5th Conference on Production Systems and Logistics

Framework For The Successful Set-up Of A Common Data Model In The Context Of An Industry 4.0-ready Plant Design Process

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Abstract

The production plant design process consists of a multitude of individual engineering disciplines, which rely on a variety of digital models. The individual tasks build up on each other, while each discipline consumes information from the previous processes. However, sharing relevant data across multiple companies is challenging and susceptible to miscommunication and delays. Furthermore, integrating diverse software systems, tools, and technologies create compatibility issues and hinder seamless integration. As a result, a heterogeneous, non-automated data and information landscape is created, characterized by a high level of manual data transfer. This represents a major problem on the way towards Industry 4.0.

The goal of this paper is to provide a framework for the successful set-up of a common data model in the context of an Industry 4.0-ready plant design process across and along the value chain. For this purpose, a literature review of current problems in the cross-company and cross-departmental collaboration in the plant design process is provided and requirements for the framework are derived. Existing solutions and research projects are compiled and evaluated against the requirements, from which the framework's structure is concluded. The framework itself is intended to be holistic and must therefore not only include technical aspects (e.g. data interfaces, semantics) but also enable the entire organization and value chain to implement the common data model as part of the digital transformation process (e.g. employee skills, business strategy, legal conditions). Based on this, the framework is further elaborated by deducing calls for action for a successful set-up of a common data model within the research project *DIAMOND* (Digital plant modeling with neutral data formats). The focus should be on employees and their competencies, as these are prerequisites for shaping digital transformation. Future research must prioritize these actions to enhance technology readiness and organizational Industry 4.0 preparation.

Keywords

Common Data Model; Digital Transformation; Plant Design Process; Industry 4.0; Data Exchange

1. Introduction

The work environment is transforming with the increasing use of new and digital technologies as part of the fourth industrial revolution (Industry 4.0 – I4.0). However, the successful implementation of new technologies in existing work processes across the value chain remains difficult for various reasons, including a lack of awareness of the benefits of specific technologies, a shortage of employees and their expertise, or a lack of financial resources [1]. The company must be able to evaluate the technologies and assess them in terms of their potential and benefits [2]. Although automotive manufacturers and their suppliers have the highest I4.0 affinity compared to other industries in Germany [3], the slow introduction of new technologies also applies [4]. In comparing the nine main technology trends (= pillars) of I4.0 [5],

DOI: https://doi.org/10.15488/15309
ISSN: 2701-6277

the expertise in the *Big Data* pillar and thus, the management and analysis of data across different employee levels (managers, technical specialists, production employees) is the lowest. [6]

In present-day plant design processes, the exchange of data or information between employees across departmental and company boundaries is identified as a major shortcoming [7]. This is due to a heterogeneous tool landscape and specific data models in the individual disciplines, whose data is usually exchanged manually [8]. Manual data transfer is time-consuming and might lead to data inconsistency or loss, miscommunication and insufficient data quality [9]. Additionally, compatibility issues hinder seamless data integration into various tools [10]. Setting up a common data model (CDM) as a basis for data exchange promises to mitigate these challenges [10]. However, accompanying challenges of the digital transformation influence the implementation and must be addressed. Thus, the following research questions arise:

- What are the current challenges in the cross-company and cross-departmental collaboration in the plant design process?
- How can the challenges be categorized within I4.0 readiness models?
- What actions are needed to set-up a CDM, while holistically addressing the various challenges of digital transformation?

2. Background

2.1 Industry 4.0 readiness models

Nowadays, numerous assessment models and methods are available regarding the readiness or maturity of I4.0 implementation [11]. These I4.0 readiness models or maturity indexes are a measurement framework that assesses the level of digital transformation of a company in adopting I4.0-technologies. They provide a structured approach to evaluate and benchmark the maturity of various dimensions, such as technology, processes, organization, and strategy, indicating the extent to which an organization has embraced and implemented I4.0 concepts [12]. Existing literature reviews show a great variety of different models [11–14]. However, *Dikhanbayeva et al*. [15] conclude that the existing maturity models have certain deficiencies because they are incomplete, have limited access or miss important design principles of I4.0. Although most models follow general approaches [12], the variety of different ones shows the necessity to adapt the models to a specific use case with specific requirements to make them applicable. [9]

2.2 Common data model

A Common Data Model (CDM) is a standardized and structured representation of data that is understood across different systems and applications within an organization or across multiple organizations. It is the foundation of a central data store that manages engineering data from a wide variety of software tools [10]. A CDM serves as a common language for data integration, exchange, and interoperability, enabling seamless communication and interaction between various data sources and systems and collaboration among different stakeholders. In addition, a CDM acts as a mediator between various data sources and consumers, streamlining data integration and reducing the need for complex data mappings. This leads to more efficient collaboration in the design process. By implementing it, organizations can overcome data silos, reduce data redundancy, improve data quality, and enhance data analytics capabilities. Furthermore, a CDM facilitates efficient data sharing along the entire value chain, fostering collaboration and accelerating decision-making processes. Overall, a CDM plays a pivotal role in achieving a unified data landscape, promoting digital transformation, and supporting I4.0 initiatives in today's interconnected and data-driven business environment. [10,7]

3. State of the art

3.1 Challenges in the plant design process

To identify potentially relevant literature systematically four search term groups are formed, namely (1) plant planning/design process, (2) barriers, challenges or problems, (3) data management or common data model and (4) I4.0 maturity or readiness, and its variants and combinations are used. In addition, a backward and forward citation analysis is performed so that 47 papers are analyzed.

The papers cite 63 problems with the current plant design process, with varying degrees of frequency. Lack of soft skills and qualifications are cited most often (31 times), followed by cybersecurity concerns (27), lack of skilled workers (24), lack of financial resources (21), and clarification of standards, protocols, and contracts (19). Figure 1 shows a word cloud of the ten most frequently cited challenges.

The plant design process is carried out with the help of various companies involved and their corresponding software tools. This leads to a heterogeneous tool landscape [16]. Due to missing communication interfaces, information cannot be exchanged directly between different tools, leading to high efficiency losses [16]. Furthermore, there is a lack of a common data environment within the plant design process, resulting in fragmented information, data silos and a lack of version control [17]. The need for more data availability poses another main challenge, preventing employees from accessing specific information that they need to perform their jobs [18]. Consequently, the lack of a common data environment in the plant design process results in bad data quality and hinders seamless collaboration between companies. This creates barriers to information sharing, coordination, and effective decision-making, which impacts productivity, quality, and the overall project outcome.

In addition to data-related challenges the plant design process also encompasses challenges associated with employee competencies, strategic alignment, and external factors. The lack of soft skills and qualifications among employees contributes to delays in the development process, as they may lack problem-solving abilities, error analysis skills, and adaptability to changes [19]. Insufficient employee qualification aggravates these challenges, stressing the need for comprehensive training programs [17]. Strategic challenges arise within the organization and affect top management, departments, and cross-organizational activities. Many organizations need strategies to effectively align their internal processes with external partners, hindering coordination and cooperation [19]. These challenges include the need for cross-departmental agreements on the use of technology and standards to promote collaboration. Additionally, challenges originating from external factors impact the plant design process. A high level of bureaucracy imposes numerous requirements that restrict employee freedom and hinder process efficiency [18].

Figure 1: Word cloud of current I4.0 challenges in the plant design process based on the number of mentions

3.2 Existing solutions

Since several challenges in the plant design process might already be addressed, existing solution approaches are extracted from the literature. For this purpose, the papers selected during the problem analysis were examined for possible solutions. In total, nine different solution approaches are identified that range from intra-organizational to cross-company projects.

Müller et al. introduced a web-based platform that facilitates seamless communication and eliminates media breaks by utilizing various visualizations and file attachments [16]. Similarly, *Bartelt et al.* proposed an infrastructure for cross-company collaboration, incorporating an exchange format for tool-independent cooperation [20]. The *ENTOC* joint project aimed to optimize the engineering toolchain to enhance data availability across planning and development phases [21]. Additionally, the *BaSys4.2* project develops a middleware in the context of Industry 4.0 to enable cross-company data access in highly networked automation systems [22]. Moreover, the research association *ForBAU* focuses on ensuring consistency of 3D modeling throughout all construction planning steps [23]. Another notable solution (*Catena-X)* emphasizes standardized data exchange within the automotive industry's supply chains [24]. These solution approaches have a focus on technical and partnership problems.

Götz proposed an engineering community to address technical, partnership, human, and strategic challenges. This community fosters cross-divisional cooperation by facilitating knowledge and engineering data exchange [25]. The *AVILUS* project developed a cross-phase approach to information management that encompasses human resource and strategy challenges while focusing on creating, preparing, and utilizing digital information throughout the entire lifecycle [26]. Lastly, *Talkhestani et al*. proposed a solution approach that specifically identifies cross-domain data. Although this approach has a narrow focus, it addresses certain challenges present in the current plant design process [27].

In conclusion, the identified solutions address several challenges in the plant design process, including technical problems, partnership issues, human-related obstacles, education-related challenges, and strategic issues. However, some challenges remain unaddressed, especially regarding the employees and their competencies. This will be further elaborated in Chapter 4.

3.3 I4.0 knowledge, skills and abilities

Based on the most frequently cited challenges it becomes obvious that a prerequisite for any implementation of I4.0-technologies is a skilled and qualified workforce that not only reacts to the ongoing changes but also shapes the transformation proactively [28]. This becomes even more significant due to changes in work tasks and employees' job profiles. Need-based professional education and training offer great added value in terms of raising awareness of technologies and their implementation [29]. In this context, the competencies of the employees are of great importance for introducing new technologies since various studies have shown a correlation between using technologies and the availability of necessary competencies [28,1,2].

However, deficits in employee qualification are becoming apparent [30]. To counteract these deficits, new methods and strategies are needed for the targeted qualification of employees [31]. Although many learning concepts have already been developed for specific I4.0 applications, only a few focus on the digital transformation process of companies and the associated training of employees [30]. The 2022 *Digital Economy Index* indicates that only 54% of Europeans have at least basic digital skills, thus highlighting the need for innovative and efficient qualification strategies within digital transformation [32]. Moreover, digital competencies are less pronounced in SMEs than in large companies [33]. These aspects are in enormous discrepancy with the rapidly increasing need for digital skills in the context of Industry 4.0 in almost all occupational fields.

4. Establishing a framework

4.1 Mapping challenges within a plant design process to I4.0 readiness models

Regarding existing I4.0 readiness models, the identified challenges within the plant design process are analyzed, grouped, categorized and subsequently mapped to defined I4.0 maturity dimensions, as shown in Table 1. The dimensions are extracted and adapted from existing models: Technology (T), Human (H), Strategy (S), Organization (O), Partnership & Network (PN) and Environment (E). The categories themselves are elaborated by the grouping process. Consequently, by the combination of challenges and I4.0 maturity assessment, creating a framework on how to successfully set-up a CDM within the plant design process becomes possible, as will be elaborated within the following chapters. Furthermore, the matching table serves as a checklist for evaluating the current I4.0 maturity and improving results by indicating what evaluators must pay attention to.

The technology dimension refers to the level of adoption and integration of advanced technologies that enable digital transformation and automation, by assessing the organization's technological infrastructure, capabilities, and utilization of critical technologies. A human dimension considers human factors and capabilities in the digital transformation process and emphasizes preparing and empowering the workforce to effectively adapt to and utilize I4.0-technologies, encompassing knowledge, skills, competencies, and mindset. It acknowledges that successful implementation of I4.0 is not solely reliant on technology, but also on the people who interact with and leverage these technologies to drive organizational growth and success.

Table 1: Current challenges of the plant design process

Dimension	Category	Current Challenges
T	Data and information management	Lack of possibility to link data and information [16]; Lack of data quality control and validation mechanisms [18]; Unavailability of data [18]; Insecure data storage systems [34]; Imprecisely defined data access [35]; massive amount of data to manage, store and process [36]
	Technology integration	Immature technology [36]; Lack of back-end systems for integration [34]; Complex synchronization of the real and virtual model [27]; High heterogeneity of the different software solutions [18]; Heterogeneous tool environment [16]; Lack of clarity about the intended use [37]; Lack of technical support [17]; lack of technologies for providing information along the value chain [38]
	Standards and protocols	Lack of clear standards, protocols and contracts [34,17]
H	Attitude, mindset and culture	Resistance to further education [36]; Negative attitude towards change [39]; Different views of cooperation [17]; Negative social influence [37]; Lack of trust in the technology [37], Bad team composition [17]
	Existing knowledge, skills and abilities	Lack of soft skills and qualifications of employees [19]; Lack of sense of usefulness [37]; Limited digital literacy [28]; Limited understanding of I4.0-technologies [28]
	Access to specific employee training and education	Lack of education at universities [18]; Lack of collaboration education [17]; Lack of knowledge about the proper training [28]
S	Strategic Planning	Lack of cross-company strategy for an organization [19]; Contradictory views in different organizational units [34]; Management's reluctance to embrace new technologies [38]; Lack of clarity about the choice of the right technology [40],
	Benefits and value	Lack of clarity regarding general and economic benefits [8];
O	Leadership & management support	Lack of appropriate leaders [34]; Lack of top management support [35];
	Process and resource management	Inadequate planning of steps, goals and resources [34]; Missing benchmarks [41]; High level of bureaucracy [18], Inappropriate process organization [34]; Lack of agility and responsiveness [42]; Inefficient resource allocation and utilization [36]
	Company culture and technology awareness	Technology anxiety [37]; Lack of introduction of new roles [17]; Different views on cooperation [17]
PN	Vertical and horizontal exchange in the value chain	Different organizational structures [17]; Lack of guarantee for interoperability [18]; Misalignment of goals and objectives among partner organizations [34]
	Collaboration and trust	Low trust towards other parties [36]; No willingness to cooperate [34]; Lack of cooperation among departments [35]; Resistance towards sharing data and information [17]
	Information exchange, communication and collaboration with partners	continuous data exchange not possible [8]; lack of traceability and monitoring of changes [43,42]; lack of common data environments [17]; Failure to anticipate customer needs [44]; Unestablished collaboration between project teams [17];
	Data ownership	Concerns about data privacy [17]
E	IT infrastructure	Lack of upgradable infrastructure [40], insufficient data processing power [36]
	Data and IT security	Compliance with data protection regulations[18], ensuring secure data handling practices [18]
	Financial resources	Lack of financial resources [34]; Ignorance about the return on investment and profitability [34]; Lack of willingness to invest [18]
	Labor market	Fear of the loss of work [20]; Lack of skilled workers [34]

The strategy dimension examines the organization's strategic approach and alignment toward I4.0 adoption by assessing the extent to which a company has developed a clear vision, goals, and plans related to I4.0. The organization dimension refers to the organizational structure and culture to embrace and implement I4.0-technologies and practices. This dimension evaluates organizational preparedness to adapt and transform its structure, processes, and mindset to harness the potential of I4.0. In addition, collaborative efforts with external stakeholders to foster ecosystem collaboration are examined within the partnership dimension. The environment dimension assesses the business and macro-economic setting. A key point to note is that some challenges may span across multiple dimensions, indicating their multifaceted nature. However, the presented mapping attempts to link the challenges with their most related dimension.

4.2 Evaluation of existing solutions

Once the challenges have been identified and placed in the I4.0 readiness framework existing solutions can be evaluated for the extent to which they address and overcome the challenges. This is done by marking and summing up the challenges addressed by each solution. Table 2 provides the scope of current solutions.

In conclusion, existing solutions examined in this study do not comprehensively address all challenges identified in the current plant design process, focussing primarily on technological aspects and partnership/network issues. The absence of solutions that consider human challenges must be highlighted. Nevertheless, as demonstrated above, qualifying employees play a crucial role in successfully introducing new technologies within a company's design process. However, by not being comprehensively addressed in current approaches, it is detached from the development of the technology itself. This aspect remains a challenge that requires attention.

Moreover, none of the solutions investigated in this study have developed a comprehensive CDM within the plant design process yet, involving a representative number of key industry stakeholders. This underscores the need for a holistic approach that engages key stakeholders throughout value chains to address these challenges collectively. A framework for a successful implementation of a CDM in the plant design process must aim to fill these gaps and offer more comprehensive solutions that encompass all dimensions equally while involving key industrial stakeholders.

Table 2: Scope of current solutions

Existing Solutions & Description	T	H	S	O	PN	E
Müller et al.: Web-based communication platform for avoiding media discontinuities in plant planning [3]	◕	◔	◑	◔	◑	◔
Talkhestani et al.: Anchor point method for identifying cross-enterprise data and updating the virtual model [8]	◔	○	○	○	◔	◔
Götz: Development of an engineering community for interdisciplinary collaboration [21]	◔	◔	◔	◑	◔	○
Bartelt et al.: An approach to improve cross-company collaboration planning. [22]	◑	○	○	○	◑	◔
Schreiber et al.: Cross-platform information management [23]	◑	◑	◔	◔	◔	◑
BaSys4.2: Middleware for continuous engineering [24]	◑	◔	◔	◔	◑	◑
Catena-X: Networking the entire value chain with the help of a collaborative data ecosystem [25]	◑	○	◔	◔	◕	◑
ENTOC: Optimization of the Engineering toolchain with a focus on smart engineering [26]	◑	○	◔	◔	◑	◔
ForBAU: Optimization of processes regarding the involvement of subcontractors for construction planning [27]	◔	○	◔	◔	◔	◔

○ = not addressed, ◔◑◕ = partially addressed, ● = fully addressed

5. Calls for Action

Based on the identified problems and the proposed I4.0 readiness model, specific calls for action for setting up a CDM are derivable. These proposed tasks provide a framework for future work and suggest specific steps and solutions. For the technology dimension, it is necessary to develop a CDM that is ready to be implemented in real plant design processes with a sufficient technology readiness level [45,46]. Therefore, all features must be described and tested accordingly and a basic understanding of CDM must be created. *AutomationML* promises to serve as a suitable, open and adaptable XML-based data exchange format for seamless interoperability in industrial automation [38]. Within the human dimension, the acceptance of and trust in CDM must be improved. A valid tool that explains and predicts individuals' acceptance and adoption of new technologies based on their perceived usefulness and ease of use is the Technology Acceptance Model (cf. [37]), which can be employed. Additionally, necessary competencies can be identified by leveraging existing competency frameworks (e.g. [47]) and any competency gaps can be addressed accordingly. Customized training programs tailored to specific target groups can be developed to ensure context-sensitive learning. Barriers to training must be minimized by creating e.g. suitable learning nuggets (cf. [48]). Furthermore, making CDM a hands-on experience can be achieved by integrating the learning and research factory concept, which is a promising approach for qualifying employees and management to achieve the required skill levels [30]. These facilities aim to provide hands-on qualification, focusing on research, technology transfer, training, and education. They might serve as training centers for employees of different organizations and as demonstration facilities for introducing new approaches and technologies [49]. To foster an understanding of benefits and barriers of CDM, various initiatives such as public relations, use case demonstrations, dialogue rounds and networking events must be employed. Furthermore, organizations should establish a clear collaboration strategy with management commitment, develop a roadmap for CDM implementation, and incorporate procedures for updating CDM and the company's role by leveraging information on the latest technology trends, such as trend management and technology trend radars. To establish a cross-company process understanding, the *Conexing* platform might be used as a model, in which a unified working environment is created between different partners [50].

Table 3: Calls for action for successfully setting-up a CDM

Dim	Tasks to be completed	How / Tools / Measures
T	• Develop mature CDM (Technology Readiness Level ≥ 6) • Demonstrate at least technical feasibility • Describe features of CDM (e.g., language, attributes, interfaces, data inputs and outputs, data format, metamodel)	• Use the framework of *AutomationML* to create a common data model [51] • Develop prototype(s) with realistic and complex problems
	• Establish functional, modular Architecture	• Use, e.g., pattern-based microservice composition approach [52]
H	• Increase acceptance and trust in CDM • Identify needed competencies (skills and abilities) and competency gap	• Use of the technology acceptance model (TAM, cf. [37]) • Derive competencies from existing competency frameworks [47]
	• Offer context-sensitive training • Reduce barriers to training • Make CDM a hands-on experience • Create an understanding of benefits and barriers of CDM	• Develop customized training for different target groups • Develop suitable learning nuggets (cf. [48]) • Integrate the concept of learning and research factory (cf. [30]). • Enforce public relations and provide use cases, dialogue rounds, theme days and networking events, …
S	• Establish a clear strategy for collaboration and obtain management commitment • Develop a unique roadmap for CDM implementation. • Obtain information on latest technology trends and develop a procedure for updating CDM and the role of the company	• Setting up a defined framework for cooperation (Follow the rules of *Harris*, cf. [53]) • Recourse to roadmaps for the development of a CDM • Use trend management or technology trend radars [28]
	• Present clear standards for communication exchange	• Use of existing standards (e.g. ISO 18828)
O	• Record own processes in a suitable standardized way • predict and analyze the effects of CDM • Establish a procedure for adapting existing processes • Turn those affected into participants in the change process	• Use SIPOC (suppliers, inputs, process, outputs and customers) and map & analyze process landscape • Use of knowledge transfer methods (e.g., SECI model, cf. [54]) • Introduce change management
PN	• Promote cross-company process understanding and information exchange and harmonize processes	• Introduce Enterprise social network sites [32] • Integrate a shared work environment (e.g., *Conexing* platform, cf. [50])
	• Identify and promote the benefits of collaboration • Establish clear rules for data ownership and security	• Regular interactive team sessions • Provide Cross-company definition of standards and legal advice
E	• Increase agility of the enterprise • Comply with regulations and laws and ensure data security or infrastructure security • Obtain financial commitment for implementation of CDM	• Development of the Knowledge-Based Economy [55] • Compliance with the essential IT protection of the Federal Office for Information Security • Create a business plan and demonstrate long-term financial benefits

Within the partnership/network category cross-company process understanding and information exchange must be promoted to enable the harmonization of processes. For establishing a strategy for cross-company collaboration it is recommended to follow the rules of *Harris*, which encourage building and enforcing an awareness of cooperation [53]. Furthermore, data ownership and security rules must be established and collaboration benefits promoted. Table 3 sums up all derived actions. Based on these, the *DIAMOND* project [56] will develop a CDM for the plant design process.

6. Conclusion and Outlook

In conclusion, the diverse landscape of I4.0-technologies and the assessment of I4.0 readiness necessitate the identification of critical challenges impeding the adoption of specific technologies. Collaboration in big data spaces poses significant challenges that impact multiple organizations. They often need assistance managing digital transformation and the incorporation of new technologies within their organizational boundaries, further impeding the integration of technologies across the value chain. Thus, this paper investigated and categorized the challenges encountered in setting up a CDM within the plant design process and integrated them into an adapted I4.0 readiness model. 63 challenges were identified in response to the first research question, predominantly centered around technological challenges and a lack of knowledge, skills, and abilities. Regarding the second question, the challenges are mapped into an adapted readiness model encompassing six dimensions and 19 categories. Addressing these challenges requires targeted actions that are derived accordingly. Consequently, a comprehensive framework is provided that is suitable for the specific use case of setting-up a CDM in the plant design process. This framework answers the third research question by providing actions needed to set-up a CDM, while holistically addressing the various challenges of digital transformation. The development of CDM itself using *AutomationML* must be supported by enabling the organizations' employees to improve their skills and competencies through appropriate training. The framework serves as a holistic guideline for value networks.

Future research should prioritize these actions to enhance technology readiness and organizational preparedness for technology utilization by employees. The focus should be put on the employees and their competencies, as these are the enablers to shape the digital transformation. Therefore, it is crucial to better understand the current flow of data within the plant design process and evaluate the data quality along to identify specific training needs.

The transferability of knowledge, skills, and abilities as well as the organizational mindset developed during the implementation process of a CDM also facilitates the implementation of other I4.0-technologies due to interlocking effects. However, each technology implementation still presents its unique challenges. While this research only focuses on challenges regarding the plant design process, further challenges might hinder the implementation of other I4.0-technologies. Although the proposed calls for action do not serve as a one-fits-all solution, they are adaptable and extendable depending on other specific use cases and their requirements. The measures derived will be put into realization by the *DIAMOND* project. In it, a common data model that can be adapted to different use cases and a modern data exchange via common data spaces are being developed and tested. In addition to technical solutions, the organizations and needs of the people involved in the companies are also being considered. The project focuses on the process of plant design in the automotive industry and has 25 industry and research partners. Further tasks on how to create a CDM will be elaborated in later publications within the *DIAMOND* project. [56]

Acknowledgements

The DIAMOND research project is funded by the European Union (NextGeneration) and supported by the German Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag (Grant number 13IK011P).

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Biography

Tobias Drees (*1993) has been a research assistant at the Chair of Production Systems (LPS) at the Ruhr-University Bochum since 2023. He is focussing on the design of employee trainings in the context of Industry 4.0. Previously, after graduating in Automotive Engineering & Management with distinction in 2019, he worked as research assistant at the Institute of Product Engineering (IPE) in Duisburg.

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Dr.-Ing. Alfred Hypki (*1963) has been chief engineer at the Chair of Production Systems (LPS) at the Ruhr-University Bochum since 2015. His main research activities are robot simulation, robot programming and human-robot collaboration. Until 2009 he was a research assistant at the Institute of Robotics Research at TU Dortmund University, where he received his doctoral degree. From 2009 to 2015 he was chief engineer at the Institute for Production Systems at TU Dortmund University.

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