, the DT can perform more functions [7]. In this work, the DT is defined as a combination of digital models for the virtual representation of the exact state of a real physical object at a certain point in time, which is created through the exchange of real-time data as well as through the storage of historical data [8–10]. Another central feature is the bidirectional data exchange between the virtual and physical world [11]. The use of a DT creates a comprehensive collection of data about the physical twin, which can be used to optimise it and predict its performance [12,13]. Furthermore, the status of the physical image can be tracked over its lifetime with a DT. [14].
In addition to the benefits described above, the use of a DT incurs costs for its implementation and use. Since it is essential for companies to keep an eye on their costs, the costs of new investments should be estimated. There are several approaches in the literature to estimate the costs of IT applications. However, these approaches are very general and do not focus on the use of a DT. As the digitization level varies from company to company, this should be included in the estimation in order to get a more accurate idea of the costs incurred. Within this work, the current digitization level of a company is explicitly considered in the approach presented for estimating the costs of a DT.
This paper will first briefly discuss related work in this research field. Afterwards the cost drivers are identified by using a requirements analysis based on the characteristics of the DT to

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be introduced. Section 4 describes the cost estimation approach. Following this, the results of an industrial use-case are shown in section 5. Finally, limitations and a short outlook on further research topics will be presented in the conclusion.

2. Related work

Within this chapter related work in relation to cost estimation for DT implementation will be shortly analyzed. Therefore, three key areas are regarded independently to eventually point out the research gap and the relevance of this work.

Applications of DT. At first, different application areas for DT are identified and assigned to phases of the product life cycle (PLC). Selected applications are listed in table 1. While in the design stage mostly product-related DT applications are identified, the focus area of the DT in the production stage is limited to the production itself. The DT application of predictive maintenance as an example of the usage and service stage can be part of a product as well as a production DT and is therefore not exclusively limited to this stage of the PLC.

Table 1. Applications of DT along the PLC.

PLC stage	DT applications	Authors	Focus of DT
Design stage	Virtual verification	[15,16]	Product
	Feedback-to-design	[12,13]	Product
Production stage	Production control	[17]	Production
	Real-time monitoring	[18,19]	Production
Usage and service stage	Predictive maintenance	[20,21]	Production / Product

Generally, a high amount of DT applications in manufacturing industry can be identified while the focus of DT can be limited to a product or a production environment. The insufficient consideration and clarification of requirements in the literature for each application needs to be highlighted.

Maturity models for state of digitalization identification. In the context of Industry 4.0, maturity models help companies in identifying the status quo and consequently point out needs for action [22]. In literature numerous maturity models in the shape of questionnaires provide a holistic view of the company's maturity such as in [23–26]. In these models a maturity score for the company results from evaluating different dimensions like technology, organization, or strategy. All these maturity models have in common that they lack in focusing on DT-specific requirements. The maturity model of [27] specifically focuses on the maturity of a DT by allocating the functionalities of the DT to different levels. However, the model supposes an already existing DT and is therefore not suitable for identifying the current state of digitalization for implementing a DT.

Cost estimation approaches for digitalization projects. In literature there exist different cost estimation approaches that can be grouped in general approaches [28], model-based approaches [29,30], and application-oriented approaches [31,32]. Especially the total cost of ownership (TCO) approach which deals with the holistic identification of all costs incurring within an IT project was identified as potential basis for this work.

Research gap. The literature review on the three areas mentioned above illustrates the relevance of this work. On the one hand DT applications need to be clustered to reduce the complexity and on the other hand the corresponding requirements of the applications must be derived. Furthermore, currently no cost estimation approach for DT implementation could be identified that considers the current state of digitalization of a company within the estimation.

3. Requirements analysis for cost identification

This chapter deals with the identification of requirements for a DT as well as the resulting IT infrastructure and the corresponding cost factors for the DT implementation in industry. Figure 2 shows the analyzing process based on the identification of DT applications (cf. chapter 2) to the associated costs for DT implementation.

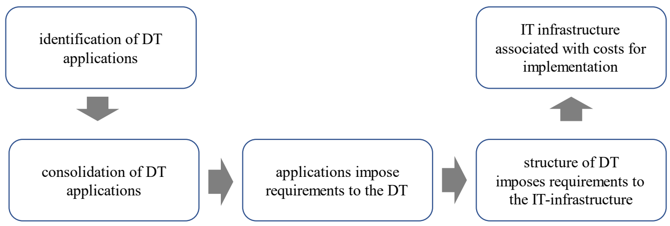

Fig. 2. Analysis process for cost identification.

Consolidation of DT applications. As there exist numerous applications for a DT along the PLC, a consolidation of the applications is required to reduce complexity and to provide a comprehensive requirements analysis. In a first step a differentiation between a production and product perspective has been made (cf. chapter 2). In this regard, the DT is considered as a system generating output or supporting in adding value in the production perspective while in the product perspective a generated system is focused. The main differences between the perspectives are listed in Table 2.

Table 2. Differentiation between production and product perspective.

Characteristic	Production	Product
Environment	Production environment within a company	Not restricted to production and especially across company borders
PLC stages	Production stage focused	Design stage and usage / service stage focused
Data exchange	By connecting production resources with internal IT systems	By external IT systems and via internet/cellular
Data usage	Internal use of data for process improvements	Product improvements via downstream data analysis
Control loop	Control of production resources directly via data analysis and models	Control of products indirect through design or service process

Regarding the cost estimation methodology (cf. chapter 4) a further differentiation within both perspectives has been made in a next step to better represent distinct fields of application within both perspectives of consideration. The production perspective is therefore differentiated between fields of DT application in *production planning and control* as well as *product manufacturing.* Furthermore, the product perspective is divided in fields of DT application considering *optimization of a product (fleet)* and *realization of a business model*.

The differences in data exchange and usage as well as the different focused PLC stages of the perspectives lead to separated requirements. Hereinafter, the production perspective is exemplary considered.

Requirements to DT. The next step of the analyzing process covers the requirements to a DT which is regarded as the general required technical necessities in establishing a DT. Therefore, the requirements are divided into sections. While in literature requirements to DT are not consistently classified in this work the following sections are proposed [18,33,10,34,35]:

- Physical system: Requirements to the hardware of the DT
- Data management and communication: Requirements regarding relevant data and data handling
- Virtual model: Requirements for the digital representation of the physical system (models and simulations)
- Services: Requirements to services for users of the DT

In figure 3 the main requirements to DT regarding the production perspective are summarized and allocated to the above-mentioned sections.

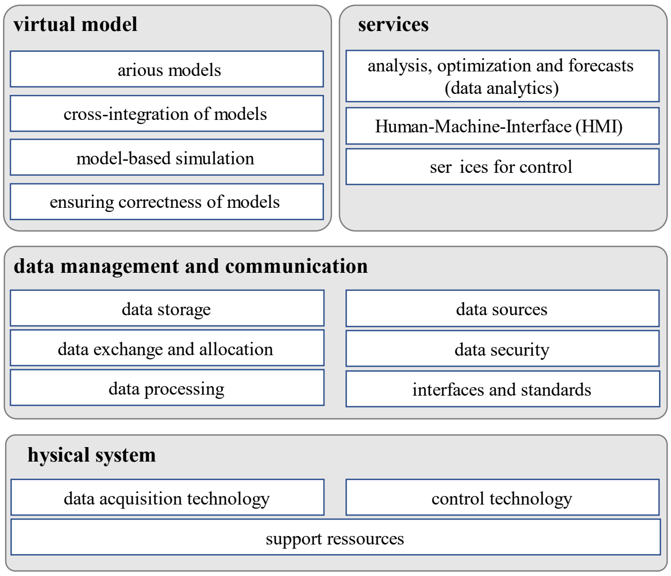

Fig. 3. Allocation of requirements to DT.

Requirements to IT infrastructure. The requirements to a DT result in requirements to the corresponding IT infrastructure of a company. In this regard, IT infrastructure is considered as the necessities for implementing and using the DT technology. Within the IT infrastructure all relevant hardware and software components as well as further institutional or personnel properties for implementing the DT are considered. In particular, the institutional and personnel characteristics are considered as requirements that are not completely attributable to hardware or software. The derived components as part of the IT infrastructure to the corresponding sections of the requirements to DT are shown in figure 4. Here, the corresponding IT infrastructure is derived from the requirements mentioned before. Again, the requirements to the IT are related to the production perspective.

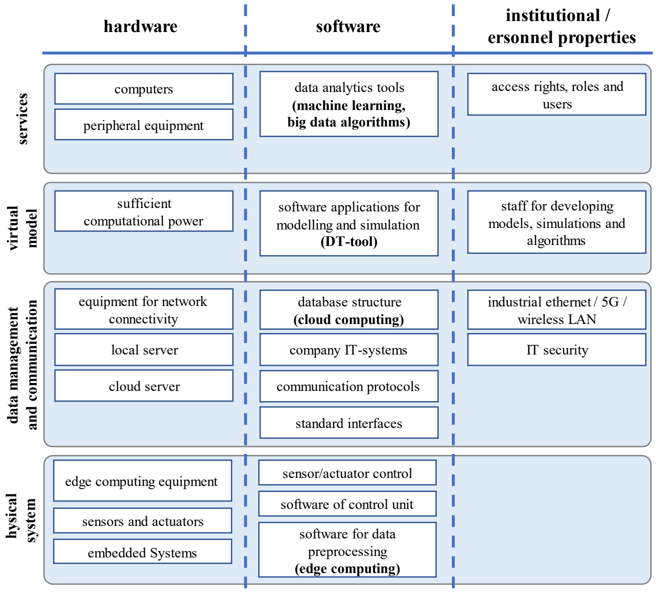

Fig. 4. Allocation of requirements to IT infrastructure.

To provide a better understanding of the dependences short examples will be given. As part of the requirements to the DT data acquisition technology is necessary for receiving relevant information of the physical system [36]. Consequently, the IT infrastructure needs hardware and software to enable data collection from the physical system. Therefore, sensors are required to generate data and for example embedded systems are necessary to process the data. Equally, there is software required on the one hand to allow sensors to work reliably and on the other hand to further process the received data. Another example in the section of the virtual model is the requirement of various models for the virtual representation of the physical system. As a result, the corresponding IT infrastructure must enable the processing of the models work depending on the DT application (real-time or near real-time) and therefore requires sufficient computational power as hardware requirement. Modelling and simulation requires specific software applications such as CAD software or FEM simulation software [18,37,34]. The specific modelling and simulation tools are highly depending on the application of the DT. A special DT-tool in the shape of an IoT platform that combines multiple software tools as one software component of the IT infrastructure can be used. Furthermore, the relevant staff for developing all relevant models, simulations or algorithms is one requirement of the institutional or personnel properties of the IT infrastructure.

Costs for DT implementation. The last step of the analysis process deals with the corresponding costs associated to the implementation of the required IT infrastructure. Although the individual costs highly depend on the use-case of a company, superior cost types for the cost estimation of a DT implementation in industry can be derived. In figure 5 the superior cost types and their subordinate cost types (cost specificities) are shown. To maintain a manageable amount of cost types for the cost estimation not all costs will be further considered (cf. chapter 5).

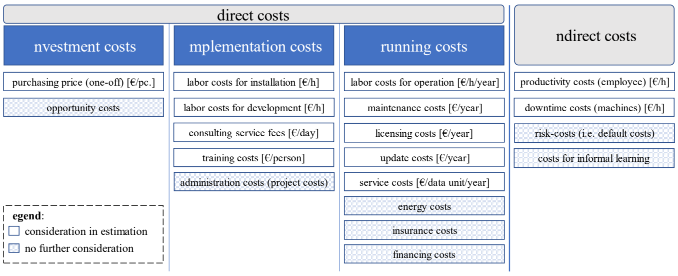

Fig. 5. Identified cost types for DT implementation.

According to the TCO the cost types can be divided into direct and indirect costs (cf. chapter 2). While direct costs are explicitly assignable to the acquisition or the use of a specific component, indirect costs are not immediately quantifiable and assignable to a specific component [28]. The direct costs can be further divided into investment and implementation costs both considered as one-off costs and running costs that are repeatedly accruing throughout the time horizon of the DT. In this work investment costs are only considered for the purchasing of DT components. Implementation costs are mainly focusing on labor costs for installation or development as well as training costs whereas consulting fees are considered as external labor costs for specific implementation scopes [38]. Running costs are subdivided in operating labor costs for staff as well as maintenance costs for hardware. Licensing costs and update costs are regarded for software. Service costs might accrue for services like renting cloud storage as infrastructure-as-a-service (IAAS) [38].
Reduced productivity of employees due to new IT implementations or downtimes of machines due to hardware implementations can be regarded as indirect costs.

This chapter served as an upstream step and a significant basis for the development of the cost estimation methodology which will be presented in the next chapter.

4. Cost estimation methodology

In this chapter the cost estimation approach will be described. The goal of the methodology is to provide a cost estimation for a DT implementation in industry considering the current state of digitalization of a company. Especially previous digitalization achievements like already existing IT systems or hardware components influence the costs significantly (cf. chapter 1). In the end, the cost estimation supports in identifying cost drivers of an early project stage.

Assumptions and prerequisites. The methodology is based on several assumptions that are required to delimitate the scope of the cost estimation. Especially before a practical usage of the cost estimation within a company the below listed assumptions and prerequisites must be considered:

- Currently no DT exists for regarded DT application area
- Companies are aware of regarded DT application and its potential benefits
- DT implementation takes place within a first pilot project so advanced DT applications like system-of-systems are not focused
- Required management attention and resources for the DT project assumed to disregard the risk of project failure
- Process modifications or new and improved processes are not considered within the cost estimation
- Not every DT application and industrial sector is sufficiently covered by the methodology as the industrial sector of manufacturing is focused

Development of check lists for conducting the status quo. As mentioned before, the identification of the current state of digitalization is key to provide a reliable cost estimation. To conduct the status quo of a company, check lists are developed for every perspective of consideration (cf. chapter 3). Every check list is structured in specific questions and predefined answer options. Each question focuses on the components of the IT infrastructure required for the DT implementation (cf. chapter 3) while the predefined answers imply a certain level of digitalization. In contrast to maturity models mentioned in chapter 2 which determine a certain maturity level, the check list's goal is to cover the requirements within the questions and answers, and at the same time bridging the level of requirement fulfilment with a factor in context to the resulting costs. The causality between the check lists and the requirements (components of IT infrastructure) with the relevant costs are shown in figure 6.

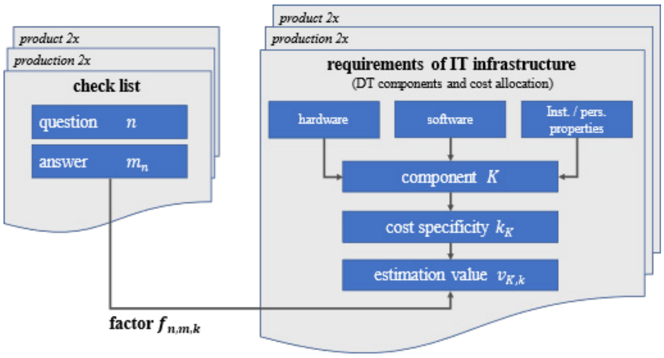

Fig. 6. Relationship between check lists and requirements of IT infrastructure.

Every component K of the IT infrastructure is linked to one or more cost types and its specificities (cf. chapter 3). Every cost specificity k_K is again linked to an estimation value $v_{K,k}$ that is required for the cost estimation. The key characteristic of the methodology is the linkage between a check list and the components of the IT infrastructure through factor $f_{n,m,k}$. On the one hand this factor reflects the state of digitalization through the answer m_n regarding the corresponding question n of the check list targeting a specific component of the DT and on the other hand the factor reflects the influence on the estimation value and the resulting costs of the specific component. Depending on the implied digitalization level of the answer the factor differs and can reach a value between 0 and 1. It becomes 1 if the answer implies no previous digitalization achievements so the corresponding costs will accrue completely. If the answer implies that the existing digitalization level fully covers the requirement then the factor becomes 0 so the estimation value will not be considered in the estimation. Furthermore, values above 1 can be possible in terms of a penalty due to a lack of an existing digitalization basis.

Structure of the cost estimation and calculation scheme. While the check lists and its relationship to the DT components build the key aspect of the methodology, further steps are required for the cost estimation. The structure of the cost estimation is represented in figure 7. As displayed in the illustration one further aspect of the methodology are parameters for each application area that are required for an increasing estimation accuracy. Especially use-case dependent values such as time horizon, number of regarded production resources or for example the number of users significantly impact the resulting costs of the DT implementation in a company.

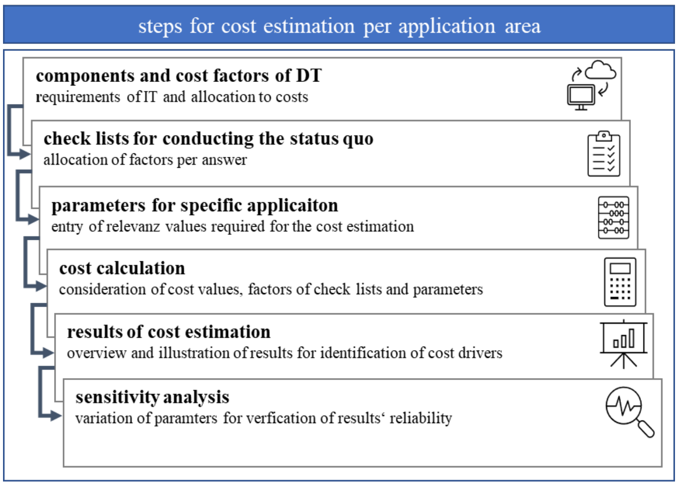

Fig. 7. Structure of the cost estimation methodology.

Based on the cost values of each DT component, factors of the check lists and the parameters the cost estimation can be executed, and the costs calculated. The underlying calculation scheme is illustrated in figure 8. In addition to figure 6 parameters p_i (with i as control variable) and potential conversion factors $u_{p,k}$ like transformation of monthly to yearly values affect the estimation value.

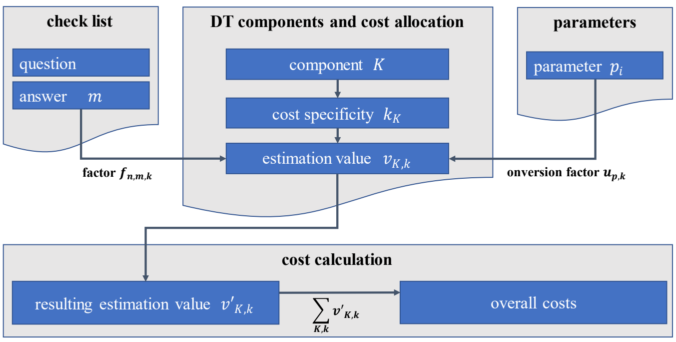

Fig. 8. Calculation scheme of the cost estimation.

The resulting estimation value $v'_{K,k}$ is calculated for every DT component based on:

$$v'_{K,k} = v_{K,k} \times \prod_n f_{n,m,k} \times \prod_i p_i \times u_{p,k} \quad \forall\, K,k \qquad (1)$$

The overall costs for the DT implementation can be calculated by summing up all resulting estimation values. In this regard the time horizon especially for running costs as well as a possible discounting of future costs need to be considered. These circumstances are disregarded in figure 8. As further steps in the methodology the results of the estimation can be displayed, and a possible sensitivity analysis can be conducted to verify the reliability of the results by varying one or more individual parameters.

The methodology is implemented in an Excel-based user tool for practical assignment.

5. Industry use-case

The proposed cost estimation methodology was tested and validated within an industry use-case in cooperation with the company EOS GmbH a leading manufacturer for additive manufacturing systems. The use-case deals with the implementation of a DT as virtual representation of the material flow of the production system. Therefore, value-adding as well as non-value-adding machines and processes are considered for the DT application. With the help of the cost estimation methodology in the shape of the Excel-based user tool the cost drivers for the DT implementation have been identified. The results of the cost estimation are displayed in figure 9. There, running costs have been identified as the main cost driver and in particular the licensing costs. In this regard, the time horizon was defined for five years.

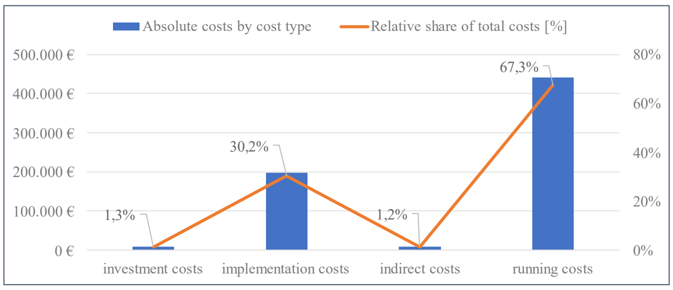

Fig. 9. Cost estimation results of industry use-case.

As the state of digitalization of the company implied by the check list was already on a high level, the costs for investment as well as the indirect costs are marginal. Especially required new software tools and data exchange standards are regarded within the implementation costs.
The costs for the DT implementation have been assumed to be plausible and could be validated in alignment with currently occurring costs. The cost estimation methodology has been proven to be an easy-to-use approach to estimate the costs of a DT implementation within a very early project state.

6. Conclusion and outlook

In this paper, an approach for estimating the costs arising from the implementation of a DT was introduced. The methodology explicitly considers the current digitization level of companies through checklists when estimating the costs. This reduces the uncertainty of companies about the costs resulting from the implementation of a DT.

Due to the modular structure of the methodology, further cost drivers can be added for specific application fields and thus the result of the estimate can be made more precisely. As a restriction, the methodology has only been validated on one use case. For further validation, additional use cases in companies from different application fields are necessary. In the requirements analysis, the complexity was reduced by bundling the areas of application. As not every possible type of DT can be applied to the method, an adaptation of the approach is necessary. Especially through further integration of different fields of application other types of DTs can be regarded.

Finally, it is important to mention that not only the costs are decisive for the success and implementation of a DT in a company. In addition to considering the costs, it is essential to precisely determine the resulting benefits and the technical requirements in order to develop the full potential of a DT. By exploiting this potential, manufacturing companies can meet the current challenges and the increasing complexity.

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