Digital Twins for Internal Transport Systems: Use Cases, Functions, and System Architecture

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Abstract

Internal transport systems are an essential part of intralogistics in production and distribution facilities. These are characterized by a variety of technologies as well as a multitude of interactions with other processes, such as warehouse, picking, and production processes. Therefore, resource planning and control of these systems is complex, especially for discontinuous conveyors. In this task, users can be supported by Digital Twins for decision-making, as they are suitable for investigating both future system states and possible actions. However, relevant use cases that are generally applicable across sectors as well as a generic system architecture for Digital Twins for resource planning and process control of in-plant transport systems have not yet been sufficiently investigated. In this paper, use cases are presented, relevant functions defined, and, finally, a generic functional and a logical reference architecture described. This is conducted with the design science in information systems research method together with a Systems Engineering approach. The use cases are determined at industrial partners of the research project TwInTraSys, which explores Digital Twins for the planning and control of internal transport systems. They are generalized and, thus, also applicable to other production and distribution facilities in different sectors. Further, the reference architecture can provide a basis for the successful implementation of the Digital Twin.

Keywords: Digital Twin, Internal Transport Systems, Intralogistics, Use Cases, System Architecture

1. Introduction

In the context of intralogistics in production and distribution facilities, in-plant transport systems are an integral component. They are used to realize material flow, meaning the execution of internal transport tasks. Fottner et al. categorize these systems by five components: the transport unit, the means of transport, the path network, the transport process, and the transport control. Transport units are composed of the transported goods and the transport equipment. The means of transport, e.g. forklifts or tugger trains, perform the actual transport and move on a defined path network. The transport process describes the individual steps needed to conduct the transport task, which is controlled by the Transport Control System (TCS) (Fottner et al., 2022).

Internal transport systems are subject to a high degree of complexity due to manifold interactions, interdependencies and highly dynamic behavior (Fottner et al., 2022). On the one hand, this is due to different alternative means and routes of transport. On the other hand, dependencies are present, particularly in the case of multi-stage processes. Therefore, these must be well coordinated in order to meet defined delivery times while taking the utilization of resources into account. The planning and control of these systems is therefore challenging. For instance, personnel planning for manually operated means of transports, such as tugger trains and forklifts, depends on the number of transports, which varies due to daily fluctuations in the order load. This is complicated by differing distributions of transports within the system as well as an insufficient data basis in IT systems.

Usually, personnel planning is based on the experience of the employees. However, this is challenging in the circumstances described. The consequence can be, for instance, excessive resource utilization, which can affect delivery reliability. Particularly during peak loads, the timely execution of transport tasks cannot be ensured.

Against the background of the complexity outlined, various possible actions and system states must be investigated. In principle, simulation-based investigations are suitable for this purpose (Agalianos et al., 2020). However, resource planning and process control can require frequent examinations, e.g. for the coordination of employees to specific areas. For this

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purpose, knowledge about the future system behavior is necessary. On the one hand, the data basis must be generated, while on the other hand, the real system must be synchronized with the virtual one. The use of Digital Twins represents a possible way to support decision-making, as they meet the described prerequisites and can investigate suitable solutions according to predefined criteria (Agalianos et al., 2020; Kauke et al., 2021). The implementation is favored in particular by the relatively high degree of automation (Mühlbauer et al., 2022).

In the increasingly complex environment of production and logistics, the use of Digital Twins is widely being researched (Kaiblinger & Woschank, 2022). Due to different applications, many definitions exist, yet they share commonalities (Zuhr et al., 2021). The International Organization for Standardization (ISO) made a recent effort in standardizing the term within the field of manufacturing. A Digital Twin is defined as a "fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation" (ISO, 2021a). An observable manufacturing element (OME) covers physical items as well as operations in production. This includes all relevant system elements, such as personnel, material, processes and equipment that are present in internal transport systems.

In the research works reviewed, the use cases and system architectures are not generally applicable to Digital Twins for planning and control of internal transport systems. However, a reference architecture supports and simplifies implementation (ISO, 2021b). In addition, this can also lead to standardization of the interfaces to other systems, e.g. Enterprise-Resource-Planning (ERP)-Systems or TCS. Therefore, the following research questions are defined and addressed within the scope of this paper.

- Which use cases for Digital Twins for resource planning and process control of internal transport systems can be defined that are generally applicable across sectors?
- Which standard functions of Digital Twins are required for resource planning and process control of internal transport systems?
- How does a logical reference architecture for Digital Twins for resource planning and process control of internal transport systems look like that can be applied across sectors?

This paper is structured as follows. First, related work that is relevant in the context of Digital Twins for in-plant transport systems, system architecture, and standards is described. Subsequently, the research methodology is explained. Then, use cases and requirements as well as the functional and logical system architecture are described. The application of the reference architecture for the creation of specific product architectures as well as the evaluation are presented next. Finally, the conclusions and contribution of the paper are summarized.

2. Related work

Coelho et al. categorize Digital Twins for applications in the field of intralogistics through a literature review in virtual models, objectives, and application areas. Furthermore, they describe a Digital Twin for distribution and production systems. The system architecture defines a virtual system, consisting of two models, a service system and a decision support system as well as a physical system. The virtual system is implemented with a simulation model. Based on existing orders, the next 24 hours are simulated and key performance indicators are determined that are suitable for decision-making (Coelho et al., 2021). Given the generic nature of the virtual model, it is not evident to what extent use cases for planning and control of internal transport systems can be implemented. Additionally, the common representation of the structure and the workflow in the same diagram can complicate the implementation.

Kosacka-Olejnik et al. conducted a literature review to investigate to what extent Digital Twins are suitable for internal transport systems. In this context, they identified future research needs. Among other things, the data basis in relation to existing real-time IT systems has to be analyzed. Moreover, it has to be defined how Discrete Event Simulation (DES) can be a core component of Digital Twins. Approaches to seamless integration of emulation and simulation constitute another research gap (Kosacka-Olejnik et al., 2021). Although the authors identified a possible trend to investigate Digital Twins for process optimization, they state that these are developed to optimize physical objects.

Korth et al. describe a concept for simulation-based Digital Twins for logistics systems. The architecture consists of an event controller, a model, a simulation component, a reporting element, and data storages for events and states of the Digital Twin. The concept is applied to personnel planning in the context of a warehouse on the one hand and to production planning in a metal processing plant on the other hand. The Digital Twin provides decision support for the user. They can adjust existing time slots and shift schedules based on experience until a satisfactory result is obtained (Korth et al., 2018). The system architecture description is generic in order to be applicable to different use cases. However, it is not apparent in detail how the digital model can be implemented. Furthermore, as the data basis of the Digital Twin is known transport orders, it can only perform personnel scheduling for the same period. This may not be sufficient if the required planning horizon is longer than the time frame for existing orders. In this case, missing transport orders must be generated or forecast to establish the data basis. Moreover, the investigation of possible solutions is based on manual user input. Due to the large scope of action, it cannot be ensured that a suitable solution is found.

Kaiblinger and Woschank review the state-of-the-art of Digital Twins in production logistics. The authors categorize the papers by their fulfillment of Digital Twin criteria, areas of application, type of virtual model, and objective. It should be pointed out that 45 % of the reviewed papers use DES as a representation of the physical entity. The objectives are in particular machine monitoring, production scheduling, Automated Guided Vehicle (AGV) control and overall equipment efficiency (Kaiblinger & Woschank, 2022). However, these mainly concern physical elements or serve short-term control purposes.

ISO 23247-1 defines the concept “Digital Twin” and relevant terms in the context of manufacturing. In addition, real-time control, off-line analytics, predictive maintenance, health check, engineering design, and production control as well as video surveillance are stated as possible applications. Moreover, benefits, such as in-loop planning and validation, as well as production scheduling assurance and process traceability, are outlined. In addition, requirements for the implementation of such systems are listed (ISO, 2021b). Furthermore, ISO 23247-2 defines a reference architecture for Digital Twins for manufacturing. Systems and sub-systems as well as functional entities for every (sub-)entity are defined (ISO, 2021b). However, on the one hand, it is not shown how these are connected and must work in a process to generate a solution. On the other hand, no logical elements are presented, which can complicate the elaboration of a specific system architecture.

Kauke et al. describe a system architecture for simulation-based Digital Twins in order picking systems. This consists of several services for data management, data generation, DES as well as analysis of the results and condition monitoring. Further, a service for the automatic adaptation of the simulation model parameters is implemented. This is based on evaluations from real data (Kauke et al., 2021). It should be emphasized that algorithms for data prediction are integrated, which are essential for investigating the future state of the system. However, functions, logical elements, and specific products are represented together in the system architecture, which can complicate implementation.

In summary, there is a need for research on the use of Digital Twins for internal transport systems. In the literature reviewed, use cases required for resource planning and process control, ranging from planning personnel for several days in advance, to scheduling and short-term sequencing of transport tasks, are not sufficiently described. On the other hand, system architectures are not adequately elaborated and clearly described. In the works examined, the architectures functions, system elements, and processes are often mixed, leaving room for interpretation. Moreover, requirements on which the system architecture is based are not sufficiently described.

3. Digital Twins for internal transport systems

In this section, the research methodology is described first. Then, the identified and consequently generalized use cases as well as the requirements are presented. Subsequently, necessary standard functions are determined and illustrated in a functional architecture. Finally, a generic logical architecture is shown, which extends the functional architecture and depicts required system elements.

3.1. Research methodology

Digital Twins can be assigned to information systems that are used in companies to increase efficiency and effectiveness. Since generic artifacts are presented in this contribution, the Design Science in Information Systems research method according to Hevner (Hevner et al., 2004) is used. Due to the large number of elements and system-wide interactions as well as dynamic behaviors, internal transport systems are complex systems. Systems Engineering (SE) has become established for the design of such systems and provides general procedures, described for example in ISO 15288 (ISO, 2015). Therefore, the creation of the artifacts is conducted with SE methods. The research method along with the SE approach is presented in Figure 1.

The use cases and requirements were elaborated at three companies as part of a research project investigating Digital Twins for the planning and control of internal transport systems. First, the production plant of a component and system manufacturer, that realizes the material flow with AGVs and forklifts, was examined. Secondly, two distribution centers of a food manufacturer were included, which carries out transport tasks with forklifts. A software company that develops TCS

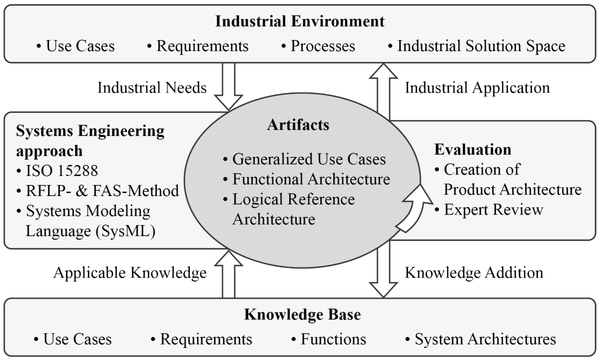

Figure 1. Research methodology based on the Information Systems Research Framework (Hevner et al., 2004) and a Systems Engineering approach

in particular for forklifts, tugger trains, and AGVs was included on the basis of the process expertise in production and distribution facilities in order to ensure broader applicability. Finally, a software provider for simulation services contributed to the review process with semi-structured expert interviews.

In the first step, the transport processes were analyzed, the problem area defined and optimization opportunities identified by a series of workshops. The use cases of all industrial project partners were examined for commonalities and aggregated. The solution space for resource planning and control was then generalized in order to be applicable across sectors. In addition, this was verified through semi-structured expert interviews with logistics process experts and decision makers, as well as literature study in order to ensure a broad level of industrial relevance.

Subsequently, requirements are identified in accordance with ISO 23247-1 (ISO, 2021a) in order to define standard functions as well as a generic functional architecture. Then, a logical reference architecture is derived from the functions. Last, the applicability of the system architecture was evaluated with the creation of specific product architectures and semi-structured expert interviews with software development experts. This procedure corresponds to the Requirements, Functional-, Logical-, and Product-Architecture (RFLP) method.

The visualization of the use cases as well as system architectures is realized in a model-based manner using the *lingua franca* Systems Modeling Language (SysML). Therefore, the implementation of this complex system is supported (Wolny et al., 2020).

3.2. Solution space

The use cases identified relate to various tasks in planning and process control of internal transport systems. In order to be generally applicable to a common solution space, they must be generalized and summarized. One possibility for this is to consider the steps of production planning and control. Medium to short term activities include the capacity planning, order release as well as sequence planning (Kiran, 2019). These are transferred to the planning and control of transport systems and shown in Figure 2 with a SysML use case diagram. Each use case of the Digital Twin is uniquely designated with the prefix *UC* and a sequential number.

Planning transport capacities for manually operated means of transport (*UC1*) is a core task. Due to corporate policies, personnel usually have to be informed about their duty schedule for several working days in advance. This not only represents a high planning effort if done manually, but is also difficult due to incomplete knowledge about the expected transport orders. The result may be either a workload for the personnel with insufficient resources to handle peak loads or, on the other hand, low utilization. To realize the use case, the Digital Twin can examine different numbers of personnel and the resulting workloads as well as effects on the system so that a recommended action can be generated.

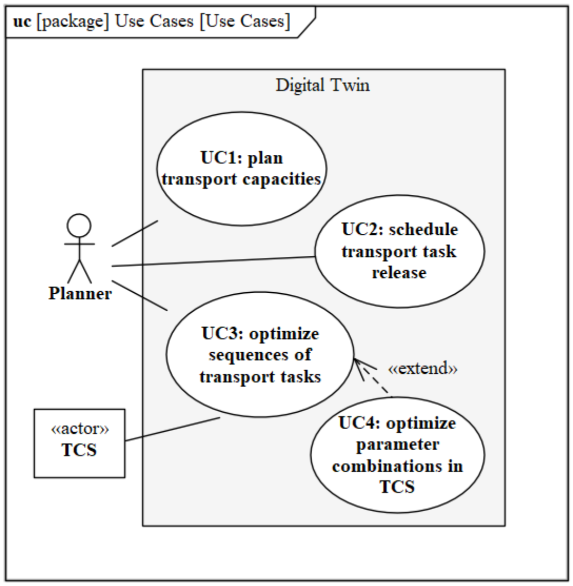

Figure 2. Use cases of Digital Twins for internal transport systems

Moreover, scheduling of transport task release by synchronizing internal transport processes is demanding due to the system dynamics and various influencing variables. If the lead times for stock transfer are chosen too long, intermediate buffers, for example, can be occupied too early, reaching capacity limits. On the other hand, adherence to delivery deadlines cannot be guaranteed if the lead times are too short. Therefore, Digital Twins can be used to plan and control task releases, e.g. with the investigation of different lead times, which constitutes *UC2*. This is especially promising when multiple process stages and work areas are involved, as manual planning is intricate.

The sequencing of transport tasks represents the last step before their operational execution. Digital Twins can be used to investigate suitable solutions (*UC3)*. In addition, they can be extended to optimize parameter combinations of TCS (*UC4*). This usually performs operational control of the transport tasks, including route planning or task assignment algorithms. In order to adapt the underlying algorithm to system-specific objectives, a multitude of parameters and their values, e.g. transport task priorities, can be varied. However, a manual adjustment of these is time-consuming and cannot guarantee a suitable solution. Digital Twins can simulate the real system and test the parameter values in various combinations in order to fulfill certain key performance indicators or targets.

3.3. Requirements

ISO 23247-1 defines requirements for Digital Twins in the context of manufacturing (ISO, 2021a). These relate, among other aspects, to the connection with its OME and the processing of its data. In transport systems, however, the data of the means of transport as well as order information are stored in IT systems. For example, the TCS controls the execution of transport tasks, which enables central data access. Other relevant data, such as production orders and bill of materials, are available in ERP Systems. Data required for robustness investigations, e.g. production equipment downtimes, can be accessed from Manufacturing Execution Systems (MES). Therefore, the Digital Twin shall process data from IT systems.

Table 1 lists requirements of Digital Twins based on the descriptions in ISO 23247-1 (ISO, 2021a). These are adapted for application to transport systems and thus represent an extension of the standard.

3.4. Functional system architecture

The Digital Twin must have specific functions in order to fulfill the use cases described. Based on requirements presented in section 3.3 and functional entities defined in ISO 23247-2 (ISO, 2021b), necessary functions of the Digital Twin are elaborated. These are used to determine a functional architecture, as shown in Figure 3. The architecture is modeled using the Functional Architecture Modeling for Systems (FAS) method (Lamm & Weilkiens, 2014) and its extended description presented in (Weilkiens et al., 2016). The blocks are connected with so called proxy ports, which are used to define interfaces. These have flow properties to represent the type and direction of the transmitted data. The latter is evident from the direction of the arrow.

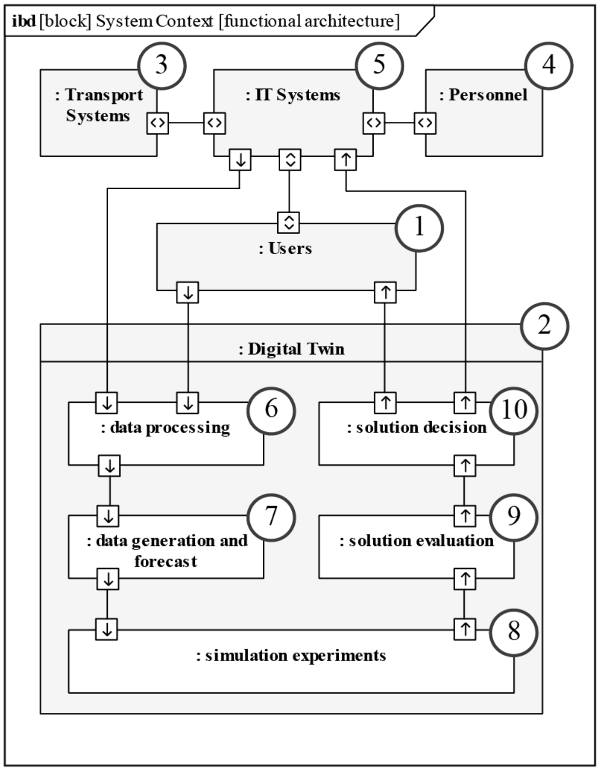

Figure 3. Functional architecture of the Digital Twin

The functional architecture of the Digital Twin, the system-of-interest, is presented in the context of the operating system. *Users* (1) interact with the *Digital Twin* (2) and are the decision makers. *Transport systems* (3) and *personnel* (4) perform the operational tasks and generate data that is stored in *IT systems* (5). The elements of the Digital Twin shown are so-called functional elements and represent main functions. According to the convention of Lamm and Weilkiens, these are defined as nouns (Lamm & Weilkiens, n. d.). Sub-functions are derived from the main functions and described in more detail in the following.

The data basis determines to a large extent the accuracy of the solution. Therefore, special attention must be paid to the quality of the input data. Functions for *data processing* (6) include automatic data input from *IT systems* (5) and manual input from *users* (1), as well as preprocessing and data storing. Due to the large investigation period and depending on the application, not all data are already available in IT systems, but

Table 1. Requirements of the Digital Twin based on ISO 23247-1 (ISO, 2021a)

ID	name	description
REQ-1	Accuracy	The Digital Twin shall describe the state of the transport system and its corresponding OMEs at an appropriate level of fidelity.
REQ-2	Communication	The Digital Twin shall be connected to IT-systems using communication protocols that enable synchronization.
REQ-3	Data acquisition	The Digital Twin shall collect data from IT-systems.
REQ-4	Data analysis	The Digital Twin shall enable analysis of the state of the transport system and its OMEs.
REQ-5	Data integrity	The Digital Twin shall correctly describe the state of the transport system and its OMEs.
REQ-6	Extensibility	The Digital Twin shall be extensible to new use cases.
REQ-7	Granularity	The Digital Twin shall provide insight into the state of the transport system and its OME at appropriate levels of detail.
REQ-8	Identification	The Digital Twin shall contain data that uniquely selects the transport system and its OME.
REQ-9	Management	The Digital Twin shall enable optimization of the transport system.
REQ-10	Security	The Digital Twin shall only communicate with authorized resources.
REQ-11	Simulation	The Digital Twin shall enable simulation of the transport system and its OMEs in operation.
REQ-12	Synchronization	The Digital Twin and IT systems shall be updated to each other's informations using an appropriate method.
REQ-13	Viewpoint	The Digital Twin shall support different views for different objectives and users.

must be predicted. Therefore, a *data forecasting* (7) function must be implemented. For data that can be generated by calculations, for example, using a bill of material explosion, a *data generator* (7) function must be provided.

A solution shall be robust in the given context and against possible future scenarios. For example, personnel must be able to complete all orders on time even in the event of unexpected additional work or earlier truck arrival times. The authors propose the use of *simulation experiments* (8) along with decision theory. The former allows the study of a variety of different parameters, such as the type and number of required resources, and is particularly suitable for Digital Twins (Agalianos et al., 2020), while the latter allows to further evaluate the robustness of possible solutions (Laux et al., 2018). Fundamentally, the user must have functions to define the possible parameters as well as future scenarios that impact internal transport systems. These could include unexpected equipment shutdowns, faster execution or a larger number of production orders, all of which affect the required transport orders.

Following the *simulation experiments* (8), suitable solutions need to be evaluated. For this purpose, a *solution evaluation* (9) function must be implemented that can determine these automatically and on the basis of defined targets. The *solution decision* (10) is made according to the chosen decision criteria (Laux et al., 2018). For this purpose, a function for defining how risk-averse, risk-taking, optimistic or pessimistic the decision maker is, has to be implemented. The final execution of the solution is done by the user.

The accuracy of the calculations depends, among other things, on the fidelity of the digital representation. Therefore, functions for automatic adaptation have to be implemented. On the one hand, this includes updating parameters such as the velocities of the vehicles. On the other hand, algorithms or models for data prediction have to be updated. If machine learning models are used, thresholds have to be defined that trigger re-training processes. For reasons of clarity, this function is not shown in the diagram.

3.5. Logical reference architecture

The functional architecture defines solution-neutral functions that are stable regardless of the concrete realization. However, more precise technical concepts and behaviors are required for an implementation (Weilkiens et al., 2016). Therefore, a solution-oriented logical reference architecture of the Digital Twin is presented in Figure 4 with a SysML internal block diagram.

The elements of the logical architecture are categorized into the User Entity, Device Communication Entity and Digital Twin Entity according to the entity-based model defined in ISO 23247-2 (ISO, 2021b). The *User Entity* (1) includes the *IT-Systems* (2), the *Digital Twin Users* (3), and a *User Interface* (4). The

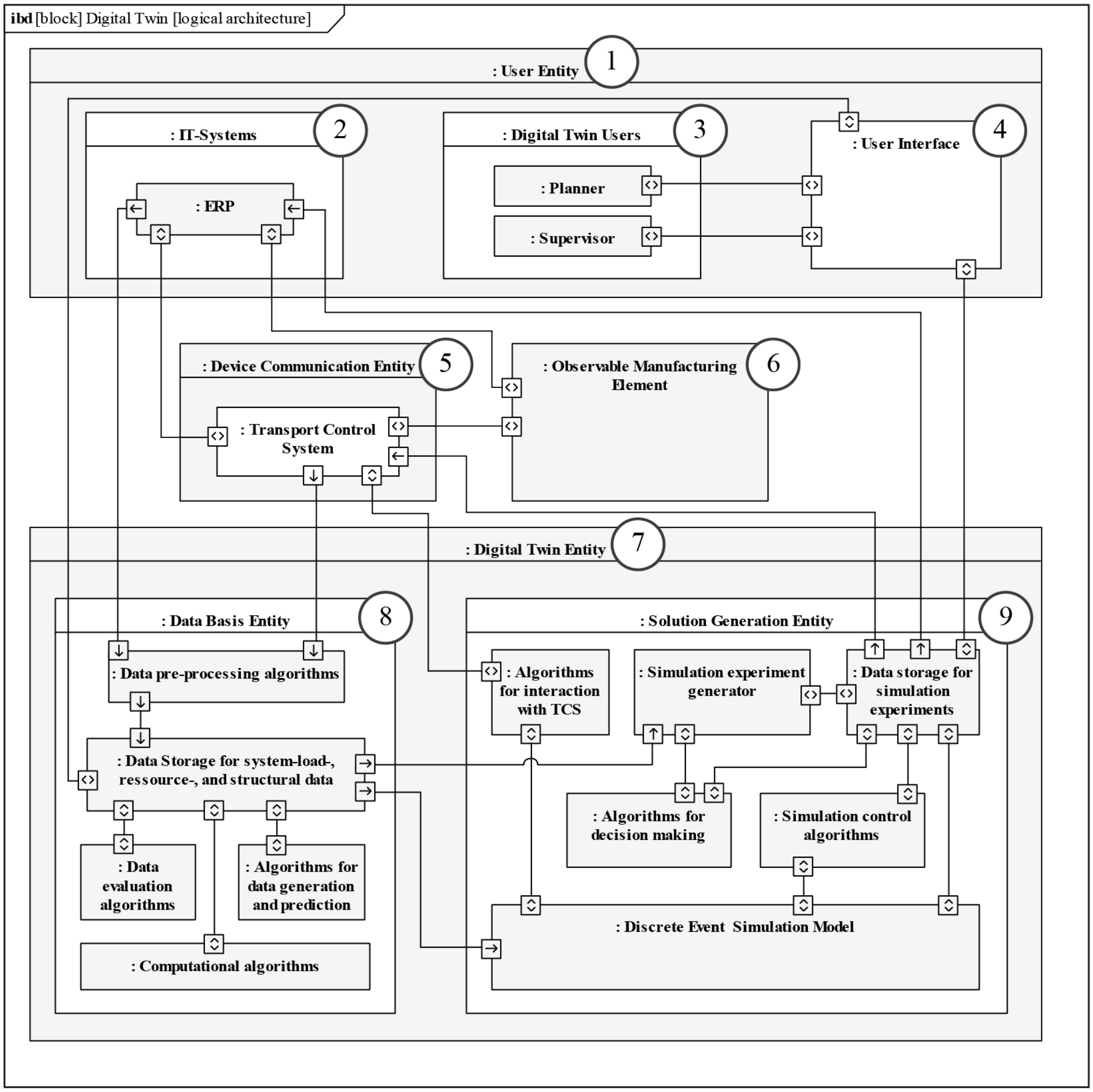

Figure 4. Logical reference architecture of the Digital Twin

Device Communication Entity (5) consists of the *TCS* together with the existing logics for data evaluation, communication, and control of the *OME* (6). These include equipment, material, transport processes, and personnel. The *Digital Twin Entity* (7) consists on the one hand of the *Data Basis Entity* (8) with elements that process input data for the simulation. On the other hand, the *Solution Generation Entity* (9) is included, which contains the *DES* as the core component of the Digital Twin. This requires algorithms that generate experiments and determine solutions.

At the beginning of an analysis, data is read in from the *IT Systems* (2), e.g. *ERP-systems* or *MES*, and the *TCS* (5), to the *Data Basis Entity* (8). For this purpose, interfaces must be implemented. The data is checked for completeness and correctness using *data preprocessing algorithms* and, if necessary, treated before it is mapped to the defined data model so that it can then be saved in the *data storage for system-load-, ressource-, and structural data*.

As described in section 3.4, the required data may not be complete. Therefore, *algorithms for data generation and prediction* are incorporated. For instance, it is possible to generate transport orders from existing production orders using a bill of material explosion with knowledge of the delivery units. Since production orders can require the material in individual deliveries over a longer period of time, the transport orders must be scheduled according to the expected processing time. Data that is not completely available must be forecast. This can include, for example, additional transports for empties or empty trips. Furthermore, production or consignment orders may have to be determined for the required time period. Algorithms that can derive forecasts from historical data are used for this objective. Machine learning models can be suitable for this purpose (Aamer et al., 2021). Compared to statistical algorithms, these offer extended possibilities for recognizing relationships and incorporating external information (Vandeput, 2021).

Further, *data evaluation algorithms* are necessary, which calculate relevant values from input data. These are for example transport durations, velocities of the means of transport or durations of machine downtimes. After the calculation, these are stored and are available for further processing. The data are necessary in particular for the continuous updating of the DES and thus enable to maintain the accuracy of the digital representation.

The *Solution Generation Entity* (9) is used to identify suitable solutions. To achieve this, a sole use of the DES is not sufficient. Rather, *computational algorithms* (8) are necessary, which provide important input data. This can be illustrated using *UC2* as an example. A computational algorithm, e.g. a heuristic, is used to generate suitable sequences for releasing transport tasks. These are then imported from the DES and are a basis to examine lead times with simulation runs.

In order to satisfy the requirements, the *Solution Generation Entity* (9) of the Digital Twin must recommend robust solutions. The authors propose a multi-step approach to determine a valid solution. First, the factor levels have to be defined. These are the parameters and their value ranges that can be varied during the simulation (Kleijnen et al., 2005). For instance, the use of different numbers of personnel or means of transport as well as shortcuts can be examined. This input is performed by the user, who has knowledge about the operational feasibility. Thus, only factor levels are examined, which can be actually realized. These are stored in the *data storage for simulation experiments*.

However, if all possible parameter combinations (full factorial design) are to be examined, many simulation experiments have to be performed. Algorithms for design of experiments (DOE) can be used for reducing the number of experiments (Kleijnen et al., 2005). Nevertheless, a substantial number of experiments may be present, which is coupled with a long simulation runtime. Therefore, the authors propose a pre-evaluation and narrowing of the factor levels. For this purpose, knowledge is needed that could be generated with appropriate machine learning models suitable for knowledge discovery from previously performed data farming analyses (Lechler et al., 2021). This information is used to select the most promising factor levels to be investigated. The applicability of machine learning models for a pre-evaluation of the factor levels will be investigated in further research.

Subsequently, simulation experiments can be generated by the *simulation experiment generator* using DOE. Simulation runs execute the experiment, also called design points (Kleijnen et al., 2005), and store the results for further processing. This requires a system architecture that enables automatic model generation and execution (Lechler et al., 2021). In order to use already existing logics of the TCS and to avoid to implement them in the simulation model, *algorithms for interaction with TCS* are included. The DES-model invokes these when required, for example for route planning, and then processes the output generated by the TCS. This approach is referred to as emulation because the digital representation of the system is connected to a real system component (Fottner et al., 2022).

Finally, *algorithms for decision-making* are provided that automatically evaluate the performed simulation runs against defined objectives and decide the solution based upon the chosen decision criteria.

4. Application and evaluation

In order to implement a Digital Twin, the creation of a specific product architecture from the logical reference architecture is necessary. On the one hand, this names all actual products, e.g. Python Script and SQLite Database. On the other hand, necessary interfaces between the system elements are defined. The logical reference architecture was applied within the *TwInTraSys* research project to design several product architectures, which were assessed in a trade-off analysis. A possible system architecture is shown in Figure 5. All necessary algorithms for processing system-load-, resource-, and structural data from *SAP EWM* (1) and the *TCS* (2) are incorporated in an *Application for Python Scripts* (3) and integrated into *SAP HANA* (4). The in-memory *HANA Database* (5) is used as the data storage. For the generation and execution of the simulation experiments, the approach of Genath et al. is integrated. The software

SimAssist (6) is used in combination with *SimController* (7), that controls multiple simulation instances of the DES-software *Plant Simulation* (8) (Genath et al., 2021). The simulation experiments and their detailed statistics are stored in two databases (9, 10) for reasons of performance. The *Digital Twin Users* (11) interact with *SimAssist* (6) for decision support. As a result, it was possible to apply the logical reference architecture to create a product-specific system architecture for implementing Digital Twins.

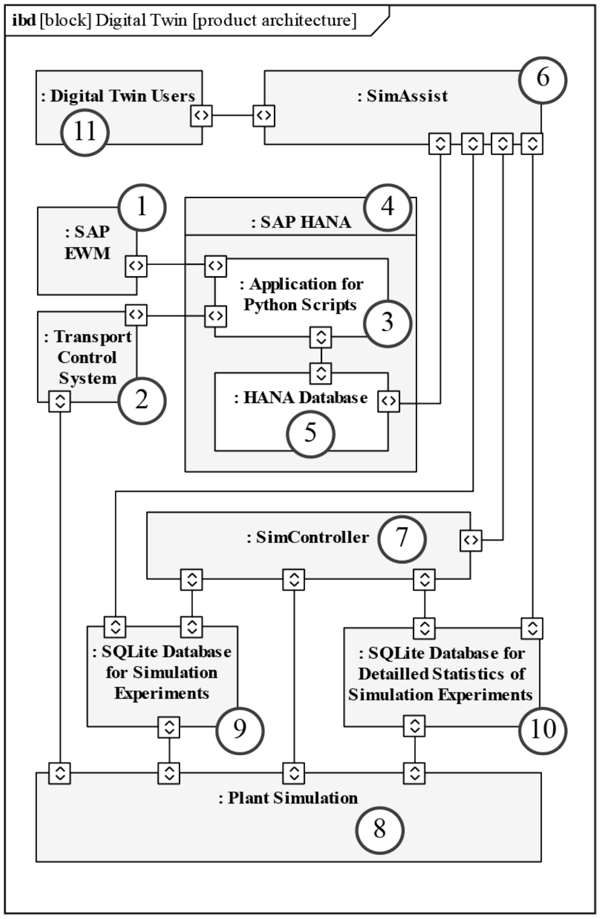

Figure 5. Product architecture of the TwInTraSys Digital Twin

The applicability of the reference architecture presented in this paper for the development of more specific product architectures and subsequently Digital Twins was evaluated in the course of successive semi-structured expert interviews. In particular, the depiction of the necessary data processing from different sources as well as the procedure for solution generation was found to be helpful. Nevertheless, further research is needed on the one hand to define the necessary data basis, as this varies due to different processes and existing data. On the other hand, the required level of detail of the simulation model must be investigated further. Moreover, the choice of a particular database for storing system-load-, resource-, and structural data was perceived as difficult because the frequency of queries and the size of data to be processed could not be generally defined. Digital Twins are currently being implemented in the *TwInTraSys* research project. An extensive evaluation of the reference architecture based on the actual implementation will follow.

5. Conclusions

Resource planning and process control of internal transport systems is challenging due to a multitude of influencing factors and dynamic system behaviors (Furmans & Kilger, 2019). Digital Twins are able to support users in decision-making by investigating solutions according to predefined criteria (Agalianos et al., 2020; Kauke et al., 2021).

In the reviewed papers, use cases have not been sufficiently addressed. This paper defines use cases of resource planning and process control of internal transport systems that are generally applicable across sectors. These are based on actual needs of industrial companies in the context of production and distribution facilities.

In this paper, standard functions of Digital Twins for resource planning and process control of internal transport systems are elaborated. In addition, a logical reference architecture is presented and can be suitable to fulfill the generic use cases. The applicability of the system architecture was evaluated with the creation of specific product architectures and semi-structured expert interviews in a first step. It must be validated in further work based on the application in different sectors.

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