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The Digital Twin: Demonstrating the potential of real time data acquisition in production systems

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Abstract

The acquisition of data and the development of different options in production system and factory planning requires up to 2/3rds of the total needed time resources. The digitization of production systems offers the possibility of automated data acquisition. Nevertheless, approaches concerning fully automated data acquisition systems are not widely spread among SME (small and medium sized enterprises). On the one hand, this is caused by the heterogeneous databases, on the other hand by insufficient data processing systems. Furthermore, the advantages of The Digital Twin are not sufficiently known due to the lack of competence in SME concerning matters of Industry 4.0. In order to transfer knowledge about the benefits of digitalization, the development of demonstrating platforms is crucial. This paper introduces a learning factory based concept to demonstrate the potentials and advantages of real time data acquisition and subsequent simulation based data processing. Therefore, an existing learning factory will be upgraded regarding both, multi-modal data acquisition technologies as well as a locally independent optimization environment. Thereby the requirements of SME concerning flexible, easy to use, scalable and service oriented digitization applications are met. The approach is part of a concept for the realization of a Cyber Physical Production System (CPPS) in SME that ensures the development of an image of the production with the aid of a multi-modal data acquisition.

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Keywords: Digital Twin; Industry 4.0; Process optimization

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1. Motivation

Industry 4.0, especially cross linking technologies in existing machinery is a dominating topic in production engineering. The digitization along the value chain proofs itself essential for the industrial future, e.g. to support flexibility, modularity and adaptability in automated assembly systems [1] (p. 5) [2]. To accomplish horizontal integration, i.e. between companies, of Industry 4.0, the vertical integration, i.e. within companies, in enterprises and therefore in the production system as the core of value creation itself has to be ensured [3] (p. 181). Nevertheless, methods of industry 4.0 are not widely implemented in manufacturing operations [4] (p. 7). Although topics concerning Industry 4.0, cyber-physical systems and self-optimizing manufacturing systems etc., are in the focus of most future projects in enterprises [5] (p. 8) [6] [7], the lack of specific knowledge is inhibiting the implementation of digitization technologies significantly in all grades of experience (Fig. 1) [5] (p. 57).

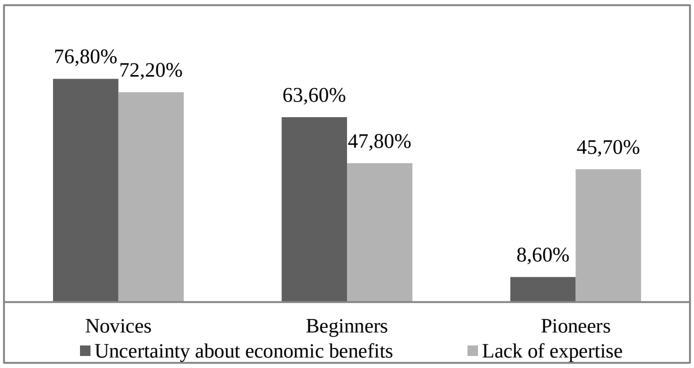

Figure 1: Reasons for inhibition of the realization of Industry 4.0 [5] (p. 57).

Therefore, professional and academic education is essential for the implementation and success of Industry 4.0 [8] (p. 214). In this context, demonstrators, e.g. in learning factories, are crucial to inform industrial users about the potential and efforts of implementing cross linking technologies and therefore Industry 4.0 [9] (p. 35). The paper presents a learning factory concept to demonstrate the benefits of a Digital Twin of the production system in comparison to the common approach of value stream mapping for enhancing transparency and revealing potentials for optimization measures in production systems. The concept addresses the need of enterprises to enhance transparency and the derivation of short-term production control as well as process optimization based on near-real time data [5] (p. 38) [8] (p. 90). Due to the fact of the great share of time for manual data acquisition and developing variants, which range from 41 % to 74 % (medium 58 %) of the overall time consumption [10] (p. 357), an approach for multimodal data acquisition in production systems is presented.

2. State of Scientific Knowledge

Besides definitions of learning factories, *Abele et al.* introduce six application scenarios for learning factories: Industrial and academic application, remote learning, changeability research, consultancy application and demonstration scenarios are differentiated to cover the varieties of existing learning factories [11]. The learning environment for the Digital Twin can be classified as a combination of academic application and demonstration scenario. Within existing learning factories in the field of production environment, the focus is set on teaching methods of lean production and lean logistics [12, 13, 14, 15, 16]. Additionally, numerous learning factories are addressing the topics of resource and energy efficiency [17, 18, 19].

Further projects mainly consider a wide range of production processes, e.g. product creation, assembly, manual assembly, robotic and additive manufacturing processes [20, 21, 22, 23].

In the course of rapidly developing information and communication technologies (ICT), resulting in the digitization of whole production systems, learning factories need to adapt and include promising technologies into their learning environments [24, 25]. In the project “Effiziente Fabrik 4.0” Abele et al. state that definition and implementation of Industry 4.0 use cases are important to drive digitization of small and medium sized enterprises [26] (p. 4, 42). They also conclude that new methods for real time localisation need to be developed [26] (p. 22).

The learning factories BIBA in Bremen and SmartFactoryKL in Kaiserslautern are part of this project according to *Abele et al.* [26] (p. 27, 32). Furthermore, knowledge transfer is realized in the learning factories of TU Darmstadt (CiP: center of industrial production and ETA: center for energy efficiency) as described by *Wank et al.* [27]. *Prinz et al*. are developing learning modules for Industry 4.0 at the LPS learning factory at Ruhr-Universität Bochum focussing on “assistance systems, decentralization & services, crosslinking & integration, data acquisition & processing and self-organization & autonomy” [28].

Kemeny et al. describe the “Smart Factory” for teaching principles of cyber-physical systems and Industry 4.0 in a simplified production environment at Fraunhofer Project Center at MTA SZTAKI (Hungary) [29]. *Faller* and *Feldmüller* developed an Industry 4.0 learning factory at Bochum University of Applied Sciences covering the topics of technical and organizational integration of field level, control level, management level and C-level [30]. *Thiede*, *Juraschek* and *Herrmann* implemented a learning factory module about cyber-physical production systems in terms of a team project to support professional education for Industry 4.0 at TU Braunschweig [25].

Gräßler, *Pöhler* and *Pottebaum* conceptualize the upgrade of an existing production laboratory at the University of Paderborn towards a cyber-physical production system learning factory for decentralized production control and reconfigurable production elements using Internet of Things (IoT) [31].

Further learning factories focusing on different aspects of cyber-physical production systems are e.g. the Demonstration Factory of RWTH Aachen as described by *Schuh et al.* [32], IFA Learning Factory according to *Seitz* and *Nyhuis* [33] and SmartFactoryOWL as described by *Schriegel* [34]. Also the Model factory at Potsdam University as described by *Ullrich, Lass* and *Heim* [35], and the Teaching Factory at University of Patras as described by *Rentzos et al.* [36] have to be mentioned.

The concept of the Digital Twin is not yet addressed in the presented learning factories and therefore will be elaborated. This paper focuses a learning environment that covers the comparison of value stream mapping presented by *Erlach* [37] for process optimization and the use of a Digital Twin for required continuous near-realtime optimization cycles in the context of cyber-physical production systems as requested by *Bauernhansl et al.* [38] (p. 19).

3. Digital Twin Learning Factory

In the context of digitization, the capture, storage and analysis of data will become more and more significant. IT environments within enterprises, ranging from embedded systems on shop floor level to operations and manufacturing execution systems or resource planning systems, will form the basis for the Digital Twin of production plants. However, especially within SME, IT systems are only fractionally implemented, particularly holistic solutions are lacking. Therefore, a learning concept needs to be developed and implemented, enabling participants to familiarize themselves with needed technologies, implementation effort and advantages of the Digital Twin.

The Chair of Manufacturing and Remanufacturing Technologies at Bayreuth University built up a resource efficiency oriented learning environment in 2014, serves an optimal basis for transferring the potentials of the Digital

Twin to participants. The learning environment is an example for a reconfigurable production, consisting of a production process for carbon fiber parts and related tool forms as well as an assembly line and thereby provides an experiential training and learning experience for undergraduate and graduate students as well as researchers and industry professionals [39, 40, 41]. The environment (Fig. 3) offers turning (P6), cutting (P1) and milling (P2) machines, each with different throughput as well as processing times and a subsequent stationed surface cleaning machine (P3). Regarding manual labor workplaces, a paint booth (P7) and both a pre-assembly line (P4) as well as an assembly line (P5) are placed in the learning factory. Besides that, different means of transportation are available.

The main goal of the learning factory is to make participants aware of the advantages of the Digital Twin in Industry 4.0 applications. Additionally, the addressed knowledge elements include data acquisition, data storage and data analysis as well as a subsequent derivation of optimization scenarios. Hereby, the training session is based on gamified

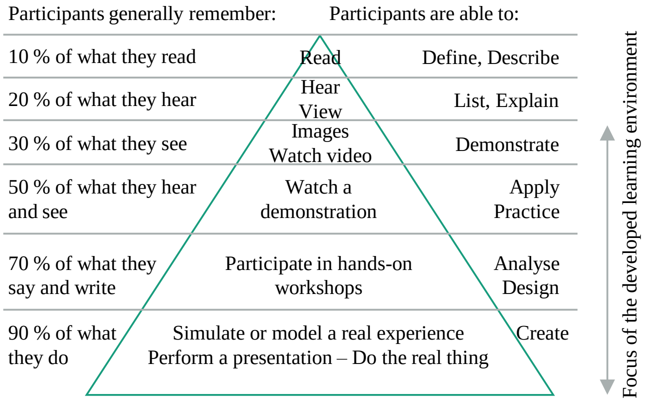

Figure 2: Dale's cone of experience [43, 44].

and audio-visual learning approaches taking into account that experience and participation lead to improved learning effects [12, 42, 43]. To ensure a sustainable and effective transfer of know-how, a blended learning concept based on Dale [43] is applied for training participants (Fig. 2).

To show the advantages of the Digital Twin, the training session is structured as follows:

1. Value stream mapping in groups
2. Optimization of layout based on individual value streams
3. Poster session "Data acquisition", "Data warehousing" and "Data analysis and derivation of optimized scenarios"
4. Workshop for comparison of results and method

In order to make the participants aware of the method of value stream mapping, an entire value stream for all product variations must be conducted. Therefore, participants are divided into groups, which are confronted with a complex production environment, consisting spatial separated process steps with requirements regarding simultaneousness (Fig 3). The potential outcome will be a plurality of variants in terms of both sequences and optimization potentials, due to different perspectives held by the individual groups. Subsequently, the value streams as well as derived optimized solutions will be discussed by participants as well as lecturers.

In order to transfer knowledge about the Digital Twin, a poster session regarding the concept, especially the main three pillars, namely data acquisition, data warehousing and data analysis including derivation of scenarios, is conducted.

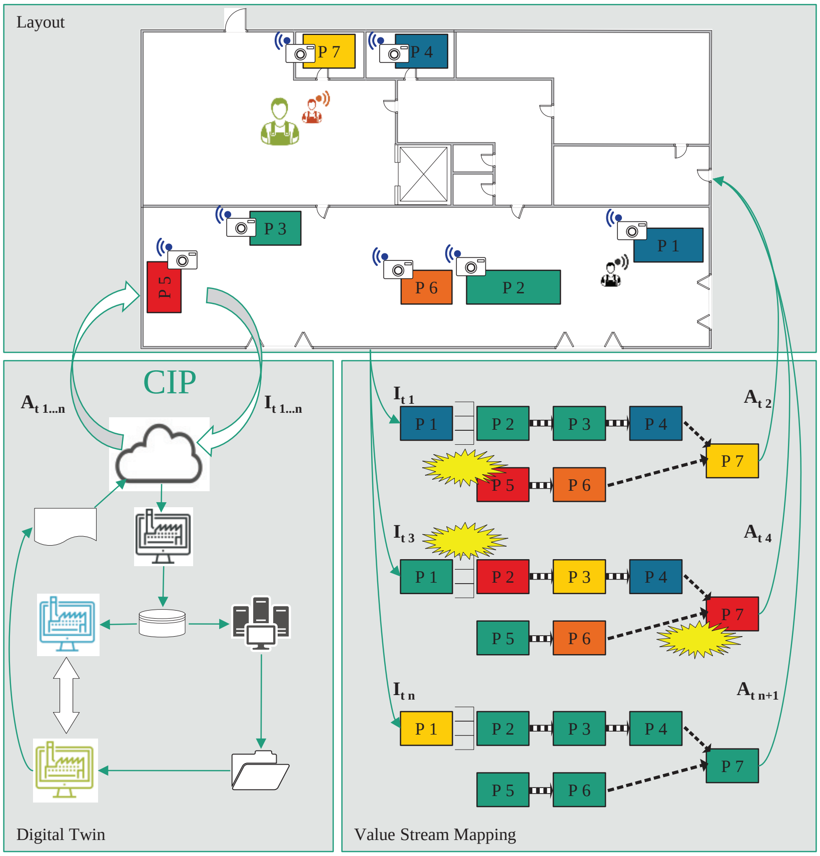

Figure 3: Comparison between the Digital Twin and Value Stream Mapping. Digital Twin: Near real time linked simulation of the production system for continuous data acquisition, VSM: Manual Data acquisition is conducted to get a snapshot of current state.

Table 1: Legend to Figure 3

Symbol	Explanation
	Working (green); Set-up (yellow); fault (red); Waiting (blue); Standby (Orange)
	Cloud-solution
	real-time linked Digital Shadow; Digital Twin; Digital Twin with optimized set of parameters
	Continuously updated database; Optimization; Optimized set of parameters; Production control-improving recommendation;
	Participant recording the process
	Production employee with sensor-based tracking; Data transmitting machine vision module
$I_{t\ n}$ $A_{t\ n}$	Information and Actions taken at the time n

3.1. Data acquisition

Data acquisition represents a crucial part for implementing a Digital Twin of production environments. Regarding data processing within industrial productions, two types of data can be differentiated, namely, volatile and nonvolatile data. The latter is captured by measurements and interviews, since it consists relevant layouts, specifications of machinery, lists of products including variations, bills of material and qualification levels of employees. In order to capture volatile data, consisting motion of employees, movement of means of production, flow of material, time of production as well as processing time and utilized capacity of machinery, real time locating systems and image processing systems are used. For real time indoor location, a wireless system consisting of anchors and sensors based on radio communication is implemented. Image processing is performed on a tailor-made Android-based system.

It is aimed to provide a solution for data acquisition with a combination of existing technologies. Furthermore, the participants must be aware of the classification of data needed for the Digital Twin and their contents.

3.2. Data warehousing

Following data acquisition, a concept for data storage including interfaces is needed. Since a Digital Twin, relying on standardized and established technologies and solutions, potentially shows a wider range for implementation, an existing cloud solution for data storage is presented. Furthermore, the main requirement for data capturing and storage is a network interface between data acquisition technologies and cloud solution for data storage.

The goal is to provide a solution for data storage, relying on existing cloud solutions. Furthermore, the participants must be aware of existing.

3.3. Data analysis and Derivation of Optimization Scenarios

In order to use gathered and stored data, a system containing software as well as necessary interfaces is needed. For reasons of transferability, Technomatix Plant Simulation represents the basis for data analysis and derivation of optimized scenarios. The goal is to demonstrate used algorithms, e.g. artificial neuronal networks for machine vision, and optimization methods, e.g. genetic algorithm tools implemented in Technomatix Plant Simulation, to show how scenarios can be derived.

Following the poster session, a workshop for comparison of results and methods is conducted. It is aimed to highlight the differences between possible solutions of the manual, static method value stream mapping and the dynamic Digital Twin are highlighted. A benefit analysis was conducted and is summarised in Tab. 2. Additionally, participants must be aware of the single efforts in terms of implementing the Digital Twin and conducting a value stream.

Table 2: Characteristics of VSM and the Digital Twin

Characteristics	**VSM**	**Digital Twin**
Continuous data acquisition	○	●
Repetition effort	◑	○
Automated derivation of optimization measures	○	●

Repeated derivation of optimization measures	○	●
Installation effort	○	◕
Capturing of motion data	○	●
Observance of events with high simultaneity factor	○	●
Low: ○ Medium: ◑ High: ●		

4. Conclusion and Outlook

In this paper a learning concept to show the benefits of automated data acquisition and processing and therefore the Digital Twin of a production system is presented. The comparison between the Digital Twin and common tools of process optimization, e.g. VSM, is carried out and shows the benefits of digitalization in a vividly manner. Benefits of the proposed new approach for the analysis and modification of production systems can be experienced by participants in practical training sessions, especially continuous data acquisition, automated derivation of optimization measures and capturing of motion data. Parallel to the development of the learning concept the interface between the data acquisition technologies and the material flow simulation is defined. The physical implementation of the system enabling the Digital Twin will be the last step in the realization of the learning concept at the Chair of Manufacturing and Remanufacturing Technologies at Bayreuth University.

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