MODERN SYSTEMS 2024

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Nice, France

MODERN SYSTEMS 2024 Editors

Manuela Popescu, IARIA, USA

MODERN SYSTEMS 2024

Forward

The International Conference of Modern Systems Engineering Solutions (MODERN SYSTEMS 2024) continues a series of events focusing on systems development considering the variety of combination between requirements, technologies, and the application domains. The conference was held in Nice, France, November 3 - 7, 2024.

We are witnessing a paradigm shift in systems engineering approaches caused by several facets of society and technology evolution. On one side, the mobility, the increase in processing power and the large storage capacity created the capacity needed to deliver services to everybody, everywhere, anytime. On the other side, new computation approaches, data gathering, and storage combined with advances in intelligence-based learning and decision-making, allowed a new perspective for systems engineering.

The advanced pace of technological achievements is supported by Cloud/Edge/Fog-based computing, High Performance Computing (HPC), Internet of Things (IoT), Big Data, Deep Learning, Machine Learning, along with 5G/6G communications (integration of terrestrial/special systems) and mobility. As such, deployment, operation and technologies, integration, maintenance became a cornerstone for developing systems complying with functional and non-functional requirements.

We take this opportunity to thank all the members of the MODERN SYSTEMS 2024 Technical Program Committee as well as the numerous reviewers. The creation of such a broad and high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to the MODERN SYSTEMS 2024. We truly believe that, thanks to all these efforts, the final conference program consists of top quality contributions.

This event could also not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the MODERN SYSTEMS 2024 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope the MODERN SYSTEMS 2024 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress with respect to modern systems. We also hope that Nice provided a pleasant environment during the conference and everyone saved some time for exploring this beautiful city

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Towards a User-Centric Systems Engineering Approach

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***Abstract*—In the face of increasing complexity in product development, the adoption of systems engineering, particularly model-based systems engineering, has become essential. However, incorporating systems engineering in companies encounters resistance due to concerns about additional expenses among others. While concepts like domain-specific systems engineering aims to enhance user acceptance by tailoring domain-specific languages, we argue for a more comprehensive approach. This research proposes a shift toward user-centric systems engineering, establishing the groundwork by defining the user's role and outlining means of support. The key aspects identified for a such an approach include facilitating tool interoperability to allow users to leverage familiar tools, reducing complexity in tools and modeling languages, and adopting a lean thought model to overcome barriers associated with formal systems engineering. User-centric systems engineering aims to involve the user throughout the entire systems development lifecycle, ensuring their needs and perspectives are integrated into every phase—from initial requirements to system deployment and maintenance. By focusing on the user's role and emphasizing interoperability and simplicity, this research aims to enhance the acceptance of systems engineering and provide a basis for future studies, ultimately improving system development outcomes across industries.**

***Keywords*-model-based systems engineering; domain-specific systems engineering; user-centric systems engineering**

I. Introduction

In the contemporary landscape, characterized by digitalization, global competition, and sustainability, the complexity of products and product development is increasing. This transformation, coupled with a growing trend towards service-enabled systems, results in a new realm of complexities for companies. To effectively tackle this complexity, both at the product and organizational levels, a structured methodology is needed. In that regard, the adoption of Systems Engineering proves invaluable. It is also worth mentioning that model-based systems engineering (MBSE) has proven to be especially suitable for addressing complexity. MBSE is centered around evolving a system model, compromising system specification, design, validation, and configuration management leading to a "single point of truth" making it easier to maintain consistency and assure traceability [1]. However, the introduction of systems engineering and especially MBSE in companies seems challenging. While there are various reasons why the introduction can be challenging, research like in [2], [3] and [4] underscores the hurdles associated with a lack of acceptance and motivation, both at the managerial level and among specialized personnel. In [4], it is further stressed that the willingness of all stakeholders is required for a successful implementation. This willingness can be linked to certain hurdles making the introduction of systems engineering unattractive for current employees. These hurdles are for example the lack of an amortization concept for increased modeling work, and too complex tools with a lacking integration into existing IT infrastructure [2]. This is also reaffirmed by [3] stating that a systems engineering tools are not generally applied in a wider context to support a collaborative environment integrating different technical domains. However, there are already methodologys adressing user acceptance through exploiting particular application domains as common ground. So called domain-specific systems engineering (DSSE) is an approach within systems engineering that focuses on tailoring engineering methodologies, practices, and tools to specific domains or industries. Exemplary domains where research towards DSSE has already taken place are the Smart Grid domain [5] or industrial automation systems [6]. The research on this topic is ongoing for years and accordingly well-founded. In [7], a review on DSSE is given including a summary of existing work as well as reviewing the general approach of DSSE. And while it is stated to increase the practical applicability of MBSE they conclude that DSSE cannot be seen as a final solution. They stress that early implementations fell short due to a poor user acceptance, stressing that a user-centric perspective is needed. So, while this approach points in the right direction it does not go far enough. Instead, further evolution is necessary to turn the domain-specific into a user-centric systems engineering (UCSE) approach that better addresses the individual needs of the participating stakeholders. Our systems engineering maturity model depicted in Figure 1 Illustrates this intended evolution. A further description of the individual maturity levels is given in Table 1. Concluding in this short paper, we argue that the lack of acceptance both in the management as well as on the user side of systems engineering concepts lead to the need of a user-centric approach to systems engineering. We opt to address the challenges by specifically looking at the needs and hurdles of the individual user or user groups applying systems engineering concepts. The remainder of this paper is structured as follows: Section II explores the role of the user in systems engineering. Section III outlines key approaches to

TABLE I. MATURITY LEVELS AND SCOPE IN SYSTEMS ENGINEERING

Maturity Level	Scope and Focus
Level 0	Interdisciplinary engineering focuses on aligning individual disciplines. Engineers work with their corresponding design and development tools.
Level 1	In classic Systems Engineering / MBSE, the whole system comes into focus, and an alignment between technical and business aspects is sought. model-based systems engineering tries to align different models and integrate them using object-oriented modeling concepts, often based on general-purpose modeling Languages such as SysML. Modeling is done mainly by architects.
Level 2	Domain-specific systems engineering strives to establish a common understanding among all stakeholders. Technical modeling concepts are hidden behind domain-specific modeling concepts. Model manipulation is mainly done by architects. The intention of established models is (1) to be understood by all stakeholders and (2) to be compatible and interoperable with models from complementary domains.
Level 3	User-centric systems engineering strives for the active participation of different stakeholders in the modeling process. It acknowledges the individual needs of stakeholders and offers model access for various tools with a different focus. Further, it acknowledges the different needs according to the development logic realized.

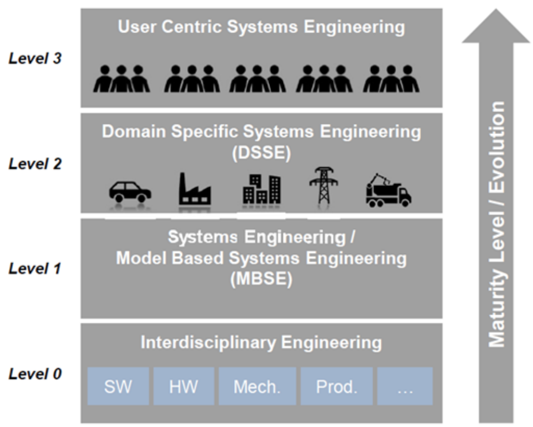

Figure 1. Systems Engineering maturity levels.

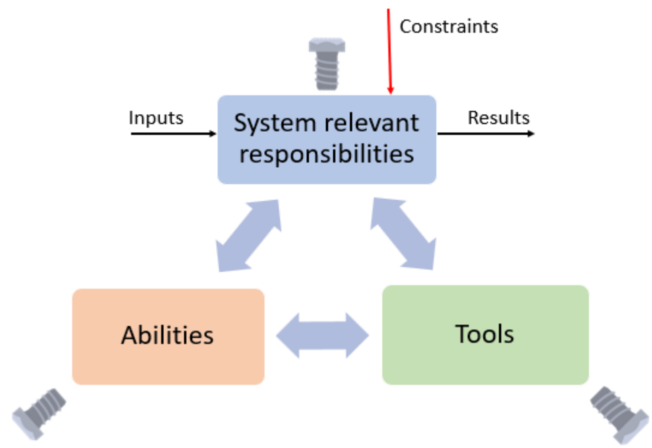

Figure 2. User definition.

support the user, focusing on reducing complexity, enhancing tool interoperability, and adopting a lean thought model. Finally, Section IV presents conclusions and outlines future research directions for advancing UCSE in both theory and practice.

II. UNDERSTANDING THE USER ROLE IN SYSTEMS ENGINEERING

In undertaking a research inquiry into a user-centric systems engineering approach, the foundational step involves a definition of the term user within this specific context. A most rudimentary definition can be formed asking what the tasks of a user are and how he fulfills them. Considering this, the characterization of a user unfolds through a combination of their responsibilities, their abilities and the tools needed to fulfill the responsibilities. Where the responsibilities can be defined as a set of tasks intertwined with specific constraints—whether these could be temporal considerations, the mandatory utilization of designated tools or similar. The ideal supported user has the ability to perfectly use a tool to complete a responsibility in its entirety. This definition leads to Figure 2 depicting a basic user with responsibilities, tasks, and abilities. These three characteristics can be thought of as adjusting screws working together collectively shaping the degree of support provided to a user. If any one of these screws is not properly adjusted, it can lead to problems or dissatisfaction for the user. For instance, the absence of a specific ability can result in responsibilities being inadequately fulfilled or not met at all. Addressing this scenario involves strategic options such as enhancing the user's ability through training, reducing their task load to allocate more resources, or deploying tools that alleviate task complexity. However, it is essential to consider both individual responsibilities and the interconnectedness of responsibilities among users. Poor information flow or unclear responsibilities can create unnecessary complications. Ensuring a well-organized user structure involves managing these interdependencies. For instance, using diverse tools may require frequent information conversion, whereas consistent tool usage reduces this burden. Therefore, supporting users in the systems engineering process requires focusing on their responsibilities, abilities, and tools, as well as the overall working structure.

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III. How to support the user in Systems Engineering

This section lays the groundwork for advancing research in the direction of a user-centric systems engineering approach. As previously outlined, we have identified three focal points for supporting the user: their abilities, tools, and conceptual support through an exploration of their responsibilities and interconnections with other users. Subsequent sections will provide a forward-looking perspective on the anticipated research for each of these three aspects. This analysis is informed by both the drawbacks observed in DSSE and insights gathered from interviews with company partners implementing systems engineering in specific projects.

A. Tools: Facilitate tool interoperability

As outlined in the introduction a huge hurdle for the introduction of systems engineering is the significant number of different tools and the missing acceptance to learn new tools. As for modeling systems the de facto standard is OMG's System Modeling Language (SysML). And despite the broad acceptance, different limitations exist, such as poor interoperability between various tools or a lack of precision. To address these shortcomings, in 2017, the OMG issued a Request for Proposal (RFP) for the specification of SysML v2. As stated on the OMG homepage, "the emphasis of SysML v2 is to improve the precision, expressiveness, interoperability and the consistency and integration of the language concepts relative to SysML V1.x. [...] the language will be specified as both a SysML profile of UML and as a SysML metamodel" [8]. In parallel to the SysML v2 RFP, the SysML v2 API and Services RFP focused on services to operate on SysML v2 models and connect SysML v2 models with models in other disciplines. As stated by OMG, this API shall be "implemented by SysML v2 modeling environments and shall support a wide range of operations related to the model query, construction, view/viewpoint management, analysis, management and transformation for SysML v2 models" [9]. According to the OMG roadmap, the final specification of SysML v2 will be submitted in the first quarter of 2023, and an acceptance is expected no later than in the first quarter of 2025. Despite the long timeline until the final standard's release, it is already possible to explore the capabilities. This can be accounted for by the tight integration of the systems engineering community during the development of the specification. To be more precise, the current state of specifications has been made publicly accessible at GitHub with a close to monthly release frequency. Moreover, in parallel with the specifications, a pilot implementation has been developed and made accessible via the same repository. Though the standardization process of SysML v2 is in a very early stage, the specification is already quite mature. It indicates a clear direction, and the impact of SysML v2 on our research is significant as it delivers a plethora of new opportunities on the one hand and is expected to solve issues, such as tool interoperability on the other hand. This affects not only modeling environments but also the capabilities of model verification and validation or the integration with other tools. Moreover, the pilot implementation's existence will allow us to explore the envisioned capabilities of having a bridge between different tools and experiment with new ideas.

B. Abilities: Reducing complexity

The introduction of MBSE to existing development processes results in inherent overhead. Every user is required to possess proficiency in the additional systems engineering relevant tools and comprehend and use certain modeling languages. The inherent complexity of these tools is a huge barrier for users accepting the introduction of systems engineering. However, this complexity can be reduced through utilizing advanced Large Language Models (LLM), such as GPT-4, which enables the user to explain and express certain views of a system model in natural languages. Especially for user without Systems engineering background, AI and LLM could simplify the entry into systems engineering processes by reducing the inhibition threshold for systems engineering tools and eliminating misconceptions by translating and explaining constraints in natural languages. Repetitive and error-prone tasks could be supported by the AI and suggestions for improvement can be incorporated directly during development. The potential to support system engineering with AI is promising. While fully integrated solutions are yet to be realized, current capabilities allow for interaction and the creation of document-based system views. AI integration to model-based processes would fully utilize the potential and ensure interoperability of these models. Despite these limitations, beginners in the field can already benefit from the use of Large Language Models, by making the first steps more accessible and less intimidating. In this regard, in [10] an initial investigation was conducted to explore the feasibility of large language models for user-centric model-based systems engineering.

C. Responsibilites: A more flexible thought model

To support a user through his responsibilities, it is necessary to refine them, ensuring they are optimized, devoid of redundant tasks and unnecessary constraints. Aside from constraints tied to specific tools and abilities (e.g., mandatory tool usage), the optimization of responsibilities hinges on refining the underlying systems engineering processes. The central aspect, in this case, is the need for a developing and modeling concept that enables individual tailoring to reduce unnecessary tasks and complexity. This idea of proactively identifying and removing unnecessary overhead is not new. This approach is a well-established concept known as lean. The origins of lean can be related to lean manufacturing as part of the" Toyota Way" [11] and can be dated back to the post-war ages. It was intended to improve production cycle times by identifying and eliminating activities that do not add value ("waste") for the customer [12] [13]. The establishment of a thought model aiming at "reducing waste" since that has been adopted for different applications such as lean software development, lean project management, or lean product development. As such, lean appears to be a valid thought model for challenging and organizing MBSE approaches which often appear to be clumsy and overkill for engineers. Literature research, in that case, yields only a few outcomes, such as a 2010 contribution to the INCOSE International Symposium targeting "lean enablers for systems engineering" [14], or a relatively comprehensive but still general book published by Oppenheim in 2011 [15]. In the recent past, different publications came up specifically targeting the integration of lean and MBSE, such as Brusa's considerations on manufacturing [16], or the different approaches from Buczacki or Allen investigating lean product development [17] respectively model management [18]. We posit that the lean concept could serve as a valuable thought model for further extending the DSSE approach towards UCSE.

IV. Conclusion and Future Work

In conclusion, this study highlights the shift towards increasingly complex systems, underscoring the imperative role of systems engineering. However, the lack of acceptance for additional Systems engineering expense is challenging. While existing research, such as domain-specific systems engineering aims to improve user acceptance through tailored languages for domain experts, we believe this goes not far enough and propose the necessity for research towards a more user-centric systems engineering approach. With this research we want to lay the foundational groundwork by delineating the concept of a user and exploring avenues for their support. Several key elements are identified for a user-centric systems engineering paradigm. Firstly, there is a critical need to facilitate tool interoperability, allowing users the flexibility to utilize familiar tools. Secondly, the reduction of complexity in tools and modeling languages is essential, thereby minimizing barriers to acquiring new skills. Lastly, recognizing formal systems engineering approaches as potential obstacles, we advocate for the adoption of a lean thought model. This model aims to streamline processes and eliminate unnecessary complexities, addressing the challenges associated with traditional approaches. Looking ahead, critical areas for future research will encompass exploring the ramifications of SysML v2. The evolving landscape of SysML-v2 harbors the potential for heightened interoperability, facilitated by the establishment of an API that broadens the scope for interaction with various tools. Furthermore, the study advocates for an intensified focus on lean systems engineering and its role in eliminating unnecessary complexities. Future research endeavors should explore and expand upon the practical implementations and benefits of lean systems engineering in the context of modern systems development. Additionally, the integration of AI-supported modeling, presents a frontier for exploration. Investigating how artificial intelligence can enhance the modeling process, reduce complexities, and augment user capabilities will likely be a key area of interest. Future research should strive to unravel the potential of AI-supported modeling and its impact on user-centric systems engineering. These research trajectories are geared towards advancing the UCSE approach, envisioning a future characterized by improved interoperability, efficiency, and user-centricity. This ensures that systems engineering, with its holistic and structured approach, aligns seamlessly with diverse user needs.

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References

[1] A. M. Madni and M. Sievers, "Model-based systems engineering: Motivation, current status, and research opportunities", *Systems Engineering*, vol. 21, no. 3, pp. 172–190, 2018.

[2] R. Dumitrescu, A. Albers, O. Riedel, R. Stark, and J. Gausemeier, "Engineering in germany-the status quo in business and science, a contribution to advanced systems engineering", *Paderborn*, 2021.

[3] T. Huldt and I. Stenius, "State-of-practice survey of model-based systems engineering", *Systems engineering*, vol. 22, no. 2, pp. 134–145, 2019.

[4] D. Wilke, R. Grothe, L. Bretz, H. Anacker, and R. Dumitrescu, "Lessons learned from the introduction of systems engineering", *Systems*, vol. 11, no. 3, p. 119, 2023.

[5] C. Neureiter, M. Uslar, D. Engel, and G. Lastro, "A standards-based approach for domain specific modelling of smart grid system architectures", in *2016 11th System of Systems Engineering Conference (SoSE)*, IEEE, 2016, pp. 1–6.

[6] I. Scheeren and C. E. Pereira, "Combining model-based systems engineering, simulation and domain engineering in the development of industrial automation systems: Industrial case study", in *2014 IEEE 17th International symposium on object/component/service-oriented real-time distributed computing*, IEEE, 2014, pp. 40–47.

[7] C. Neureiter, C. Binder, and G. Lastro, "Review on domain specific systems engineering", in *2020 IEEE International Symposium on Systems Engineering (ISSE)*, IEEE, 2020, pp. 1–8.

[8] Object Management Group, *Systems Modeling Language (SysML®) v2 Request For Proposal (RFP)*, Jun. 2018.

[9] Object Management Group, *Systems Modeling Language (SysML®) v2 API and Services Request For Proposal (RFP)*, Jun. 2018.

[10] E. Bader, D. Vereno, and C. Neureiter, "Facilitating user-centric model-based systems engineering using generative ai", in *Proceedings of the 12th International Conference on Model-Based Software and Systems Engineering - MBSE-AI Integration*, 2024, pp. 371–377, ISBN: 978-989-758-682-8. DOI: 10.5220/0012623200003645.

[11] T. Ohno, *Toyota production system: beyond large-scale production*. Productivity press, 2019.

[12] K. Abu Bakar, M. F. Mohd. Sam, and M. I. Qureshi, "Lean manufacturing design of a two-sided assembly line balancing problem work cell", in *Symposium on Intelligent Manufacturing and Mechatronics*, Springer, 2021, pp. 249–259.

[13] J. Womack, D. Jones, and D. Roos, *The machine that changed the world, based on the Massachusetts Institute of Technology 5-million-dollar 5-year study on the future of the automobile*. New York, NY: Rawson Associates [u.a.], 1990, VIII, 323, ISBN: 0892563508.

[14] B. W. Oppenheim, "Lean enablers for systems engineering", in *INCOSE International Symposium*, Wiley Online Library, vol. 20, 2010, pp. 1996–2092.

[15] B. W. Oppenheim, *Lean for systems engineering with lean enablers for systems engineering*. John Wiley & Sons, 2011.

[16] E. Brusa, “Synopsis of the mbse, lean and smart manufacturing in the product and process design for an assessment of the strategy" industry 4.0".”, in *CIISE*, 2018, pp. 21–30.

[17] A. Buczacki, “An integrative model based systems engineering (mbse) and lean-based approach for development of new complex products”, *Multidisciplinary Aspects of Production Engineering*, vol. 2, no. 1, pp. 425–434, 2019.

[18] C. Allen, M. Di Maio, G.-D. Kapos, and N. Klusmann, “Mddp: A pragmatic approach to managing complex and complicated mbse models”, in *2016 IEEE International Symposium on Systems Engineering (ISSE)*, IEEE, 2016, pp. 1–8.

Increasing Manufacturing Resiliency by Using an In-line Qualification Approach

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***Abstract*—Improving flexibility in the manufacturing industry has always been a challenge. Workers at assembly lines have to cope with a flexible and rapidly changing production process. To meet these challenges, an assistance system is proposed that is used during the production process to provide workers with near real-time instructions regarding changes to the production process. This enables the development of a versatile production range that includes large and small series, as well as customised solutions. An example of an automotive assembly line is used to demonstrate the feasibility of the system. In conclusion, the proposed system advocates an in-line qualification process for workers that would facilitate a paradigm shift towards agile manufacturing and lead to a significant increase in resilience.**

Keywords-Resiliency; Assistance System; Agile Manufacturing; In-line Qualification; Change Management.

I. Introduction

Resilience is an essential attribute of manufacturing systems as it provides the ability to withstand challenging circumstances and adapt to disruptions without incurring significant additional costs [1]. The five key components of operational resilience, namely a) risk identification and management, b) business continuity planning, c) IT resilience, d) crisis management and response, and e) adaptive governance and culture, serve as the foundation for a comprehensive and effective resilience approach [2], [3].

This section examines the motivation, challenges, aims, research questions and contribution of this study. Our objective is to facilitate a flexible production that includes both large and small series as well as customer-specific production. To accomplish this, we have created a corresponding near real-time assistance system that promptly provides workers with guidance on modifications to the production process.

A. Motivation

Manufacturing is a critical component of economic activity. Therefore, a comprehensive approach is needed to fully understand and model resilience. It is not enough to consider only raw material shortages, disruptions from natural disasters, such as earthquakes, or expert commentary as determinants of resilience. Instead, a careful examination of all current and emerging variables that affect the manufacturing sector is required. The incorporation of deep and broad learning has emerged as a promising solution to improve the predictability of the manufacturing sector and strengthen its resilience to changing circumstances. These technologies have the potential to address data generation and analysis, making them ideal candidates to address the modern challenges faced by manufacturers [4].

Although organisations are aware of the importance of resilience, they often struggle to determine the extent of their resilience needs. They may lack an understanding of the true meaning of resilience and, as a result, may not be aware of the appropriate level of investment required for resilience. In addition, companies may be unsure of the level of effort required to establish a resilient operating framework across their organisation. Some companies have taken the initiative by appointing a single individual to focus on building resilience, while others have created dedicated teams to address this challenge. To foster resilience, organisations need to develop a wide range of capabilities that allow them to increase visibility, flexibility and speed of response to disruptions. Achieving just a few of these qualities is not enough [5], [6].

B. Challenges

Designing a resilient production environment has many implications for workers and foremen. The following extracts outline the main challenges associated with this flexible production process, particularly from the perspective of the worker (trainee) and the foreman (trainer).

Chall:Effort: Workers receive more information in the same amount of time, resulting in more training hours for them.

Chall:Relevance: As workers are given more information in the same amount of time, there is also a higher risk of overwhelming them with irrelevant content.

Chall:Timeliness: If workers are absent for a period of time, for example due to sickness or holidays, it is more likely that changes, and therefore the provision of new training materials, will fall into this period. As a result, workers may receive the new information too late or not at all.

Chall:Accuracy: More information in the same amount of time also has an impact on the quality of training materials. Trainers produce a lot more material in the same amount of time, resulting in more work for them. This increases the risk that the information provided is not detailed enough and that workers make mistakes in production processes when following the new instructions.

Chall:Understandability: The same argument leads to an increased risk that instructions will not be clear and unambiguous enough for workers to act as intended by the trainers.

Chall:TailoredSummaries: Trainers have to go through a larger amount of material, which increases the risk that summaries of information are not always tailored to the target audience.

Chall:Device: As workers in a resilient production environment should access information in a flexible manner close to their workstations, the increased amount of information needs to be prepared and presented not only on papers but also on different digital devices, such as mobile phones, tablets and Virtual Reality (VR) lenses, leading to a higher effort for preparing and presenting the information.

Based on the challenges identified and presented, an appropriate solution addressing the challenges must satisfy the following requirements:

Req:Effort: There should be no additional training effort for workers and preparation effort for foremen (Chall:Effort).

Req:Relevance: To avoid overwhelming users with irrelevant content, it is crucial that the information provided is pertinent to their specific workplace and job responsibilities (Chall:Relevance).

Req:Timeliness: Revised guidelines must be communicated and made available in a timely manner, ensuring they are current before being put into practice on the assembly line (Chall:Timeliness).

Req:Accuracy: Ensuring the accuracy of the provided information is crucial to prevent mistakes when following the new instructions (Chall:Accuracy).

Req:Understandability: It is essential that instructions are clear and unambiguous for the intended audience, enabling them to act in accordance with the information provided (Chall:Understandability).

Req:TailoredSummaries: The provision of tailored summaries, such as information sheets and training videos, is contingent on the user's role. Consequently, different materials must be made available to those with different roles, such as workers, apprentices, engineers, and students. There should be no additional burden on those responsible, e.g., time-saving compilation of information for foremen, meaningful amount of new information for workers (Chall:TailoredSummaries).

Req:Device: In addition to monitors affixed to machinery, the information should be presented on diverse output devices, with a preference for mobile technologies, such as tablets and VR lenses, thereby enabling personnel to access the data in a flexible manner in proximity to their workstation (Chall:Device).

Req:Notifications: Workers should be automatically notified of appropriate changes and should also be able to manually retrieve changes based on specified filters, e.g., only display information from the present time up to three weeks prior (Chall:Notifications). Potential alterations to the structure of incoming data must be detected (Chall:Understandability).

Req:PushPullData: The proposed system should incorporate two distinct notification approaches: a 'push' mechanism, which automatically presents updates to the employee via a specified medium, and a 'pull' mechanism, allowing for selective retrieval of information. This dual-strategy solution should be implemented to ensure that workers can receive automatic notifications of changes, as well as have the ability to access specific updates as needed (Chall:Notifications).

Req:Adaptability: It is essential that the solution is adaptable, facilitating its implementation in a variety of work environments, including various workplaces, maintenance areas, and industrial plants (Chall:Adaptibility).

Req:DataSources: Input data must be derived from diverse sources across various locations, encompassing a wide range of materials. These include operational guidelines, user manuals, scholarly articles, both two-dimensional and three-dimensional illustrations, computational models, quality control documents, instructional guides, and information generated by machinery.

Req:DataFormats: Information has to be presented in various formats, including textual, visual, auditory, and video content. For instance, data can be stored in file formats, such as ASCII, HTML, PNG, or TIFF.

C. Aim

The overall aim is to provide a flexible production range, encompassing both large and small series, as well as customised production by developing an appropriate worker assistance system. Assistance systems are technical systems that support people in performing activities and make task processing more efficient, and may be partially based on artificial intelligence. Worker assistance systems are assistance systems that provide production workers with the information they need at their workplace, supporting and guiding them step-by-step through complex work processes. The information provided is tailored to the worker's level of knowledge and needs.

Designing a resilient production environment in training will lead to an increase of the frequency of worker training. The understanding for the systems at the work places of workers can be increased by disseminating knowledge and offering training content. Real-time provision of targeted information is an requirement to achieve this. The aim is to facilitate a continuous knowledge transfer. This can be achieved by avoiding the need for time-consuming off-line instructions. Virtual post-its on the assembly line, alerting workers to new information, can serve as a thought model.

Thus, the primary objective of this study is to provide a practical approach to the in-line qualification of workers, which in turn leads to more flexibility in the production process, enabling agile manufacturing and ultimately increasing the resilience of the organisation. The aim is to develop a methodology that is independent of the specific use case presented here, so that its implementation can be easily adapted to similar cases in the manufacturing industry. Furthermore, the generic approach allows the methodology to be applied to analogous problems where in-line qualification is required.

Based on the aim, the main research question of this investigation and a corresponding research thesis are given.

Research Question 1 (Feasibility study) *To what extent is it possible to create an worker assistance system for the in-line (i.e., during the production process itself) qualification of workers", so that the requirements described above are met?*

Thesis 1 (Assistance system fulfils requirements) *The assistance system proposed within this study meets all requirements given above and thus addresses the worker's needs and challenges given in Section I-B effectively.*

D. Contribution

We present a solution concept, including some implementation details, with the aim of achieving in-line qualification of workers in the manufacturing industry in near real-time, i.e., as soon as the change in the production process specification reaches the information system. To avoid confusion, the term "near real-time" is used, which implies that the required latency is not guaranteed, as in real-time systems, but only envisaged. In simple terms, for real-time systems, the latency of the system is part of its functional correctness; a near real-time system will function correctly if the required latency is inadvertently not achieved.

We illustrate the feasibility of the concept for an example from the manufacturing industry assembly line. The concept is largely independent of the research projects mentioned above and can therefore be easily transferred to other research/industry projects.

E. Paper organisation

The remainder of this paper is structured as follows. Section II provides an overview of existing work related to the problem described. A description of the strategy is presented in Section III. Section IV demonstrates the feasibility of the strategy using an example of a car assembly line. The presentation of the main results and discussions based on these results constitute the content of Section V. Section VI summarises this contribution and draws perspectives for future work.

II. Related work

This section examines the current advancements and relevant research in the realm of assistance systems, whilst also introducing the fundamental concept behind these systems. Following this, a comprehensive overview will be provided, detailing the applications of assistance systems across various domains in both industrial and research settings.

As we enter the era of Industry 5.0, defined by the integration of digital technologies with human-centric approaches, assistance systems are playing an increasingly crucial role in reshaping the manufacturing landscape. Unlike previous industrial revolutions that primarily emphasised machinery and automation, Industry 5.0 focuses on blending state-of-the-art technologies with human innovation and inventiveness [7]. In this context, assistance systems have emerged as a fundamental shift towards achieving Vision 5.0 [8].

Cognitive systems are advanced technological solutions capable of autonomously tackling human challenges and formulating strategies [9]. These systems offer customised information, assist in overcoming skill gaps, and aim to enhance social innovation, employee contentment, and well-being [10], [11]. Contemporary assistance systems are typically highly focused and task-specific, digitally encapsulating expert knowledge. There is no single, all-encompassing solution applicable across various industries. Assistance systems are technological tools that aid individuals in carrying out tasks and improve the efficiency of task completion, sometimes incorporating artificial intelligence. In the manufacturing sector, worker assistance systems furnish production staff with essential information at their workstations, offering guidance and support throughout intricate work procedures. The information provided is tailored to suit the individual worker's expertise and requirements [12].

The concept of Industry 5.0 envisions future manufacturing facilities that are sustainable, resilient, and human-centric. These facilities will demand intelligent and adaptable capabilities from both advanced production systems and human workers. Furthermore, in the ever-changing landscape of Industry 5.0, employees should possess the flexibility to swiftly alter their roles, either by acquiring new competencies or simply for the sake of variety [13].

A machine operator assistance system termed Self-learning Assistance system for Machines (SAM) has been created for processing machines [14]. This system combines machine learning with human knowledge to reduce production interruptions. Another assistance system, known as "weasl", has been developed as an assembly line control system. It provides employees with work plan options tailored to their individual qualifications [15]. Additionally, a self-learning fault assistant for machines has been introduced [16], which analyses failures and proposes solutions. This system merges artificial intelligence with human expertise to generate a novel dimension of knowledge.

Visual Knowledge Share (VKS) software [17] serves as a versatile system for assisting workers, enhancing production processes through the implementation of dynamic and interactive digital work instructions. The system offers step-by-step visual guidance based on qualifications, enabling quick adaptation and reducing the likelihood of human error. Schaeffler Special Machinery [18] bolsters its capabilities by integrating intelligent, Artificial Intelligence (AI)-powered assistance systems that aid in the supervision and management of production processes. Additionally, the rule assistant creates a link between occurrences and suggested actions (Schaeffler Machinery Ass Systems).

The Fraunhofer Institute offers support systems for manufacturing settings. Furthermore, it delivers research and development solutions related to sensor-based worker aid in assembly environments [19]. In a recent project with a leading automotive supplier, Fraunhofer has created a prototype system that supports an employee working on a semi-automated production line who manages several machines. The system employs various proprietary algorithms to determine optimal work procedures based on current machine and sensor information. Subsequently, the worker is notified of the best next action via LED strips on the floor, a smartwatch, or a large display system in the facility [20].

A study in [21] examines current technological support in the form of worker assistance systems. The research identified three main categories of these systems: sensory, physical and cognitive. The Executive Level for Assembly Manufacturing processes system (ELAM) [22] offers a viable solution for industrial manufacturing facilities where manual assembly of components into products is performed. This system is particularly beneficial in environments where product specifications are variable and multiple versions of the same item are produced. ELAM ensures that workers receive necessary information at the most appropriate time and place throughout the factory and at all required points. In [23], a sensor-based worker assistance system is described. This system enhances equipment operation, boosts production capacity and improves the reliability of processes.

The Fraunhofer IOSB-INA [24] specialises in creating customised assistance systems for various manufacturing environments. These systems are designed with modularity in mind, enabling their application across a wide spectrum of scenarios. They can support both unskilled and skilled workers in complex assembly tasks, as well as provide aid to individuals with cognitive and physical disabilities. This approach paves the way for more inclusive employment opportunities in the manufacturing sector.

A system for production planning and control that focuses on human-centred assistance is described in [25]. This system also offers decision support recommendations to aid operators in managing production. In [26], a worker assistance system for manual production tasks is introduced. This system can provide real-time instructions through sophisticated image processing and is suitable for deployment in areas characterised by high assembly variance, fluctuation, and complex process sequences. Such environments create a persistent high demand for training in manual production tasks.

Research outlined in [27] introduces a novel worker assistance system aimed at enhancing the subsequent optical end-of-line inspection procedure. Following assembly, components are positioned before the system's camera for examination, which simultaneously provides automatic and uninterrupted documentation. This method ensures comprehensive optical inspection, thereby enhancing product quality irrespective of operator engagement

A novel assistance systems has been created that considers human factors in manufacturing environments [28]. This system adapts both equipment and directives provided to employees based on their individual cognitive and physical needs. The DESC worker assistance platform [29] delivers comprehensive information to production staff at their work areas, whilst simultaneously guiding them through intricate operational procedures. It supplies the appropriate information for each process at the optimal moment, taking into consideration the worker's expertise level and personal requirements.

A classification of worker assistance systems in manufacturing, taking into account the human element, is given in [30]. An approach to the application-specific design of worker assistance systems in manufacturing is given in [31]. ShopWorx, an assistance system, improves operational efficiency by providing relevant production information in a timely manner. The system provides near real-time trends and predictions that enable operators to take proactive measures before problems occur and make decisions that optimise production [32].

A novel system to assist workers has been created to support both skilled and novice employees throughout the entire packaging procedure. This system offers detailed and accurate instructions for each step, particularly for intricate tasks [33]. A comprehensive examination of assistance systems is presented in [34], with a specific focus on assistance technologies designed for use in manufacturing settings.

Assistance systems have been developed and implemented by Bauer Maschinen [35] to streamline increasingly intricate work procedures. These systems also serve to safeguard both personnel and machinery by preventing incorrect equipment operation. Enhanced drilling performance and reduced wear on machinery and tools are achieved through rapid and automated control and regulation mechanisms. A key strength consistently offered by Bauer equipment is its superior human-machine interface.

PSI Technics [36] has developed "mupudia", a versatile digital assistant designed for various industrial applications. This tool provides step-by-step guidance to workers across multiple processes, including assembly workflows, quality control in production, repair and maintenance procedures, and the setup of systems and machinery. Assistance systems [37] play a crucial role in enhancing virtual product and process development. Research is underway to create and analyse techniques for finite element simulations.

Assembly by Motion [38] presents a novel worker support system that can be readily incorporated into existing setups. It offers automated management of logistics, manufacturing, and quality processes, unifying them into a single platform. The system aggregates information from camera-based surveillance of production stages and tracks both the workpiece and logistics. Ulixes [39] delivers a comprehensive approach to aiding workers on assembly lines, offering guidance across all aspects. In [40], a portable assistance system is introduced, supporting the smart factory of the future through a flexible and adaptable modular design. A framework for classifying assistance mechanisms in the realm of intelligent manufacturing is presented, taking into account ongoing academic research [41]. Last, but not least, a framework for designing Industry 5.0 smart manufacturing systems, centred on the symbiosis between humans and automation, has been examined [42]. This approach enables both machines and humans to generate knowledge and learn from one another, fostering a beneficial co-evolution. It aids in comprehending the interplay between humans and machines, as well as facilitating the development of effective collaboration between individuals and intelligent manufacturing systems. Furthermore, the ISO 23247 series defines a framework to support the creation of digital twins of observable manufacturing elements including personnel, equipment, materials, manufacturing processes, facilities, environment, products, and supporting documents. A digital twin assists with detecting anomalies in manufacturing processes to achieve functional objectives, such as real-time control, predictive maintenance, in-process adaptation, Big Data analytics, and machine learning [43].

In conclusion, this work's approach sets itself apart from conventional assistance systems by allowing workers to qualify in-line on the job, thus enabling and adapting manufacturing processes, including those for bespoke or small-scale production. Traditional assistance systems only offer vocational training offline, separate from the production process. It is important to note that there is no one-size-fits-all assistance system; the specific domain and system context must be considered when implementing such systems. In comparison to version control systems like Git [44], the proposed assistance system can handle not only text-based content, but also visual, audio, and video formats. Generally speaking, the scope of the presented assistance system differs substantially from that of ours. The objective of the existing technology was to create and deploy systems that would assist workers throughout the manufacturing process, thereby easing their tasks. In contrast, this investigation centres on the potential for assistance systems to facilitate flexible production methods and, as a result, enhance resilience.

III. Strategy

This section explicitly delineates the focus of the underlying investigation, providing a concise overview of the motivations and objectives of the study. Furthermore, the strategy that will be employed to achieve these goals is outlined. This is in relation to the detailed use case study presented in Section IV.

To reiterate, the aim is to design a resilient and agile production environment and to increase the understanding of the system by disseminating knowledge. More specifically, the aim is to achieve a continuous, scalable, near real-time transfer of knowledge so that the solution can be used in a variety of industrial contexts, including different plants and workshops.

The basic idea is to achieve this by eliminating the need for time-consuming offline instructions: Relevant changes in manufacturing processes should be automatically detected and workers should be informed about changed technical specifications, e.g., by updating relevant drawings, manuals, quality specifications. The changes are prepared for learning content and then displayed as push messages to machine operators while they are working on the machine (e.g., on a tablet, on AR glasses, on a monitor at the machine). The idea can be illustrated by the following thought model: Post-its on assembly line walls notifying workers of changes are replaced by virtual post-its notifying workers of relevant changes in a timely manner.

The proposed solution concept for the in-line qualification of workers is depicted in Figure 1. It contains the following main components:

Database server: A database server with data repositories as sources of relevant data for employee training. A variety of data sources are taken into consideration, including operating instructions, manuals, scientific publications, two- and three-dimensional drawings, scientific and technical publications, simulation models, quality specifications, tutorials, machine data.

Back-end: A back-end to prepare the relevant data. The back-end contains modules for pre-processing the data in a structured form, for storing the data and for detecting changes in the data. The pre-processing stage must yield high-quality data to ensure optimal performance.

Front-end: A front-end for appropriate presentation of relevant changes based on the changes extracted in the back-end.

The solution concept includes a classic server-client application with both back-end and front-end components. It places significant emphasis on the crucial aspects of IT security, maintainability and modularity.

The general procedure for delivering new learning content follows the specification of the flowchart features as described below. The procedure is also depicted in Figure 1 in terms of green arrows.

1) The back-end periodically polls the database server for new data.
2) If new data is available, then it is transferred to the back-end.
3) The back-end converts the data into a structured form, depending on the data type and format, and extracts the necessary metadata (such as author and date title).
4) The data is then stored in a database.
5) The module „Change detector" checks the data for changes. The current set of data is compared to its predecessor set.
6) Within the database, a visualisation data mart is set up, which organises changes in such a way that direct access to the database is reduced to a minimum.
7) Detected changes are automatically pre-selected based on plant, workstation, station, role and change type filters (module „Automatic pre-selection").
8) The pre-selected changes are checked for relevance by an expert (e.g., the foreman) at the beginning and further adjusted if necessary. Wrong changes marked as relevant are filtered out by the expert.
9) The remaining changes are then linked to didactic templates to compile the extracted information into role-specific learning and training content.
10) The learning content generated in this way is stored as instructions in another database (instructions database) and indexed for quick access using appropriate keywords.
11) The front-end regularly polls the instructions database for new instructions (push mode).

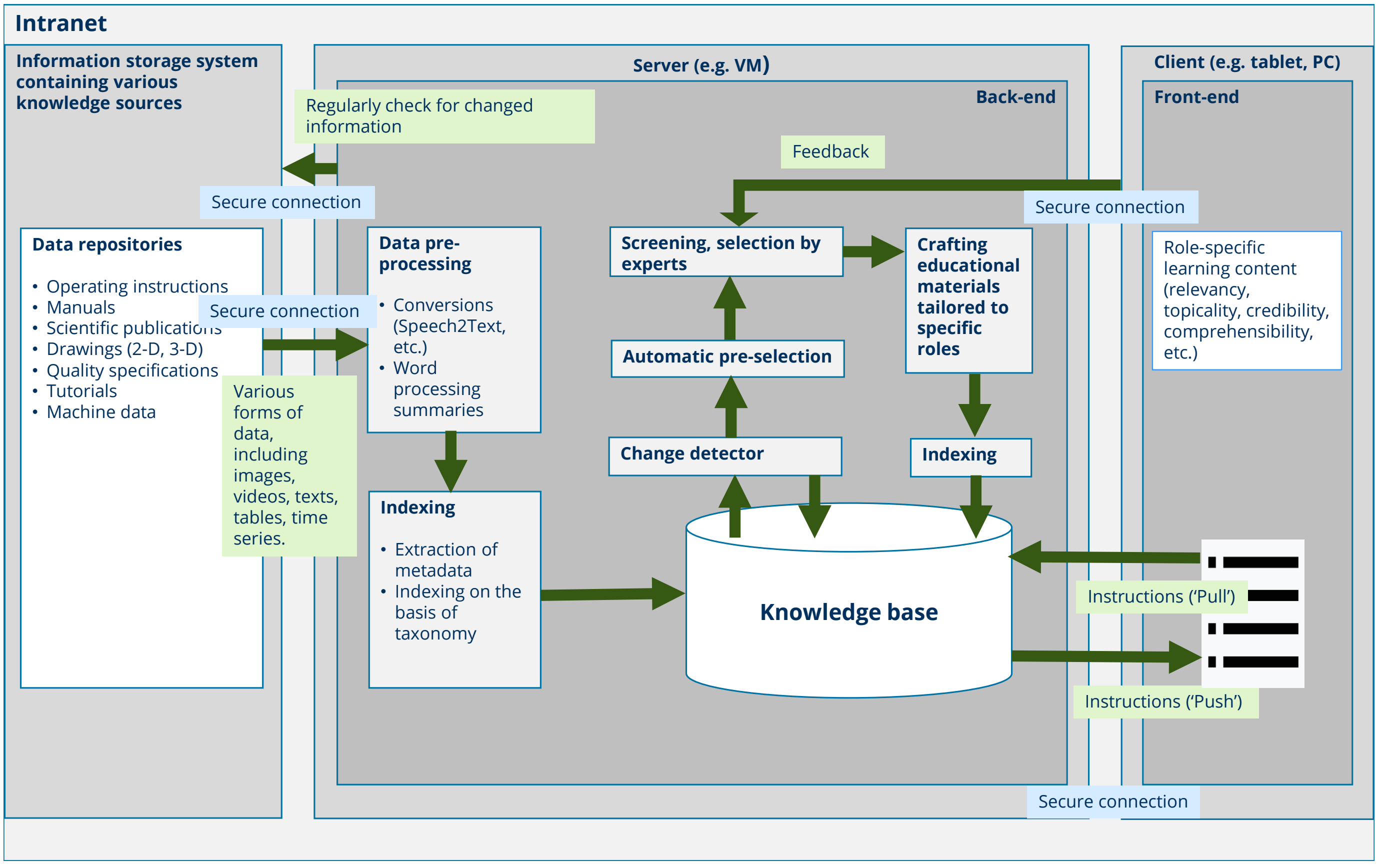

Figure 1: Diagram presenting an overview of the solution concept. The procedure for delivering new learning content to workers is depicted by green arrows.

12) Alternatively, the query can be made explicitly via the graphical user interface (pull mode).

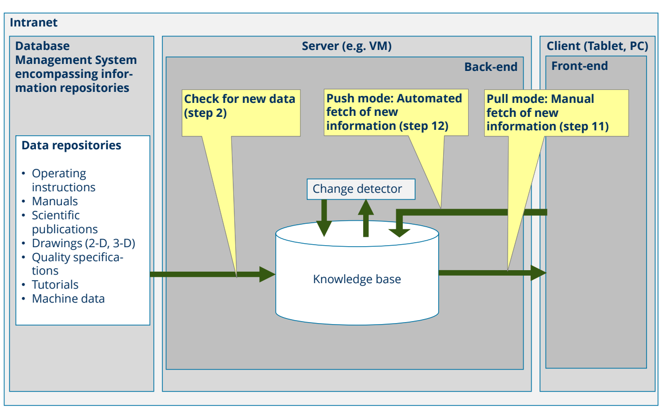

Figure 2: Visual representation showcasing near real-time concept principles. The numbering of the steps inside the yellow boxes correspond to the workflow steps in Section III.

Figure 2 illustrates the core principles of the near real-time approach. The proposed assistance system provides workers with near real-time instructions regarding modifications to the production process. A comprehensive explanation of the near real-time approach implementation will not be given here.

In terms of data source criteria, the use of historical, anonymised documents is generally considered acceptable. Data must have a high degree of structure, and information should be accessible through well-established interfaces or conventional database queries.

As the proposed solution is mainly intended for assembly line workers, the input data is assumed to be text-based assembly documents. These documents contain information about the work processes and the parts and tools involved in the work processes. In order to model the assembly documents within a relational database, the documents have been represented by several tables containing all work processes and partial work steps, required parts and required tools of each work process. The tables are described in detail by the columns they contain in Tables I, II, III and IV.

In the following, the features of the solution concept are identified and compared with the requirements in Section I:

Feat:Adaptability: The adaptability of the solution is achieved by standardising the architectural design, thereby ensuring a consistent data framework is used throughout. This enables the solution to be adapted to different work environments, including offices, service areas and manufacturing facilities. As a result, this approach also enhances the portability of the data itself. Presently, the quantity of data that can be accumulated (in regard to the instruction

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TABLE I. METADATA / TABLE COLUMNS FOR MODELLING WORK PROCESSES

Name	Description
IdList	Global identifier of list with work process in document
Id	Local identifier of work process
Description	Description of work process
EstTime	Estimated time in minutes for executing the work process
IdListPartWorksteps	Identifier of list with part work steps related to a work process
IdListParts	Identifier of list with parts required for given work process
IdListTools	Identifier of list with tools required for given work process

TABLE II. METADATA / TABLE COLUMNS FOR MODELLING PART WORK STEPS

Name	Description
IdList	Global identifier of list with part work steps
Id	Local identifier of part work step
Description	Description of part work step

TABLE III. METADATA / TABLE COLUMNS FOR MODELLING PARTS OF A WORK PROCESS

Name	Description
IdList	Global identifier of list with parts of a work process
Id	Local identifier of part
Description	Description of part

worksheet) is constrained by the stipulation that any proposed alteration must be endorsed by line managers or their equivalents and subsequently consolidated across all work areas. (Req:Adaptability)

Feat:Portability: In contrast, portability is attained through the utilisation of virtualisation techniques, encompassing both the operating system level, where virtual machines (VM) are employed, and the application level, where Docker containers and Docker Swarm are utilised.

Feat:NearRealTimeDatabase: The database is structured in a manner that allows for the efficient identification and retrieval of new information records, irrespective of the size of the database. (Req:NearRealTimeDatabase)

Feat:VisualizationDataMart: The most recent information records, including the requisite changes relative to the predecessor, are stored in suitable structures. (Req:VisualizationDataMart)

Feat:PushPullData: Push and pull strategies are foreseen in order to facilitate the retrieval of changes. (Req:PushPullData)

Feat:StructuralChanges: Unforeseen structural changes for example of the worksheets are structurally checked, as well as full range of plausibility checks of the data. For example, if a new unknown attribute turns up on the worksheet then this irregularity is identified, preventing confusion amongst the remaining valid attributes' values. Furthermore, if an attribute's expected value is incorrect or contains unexpected characters, an appropriate notification is generated, and suitable measures are implemented. Overall, conventional plausibility checks are employed. These checks are performed during the parsing process of the assembly instructions. (Req:StructuralChanges)

TABLE IV. METADATA / TABLE COLUMNS FOR MODELLING TOOLS OF A WORK PROCESS

Name	Description
IdList	Global identifier of list with tools of a work process
Id	Local identifier of tool
Description	Description of tool

Feat:PersonalView: The structure of the instruction worksheets: plant, department, down to production line, station, workplace has been used to set up the appropriate role concept, such that only the involved personal was informed about the changes. (Req:PersonalView)

Feat:DataSources: Within the implementation as of today only the assembly instruction is parsed and considered, but additional data sources are considered. (Req:DataSources)

Feat:DataFormats: Various data storage formats can be handled. (Req:DataFormats)

Feat:IdentificChange: In order to be able to detect the structural changes in the worksheets, a "change detector" has been implemented upon the "knowledge base", see Figure 3. These changes are then forwarded to the "visualisation datamart". (Req:IdentificChange)

Conclusion 2 (Solution concept fulfils requirements) *The proposed solution concept for the assistance system fulfils the requirements stated in Section I.*

The validity of Conclusion 2 follows directly from the descriptions of the features given above. Thus, the research thesis in Thesis 1 has been shown.

In conclusion, the proposed methodology advocates a paradigm shift in the manufacturing sector towards in-line worker qualification. This shift is in line with the principles of agile manufacturing and ultimately improves resilience.

IV. USE CASE

The following section demonstrates the feasibility of the proposed solution concept as outlined in Section III. For this purpose, the concept has been applied to a use case from a joint research project in the automotive domain.

The joint research project, entitled "From the conventional production plant to the resilient competence plant through Industry 4.0" (Werk 4.0), is focused on the development of flexible manufacturing solutions for the future [45]–[48]. The project aims to create and implement a robust production concept that incorporates the latest technological developments. This will facilitate the timely production of future products and enable a more rapid adaptation to unpredictable changes

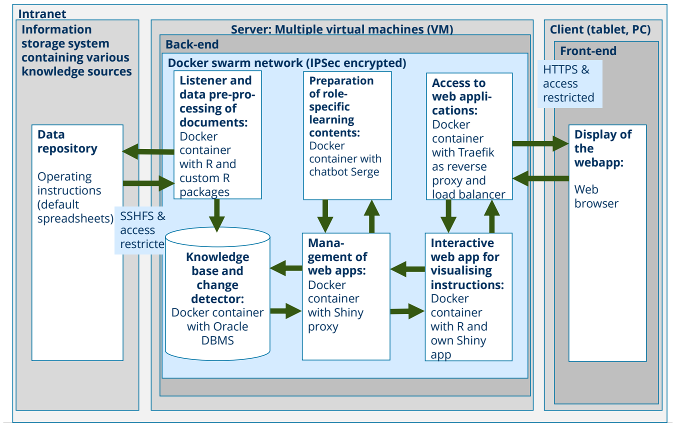

Figure 3: Overview of software tools employed within solution concept.

in market and technology requirements. The introduction of an assistance system and intuitive robot and machine operation and programming on the shop floor will facilitate the physical aspects of the workers' roles and relieve them of repetitive tasks, thus improving their work experience and reducing the physical strain associated with their roles [47].

One of the building blocks in the joint research project for a resilient production environment is the in-line qualification of workers. For this, the solution concept in Section III is applied to the specific settings within the joint research project. This involved a number of specific requirements including a focus on IT security, ease of maintenance and modularity, such as deployment at project partner Mercedes Benz (MB) and the use of standardised documents for assembly processes in PDF format.

The solution concept presented in this study forms the basis for the software prototype used within Werk 4.0. The implementation details of the solution concept are given in terms of the software tools which has been used. The employed tools in the workflow are shown in Figure 3.

In order to check if the software tools meet the system requirements in practice, especially considering the specific requirements in Werk 4.0, the features of the tools will be compared to the requirements given in Section I.

VMs: The portability of the system is ensured by virtualisation at the operating system level using virtual machines.

Docker containers: In order to ensure modularity, the software has been divided into micro services. The micro services are encapsulated in Docker containers. T Docker containers enable applications to run on different operating systems, providing isolation from their environment. This way, used tools can be easily adapted or replace, thus supporting the "Req:Adaptability" requirement.

Docker Swarm: The Docker Swarm Network (IPSec encrypted) simplifies the management of Docker container clusters. This system allows users to dynamically adjust the number of containers based on demand, effectively managing traffic spikes and maintaining application performance and uptime. In addition, Docker Swarm improves application resiliency by allowing containers to be distributed across multiple nodes within the cluster, ensuring continuous service availability even if a node fails [49]. So while it primarily addresses "Req:Adaptability", it also helps to address other requirements such as load balancing and therefore scalability.

HTTPS and SSH connections: Data transfer is secured using secure transfer protocols, such as HTTPS and SSH, with incoming data redirected from web requests over HTTP to HTTPS.

Docker networks: Separate Docker networks are used for the front-end and back-end. In addition to encrypted communication via HTTPS and SSH, encrypted data transfer between Docker containers is done at the network level via IPsec. This helps to ensure the IT security of the implementation.

ufw: The ufw program is an open-source tool for managing netfilter firewalls. It is used inside virtual machines to improve IT security.

Traefik: Load balancing of incoming requests is managed using Traefik in combination with Docker Swarm. Traefik also acts as a reverse proxy, hiding internal addresses from the outside world. This allows requests to be routed and filtered to the appropriate Docker containers. Traefik acts as a Docker-compatible reverse proxy, allowing multiple applications to run on a single Docker host. This helps meet scalability and IT security requirements.

Oracle DBMS: The Oracle DBMS serves as a knowledge base within the workflow. Oracle DBMS is a commercial multi-model and multi-purpose database [50]. It was chosen to maintain simplicity in implementation. Appropriate structures for addressing the predecessor of a new information record have been developed within the system so that the time to identify and retrieve such records is almost independent of the size of the database. This contributes to the near real-time and scalability requirements.

Makefiles: Makefile rules and shell scripts are available for sharing and convenient software deployment. This contributes to the usability requirements on the deployment side.

Serge: The chatbot Serge provides an Artificial Intelligence (AI) based conversational system. The chatbot is responsible for processing the changed information into appropriate learning content using Large Language Models (LLM). The main advantage of Serge is that it can be fully deployed locally, including data storage, to meet the strict IT security requirements.

R and shiny: R is an established open-source programming language with a focus on statistical analysis. It is used in the data pre-processing and data preparation phase of the workflow. The R package shiny allows the creation of modern, interactive web applications in R.

Shinyproxy: Shinyproxy is an open-source tool for deploying data science applications. It is used to manage the front-end web application. Shinyproxy supports established and modern authentication/authorisation technologies. In this way, it contributes to the requirements of scalability, modularity and IT security.

As described in the solution concept, the changed information is made available to the workers. For this purpose, a web application in the form of a dashboard has been created to facilitate the visualisation of instructions and changes, see Figure 4. The web application serves as a research demonstrator to show the feasibility of the proposed solution. The focus is on functionality, not on usability and user experience. The following features are implemented:

1) Multiple drop down menus are available for filtering relevant information.
2) The current filter settings are displayed for control purposes.
3) Further drop down menus are available to filter relevant changes, ranging from time intervals to number of recent changes.
4) A summary of changes including number of documents changed, number of information changed is displayed via information boxes.
5) A high level overview of changes at document level is given in the form of a table with columns for document format, document name, file size and a global document identifier. The visibility of the columns can be controlled using a multi-select menu.
6) A detailed overview of changes to assembly instruction worksheets at record level is given in the form of a table with columns including the local identifier, the description of the changed step within the worksheet format.
7) Data within the tables and selection menus is redacted for privacy reasons.
8) A button is available to manually query the database in the back-end to retrieve changes from the database.
9) In addition, the web application polls the database at regular intervals.
10) The web application is designed for multi-user operation, allowing different users with different roles to use the system and receive personalised information. For example, the system currently provides assembly instructions to different users from different work environments, including foremen, maintenance technicians and assembly workers. These users are distinguished by both group identifiers (roles) and individual identifiers. The identification process (authentication and authorisation) ensures that each person accessing the web application receives information specifically filtered to match their job responsibilities and duties.

In summary, the software tools used in the solution concept fulfil the requirements listed in Subsection I-B, see Figure 3 and the comparison of features and requirements in this section.

V. Outline of the Results

In the following, the results are outlined, the advantages and disadvantages of the proposed solution are discussed and some of the areas in which it is applicable are given.

The main research question, "To what extent is it possible to create an assistance system for the in-line qualification of workers", has been affirmatively addressed, fulfilling the requirements outlined in Section I, compare 1. Requirements were identified to tackle the challenges arising from the main research question. Based on the requirements, an appropriate solution concept has been developed which satisfies all requirements, compare Conclusion 2.

The main advantage of the system is that it helps workers to qualify for their tasks during the production process itself by displaying the changes on devices such as tablets, smart screens and VR glasses, thereby promoting flexibility in the production process. However, it is important to note that this system is not intended to replace traditional vocational training, which remains a necessary prerequisite.

The results presented are not limited to the use case presented, and the strategy can be used generally in the production environment. The prerequisite is that the production flow is stable, so that the latest set of work instructions is taken as the base value.

Adopting resilience strategies at an enterprise level does not automatically reduce costs and can in fact have a significant financial impact. The main objective of building resilience is to increase flexibility in production and prepare the business for unforeseen and unpredictable future challenges so that it can survive such disasters. However, such measures can have positive side-effects at the business level. For example, establishing an in-line training strategy can significantly reduce training time and costs, including reducing the risk of damage and mis-processing through better guidance.

The novel operational opportunities are associated with the capability for both small-scale and customised production. The suggested solution not only enhances manufacturing resilience but also improves quality by minimising errors through more precise information. Moreover, the streamlined information exchange can result in shortened manufacturing time frames.

As mentioned above, this support system was not intended to replace basic vocational training. The main risk of using such a system is that workers will overlook the change proposals and produce to the outdated specification. Workers always have to react to changes. In this case there should be a time gap between the announcement of the changes and the time when they take effect.

Furthermore, there is no practice phase in general for workers. However, it makes sense that workers can practise the changes if necessary. In order to ease the understanding of the modification proposals teaching videos can be set up.

The approach can only be meaningful and beneficial if production is almost constant, with a low rate of change, so that the worker can adapt to the proposed changes and the time and effort required to assimilate the proposed change does not significantly affect the cycle time of the production process. On the contrary, full offline training is advisable.

In summary, the presented solution concept promotes transformation in the manufacturing sector by advocating an in-line qualification process for employees. This facilitates a paradigm

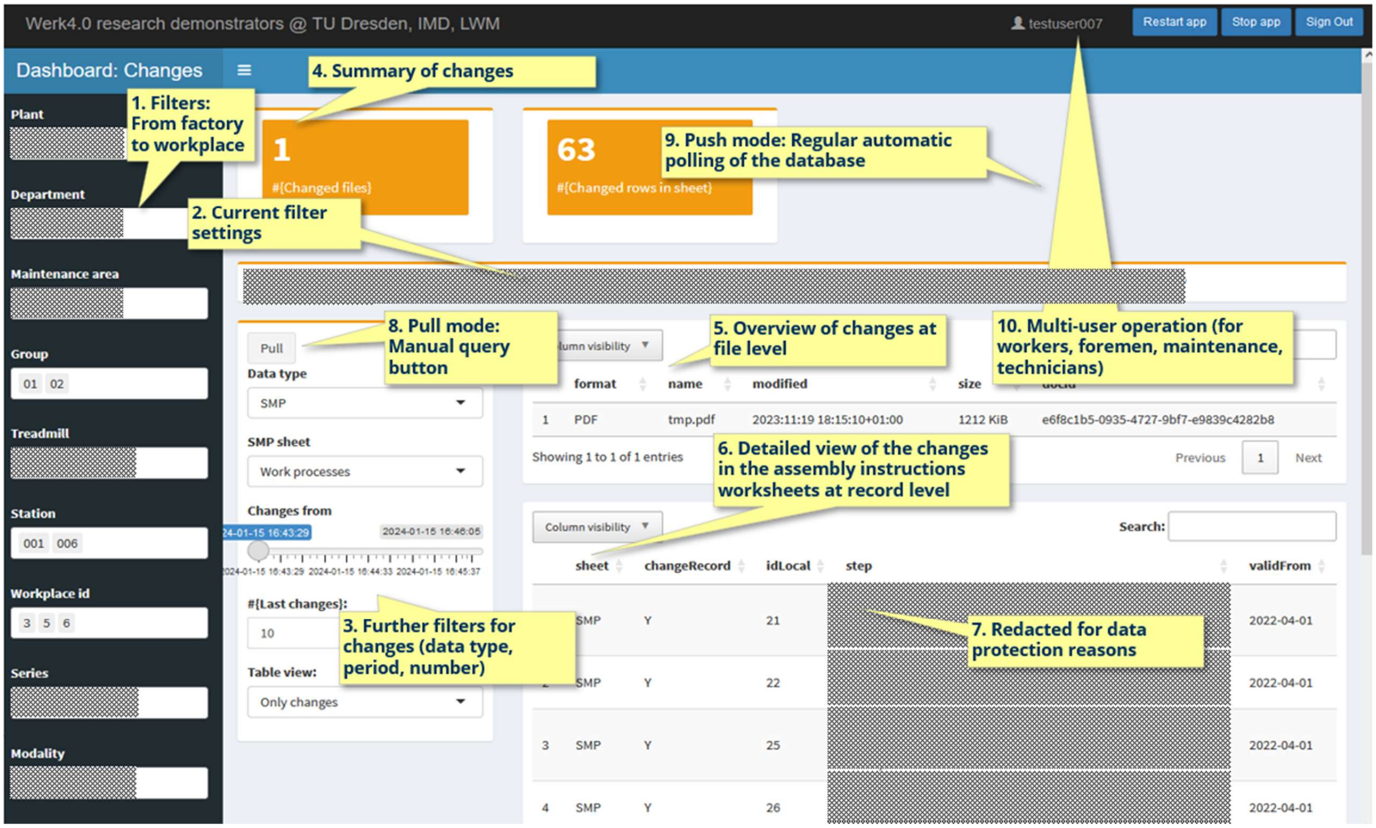

Figure 4: Web application for the graphical representation of new / updated information.

shift towards agile manufacturing and, as a result, an increase in resilience.

VI. Conclusion and Future Work

The primary aim of this study was to increase the ability of manufacturing plants to adapt to change by implementing agile manufacturing methods, this way improving resiliency. To this end, an assistance system has been developed and deployed for the scenario presented, which visualises the proposed modifications to the production process assembly line of a manufacturing plant. However, this assistance system is not designed to replace traditional vocational training, which is still a prerequisite.

A solution concept for the in-line qualification of employees was presented. The solution concept includes a classic server-client application with a back-end and a front-end. The back-end contains the part of the application that is hidden from the end user and the front-end contains the part that is accessible to the end user. The back-end contains the database (knowledge and changes) and the parsing and loading software. The front-end contains the software for visualising the data on target devices, such as tablets and VR glasses. A web-based application running in the front-end has been developed serving as a dashboard for visualising the instructions / changes.

The feasibility of the concept has been demonstrated for an automotive use case. The use case involves processing text-based assembly instruction documents in PDF format and extracting data from the documents using rule-based processes. The extracted data is stored in a relational database, which makes it easy to pre-select relevant change notifications using filters. During the loading process, the current data is compared with the historical data (predecessors) to identify proposed changes, which can then be visualised on appropriate devices. The effort to set up such a system is limited and the benefits outweigh the costs.

The requirements described in Section I were met without exception, including the near real-time requirements. The challenges faced during this research were both content-related and technological. Due to the complex structure of the work instructions, it was a challenge to parse them so that the results could be written into CSV files – which were then loaded into the relational database – taking into account the natural structure of the roles. On the other hand, the near real-time search requirements pose architectural challenges for the design of the database. A detailed description of these architectural difficulties and an appropriate approach is beyond the scope of this study.

Currently, the extracted data is stored in a relational database. For a better understanding of the data structure, an appropriate ontology can be built. In this way, the knowledge base can be queried by people who are not familiar with the structures of relational databases. Chatbots with large language models can be redirected to an internal database to be trained on local data.

There is currently no system in place to automatically verify that proposed changes have been implemented. Implementing automated quality assurance remains a complex challenge. Tracking and documenting changes is critical. A key consideration is the ability to automatically identify certain machining errors. In addition, some anomalies can be detected by examining and comparing tool-related data.

While the theoretical framework and operational specifics have been defined, the practical application at MB has yet to be evaluated in the field. The scope of the joint research project Werk 4.0 is limited to laboratory testing, which precludes any implementation in real production environments. Although discussions have been held with foremen and skilled workers about the potential use and benefits of the concept at MB, true validation in a production environment has not been possible. This remains an objective for future projects. However, more in-depth interviews, additional testing and laboratory-based simulations could provide further insight into the benefits of the concept and its viability within the production process.

It is worth noting that the impact of in-line training may vary significantly depending on the skill level of the workers, with less skilled workers potentially deriving greater benefit from this approach.

Potential applications include manufacturing plants, research centres and pre-shift training programmes for workers. The precise application necessitates further investigation. Due to the brief cycle times, it is not always suitable for use during shifts. A straightforward, unobtrusive user interface is preferable. Augmented reality glasses are particularly well-suited to this purpose.

The automated documentation of experiments from experimental designs necessitates the monitoring of alterations to instrument settings and parameters. Instructional frameworks should be developed in a variety of ways, ranging from a balanced methodology and minimal guidelines to comprehensive training materials. AI-powered conversational agents have the capacity to generate text that can be integrated into these training programmes. The concept of a near real-time relational database solution is introduced, but not developed further.

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REFERENCES

[1] F. Rydzak, P. Magnuszewski, J. Sendzimir, and E. Chlebus, “A concept of resilience in production systems,” in *Proceedings of the 24th International Conference of the System Dynamics Society*. Citeseer, 2006, pp. 1–26, retrieved: November 2024. [Online]. Available: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=029511e64e2f957ada5ebed44e966291e0f66ff7

[2] CLDigital. (2024) 5 Pillars of Operational Resilience You Need to Know Now. retrieved: November 2024. [Online]. Available: https://cldigital.com/blog/5-pillars-of-operational-resilience/

[3] S. E. Galaitsi, E. Pinigina, J. M. Keisler, G. Pescaroli, J. M. Keenan, and I. Linkov, “Business continuity management, operational resilience, and organizational resilience: Commonalities, distinctions, and synthesis,” *International Journal of Disaster Risk Science*, vol. 14, no. 5, pp. 713–721, 2023, retrieved: November 2024. [Online]. Available: https://link.springer.com/content/pdf/10.1007/s13753-023-00494-x.pdf

[4] A. Kusiak, “Resilient Manufacturing,” *Journal of Intelligent Manufacturing 31, 269 (2020)*, 2020, retrieved: November 2024. [Online]. Available: https://doi.org/10.1007/s10845-019-01523-7

[5] J. Key. What Building Operational Resilience Means for North American Companies. retrieved: November 2024. [Online]. Available: https://www.bcg.com/publications/2023/what-building-operational-resilience-means-for-north-american-companies

[6] R. Chen, Y. Xie, and Y. Liu, “Defining, conceptualizing, and measuring organizational resilience: A multiple case study,” *Sustainability*, vol. 13, no. 5, p. 2517, 2021, retrieved: November 2024. [Online]. Available: https://link.springer.com/content/pdf/10.1007/s40685-019-0085-7.pdf

[7] R. Tallat *et al.*, “Navigating industry 5.0: A survey of key enabling technologies, trends, challenges, and opportunities,” *IEEE Communications Surveys & Tutorials*, 2023, retrieved: November 2024. [Online]. Available: https://ieeexplore.ieee.org/iel7/9739/5451756/10305081.pdf

[8] ESA S.p.A. (2023) The Role of Operator Assistance Systems in Industry. retrieved: November 2024. [Online]. Available: https://www.esa-automation.com/en/the-role-of-operator-assistance-systems-in-industry/

[9] Fraunhofer IKS. (2024) Cognitive Systems. retrieved: November 2024. [Online]. Available: https://www.iks.fraunhofer.de/en/topics/cognitive-systems.html

[10] B. Pokorni, D. Popescu, and C. Constantinescu, “Design of cognitive assistance systems in manual assembly based on quality function deployment,” *Applied Sciences*, vol. 12, no. 8, p. 3887, 2022, retrieved: November 2024. [Online]. Available: https://doi.org/10.3390/app12083887

[11] P. Wotschack, G. Vladova, P. de Paiva Lareiro, and C. Thim, “Learning via assistance systems in industrial manufacturing. an experimental study in an industry 4.0 environment,” *Journal of Workplace Learning*, vol. 35, no. 9, pp. 235–258, 2023, retrieved: November 2024. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/JWL-09-2022-0119/full/html

[12] P. Brauner *et al.*, “A computer science perspective on digital transformation in production,” *ACM Transactions on Internet of Things*, vol. 3, no. 2, pp. 1–32, 2022, retrieved: November 2024. [Online]. Available: https://dl.acm.org/doi/pdf/10.1145/3502265

[13] E. Kaasinen, A.-H. Anttila, P. Heikkilä, J. Laarni, H. Koskinen, and A. Väätänen, “Smooth and resilient human–machine teamwork as an industry 5.0 design challenge,” *Sustainability*, vol. 14, no. 5, p. 2773, 2022, retrieved: November 2024. [Online]. Available: https://www.mdpi.com/2071-1050/14/5/2773/pdf

[14] Fraunhofer IVV. (2024) Self-learning assistance systems. retrieved: November 2024. [Online]. Available: https://www.ivv.fraunhofer.de/en/processing-machinery/assistance-systems.html

[15] isax. (2024) Worker guidance system weasl – the interface between employee and digital process. retrieved: November 2024. [Online]. Available: https://www.isax.com/en/weasl/overview/

[16] Peerox. (2024) MADDOX: More Efficiency in Manufacturing through Digital Knowledge Transfer. retrieved: November 2024. [Online]. Available: https://peerox.de/en/home/

[17] VKS. (2024) VKS Products - Choose The Right Plan For You. retrieved: November 2024. [Online]. Available: https://vksapp.com/products

[18] Schaeffler Special Machinery. Increase productivity using digital systems. retrieved: November 2024. [Online]. Available: https://www.schaeffler-special-machinery.de/en/products/production-it/digital-assistance-systems/

[19] Fraunhofer IPA. (2024) Healthy and efficient: assistance systems for people in production. retrieved: November 2024. [Online]. Available: https://www.ipa.fraunhofer.de/en/industry-solutions/automotive/assistance-systems-for-people-in-production.html

[20] Messe München GmbH. Assistance Systems for Workplace 4.0 in the Smart Factory. retrieved: November 2024. [Online]. Available:

https://automatica-munich.com/en/discover/topics-news/automatica-news/future-of-work/assistance-systems-for-workplace-4-0-in-the-smart-factory/

[21] B. G. Mark, E. Rauch, and D. T. Matt, “Worker assistance systems in manufacturing: A review of the state of the art and future directions,” *Journal of Manufacturing Systems*, vol. 59, pp. 228–250, 2021, retrieved: November 2024. [Online]. Available: https://doi.org/10.1016/j.jmsy.2021.02.017

[22] Armbruster Engineering. Assistance systems in manufacturing environments: A guidepost for industry 4.0. retrieved: November 2024. [Online]. Available: https://www.discovergermany.com/assistance-systems-in-manufacturing-environments-a-guidepost-for-industry-4-0/

[23] Core Sensing GmbH. (2024) Worker assistance systems for machines, commercial vehicles and medical technology. retrieved: November 2024. [Online]. Available: https://core-sensing.de/en/solutions-5/assistance-systems/

[24] Assistance systems. retrieved: November 2024. [Online]. Available: https://smartfactory-owl.de/assistance-systems/?lang=en

[25] J. Nelles, S. Kuz, A. Mertens, and C. M. Schlick, “Human-centered design of assistance systems for production planning and control: The role of the human in industry 4.0,” in *2016 IEEE International Conference on Industrial Technology (ICIT)*, 2016, pp. 2099–2104, retrieved: November 2024.

[26] IFM Electronic GmbH. (2024) The worker assistance system for manual production tasks. retrieved: November 2024. [Online]. Available: https://www.ifm.com/de/en/shared/products/ifm-mate/start

[27] Optimum datamanagement solutions GmbH. (2024) Tier 1 Suppliers ensure Quality with Worker Assistance Systems. retrieved: November 2024. [Online]. Available: https://www.optimum-gmbh.de/en/blog/tier-1-suppliers-ensure-quality-with-worker-assistance-systems

[28] J. Ulmer, S. Braun, C.-T. Cheng, S. Dowey, and J. Wollert, “A human factors-aware assistance system in manufacturing based on gamification and hardware modularisation,” *International Journal of Production Research*, vol. 61, no. 22, pp. 7760–7775, 2023, retrieved: November 2024. [Online]. Available: https://doi.org/10.1080/00207543.2023.2166140

[29] Optimum datamanagement solutions GmbH. (2024) DESC worker assistance system. retrieved: November 2024. [Online]. Available: https://www.de-group.net/portfolio/worker-assistance-system/?lang=en

[30] B. G. Mark, M. De Marchi, E. Rauch, and D. T. Matt, “Expert-based classification of worker assistance systems in manufacturing considering the human.” in *IN4PL*, 2022, pp. 184–191, retrieved: November 2024. [Online]. Available: https://bia.unibz.it/view/pdfCoverPage?instCode=39UBZ_INST&filePid=13292968390001241&download=true

[31] L. Merkel, C. Berger, C. Schultz, S. Braunreuther, and G. Reinhart, “Application-specific design of assistance systems for manual work in production,” in *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2017, pp. 1189–1193, retrieved: November 2024.

[32] ShopWorx. Revolutionizing Industrial Manufacturing: The Impact of Operator Assistance Systems (OAS). retrieved: November 2024. [Online]. Available: https://shopworx.io/blog/revolutionizing-industrial-manufacturing-the-impact-of-operator-assistance-systems-oas/

[33] tepcon GmbH. (2024) What is worker guidance? retrieved: November 2024. [Online]. Available: https://tepcon.de/en/werkerfuehrung/

[34] M. A. Lehmann, “Intelligent assistance systems for assembly tasks,” in *The Future of Smart Production for SMEs: A Methodological and Practical Approach Towards Digitalization in SMEs*, 1st ed., O. Madsen, U. Berger, C. Møller, A. H. Lassen, B. V. Wæhrens, and C. Shou, Eds., 2023.

[35] Bauer Group. Assistance Systems. retrieved: November 2024. [Online]. Available: https://equipment.bauer.de/en/assistance-systems

[36] PSI Technics. Digital Assistance Systems. retrieved: November 2024. [Online]. Available: https://www.psi-technics.com/EN/Services-Products/Business-Analytics/Digital-Assistance-Systems.php

[37] FAU Engineering Design. Assistance systems at KT-mfk. retrieved: November 2024. [Online]. Available: https://www.mfk.tf.fau.eu/forschung/schwerpunkte/virtuelle-produktentwicklung-und-konstruktionsmethodik/assistenzsysteme/

[38] IGZ Ingenieurgesellschaft für logistische Informationssysteme mbH. (2024) Assembly by Motion – IDA3. retrieved: November 2024. [Online]. Available: https://www.igz.com/en/sap-manufacturing/best-practices/assembly-by-motion/

[39] Pelemedia GmbH. (2024) Worker assistance systems; The assistant - for all occasions. retrieved: November 2024. [Online]. Available: https://www.industrial-production.de/assembly-technology/worker-assistance-systems---the-assistant---for-every-situation.htm

[40] Deutsche Messe AG. SEW-EUROPE’s Mobile Assistance Systems. retrieved: November 2024. [Online]. Available: https://www.hannovermesse.de/en/news/news-articles/sew-europe-s-mobile-assistance-systems

[41] M. Fellmann, S. Robert, S. Büttner, H. Mucha, and C. Röcker, “Towards a framework for assistance systems to support work processes in smart factories,” in *Machine Learning and Knowledge Extraction*, A. Holzinger, P. Kieseberg, A. M. Tjoa, and E. Weippl, Eds. Cham: Springer International Publishing, 2017, pp. 59–68, retrieved: November 2024. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-319-66808-6_5#citeas

[42] M. Peruzzini, E. Prati, and M. Pellicciari, “A framework to design smart manufacturing systems for industry 5.0 based on the human-automation symbiosis,” *International Journal of Computer Integrated Manufacturing*, pp. 1–18, 2023, retrieved: November 2024. [Online]. Available: https://www.tandfonline.com/doi/pdf/10.1080/0951192X.2023.2257634

[43] ISO. (2021) Automation systems and integration — Digital twin framework for manufacturing — Part 2: Reference architecture. retrieved: November 2024. [Online]. Available: https://www.iso.org/obp/ui/en/#iso:std:iso:23247:-2:ed-1:v1:en

[44] Authors of git-scm.com. git. retrieved: November 2024. [Online]. Available: https://git-scm.com/docs/git-diff

[45] SNET of TU Berlin. Werk 4.0. retrieved: November 2024. [Online]. Available: https://www.tu.berlin/en/snet/research/projects/werk-40

[46] Werner-von-Siemens Centre for Industry and Science e.V. Werk 4.0: From conventional production plant to resilient competence plant through Industry 4.0. retrieved: November 2024. [Online]. Available: https://wvsc.berlin/en/projekt/werk4-0/

[47] Fraunhofer IPK. (2024) Werk 4.0 From conventional production plant to resilient competence plant by means of Industry 4.0. retrieved: November 2024. [Online]. Available: https://www.ipk.fraunhofer.de/en/references/werk-40.html

[48] Gestalt Robotics. (2023) Werk 4.0 From conventional production plant to resilient competence plant through Industry 4.0. retrieved: November 2024. [Online]. Available: https://www.gestalt-robotics.com/research-projects-blog/werk40en

[49] E. Vázquez. Key Differences Between Docker and Docker Swarm in Container Management and Orchestration. retrieved: November 2024. [Online]. Available: https://www.chakray.com/key-differences-between-docker-and-docker-swarm-in-container-management-and-orchestration/

[50] Authors of oracle.com. (2018) Automation systems and integration — Digital twin framework for manufacturing — Part 2: Reference architecture. retrieved: November 2024. [Online]. Available: https://download.oracle.com/otndocs/products/spatial/pdf/Multimodel_Database_with_Oracle_Database_18c.pdf