Interoperability of digitization solutions as a crucial element for collaborative, hybrid work planning

Adrian Schröder[1], Michael Spitzhirn[2], Lina Katrin Lau[1], Tobias Kutzler[1]

[1] Fraunhofer Institute for Factory Operation and Automation IFF,
Joseph-von-Fraunhofer Str. 1, 39106 Magdeburg, Germany
[2] imk Industrial Intelligence GmbH, Amselgrund 30, 09128 Chemnitz, Germany
adrian.schroeder@iff.fraunhofer.de

Abstract. Continuously shortening life cycles and global competitive pressure require an accelerated and collaborative approach with data consistency and availability, as well as compatibility between planning and visualization tools for planning and rescheduling processes of production systems. For consistent application, suitable methods must be available, be known and be testable.
The Elbfabrik by Fraunhofer IFF creates a learning and interaction space where innovative digital solutions from product configuration, factory and work planning to factory operation are presented and can be tested. In this research and learning factory, digital twin technologies and methods of virtual product development are combined with the demonstration of real production processes for planning and operating a factory.
An example of an assembly workplace from the research factory will be used to show how interoperability between IoT technology and work design planning tools with virtual reality applications such as ema Work Designer (emaWD) is implemented in a common learning setting. For the procedure, data is to be exchanged in real-time via the specially developed IoT platform between the real workplace and the digital factory twin. Combined systems using open standards are seen as a solution for accelerating the planning process, increasing the involvement of employees in planning and interoperability.

Keywords: Interoperability, IoT platform, Digital Factory Planning, Digital human models, Process Simulation

1 Introduction

Manufacturing companies are faced with global competition, increasing cost pressure and ever shorter product life cycles. At the same time, there is a trend towards a mass individualization of products, which leads to a higher number of variants with decreasing batch sizes. So the production systems required for value creation have to be adapted to the new challenges in ever shorter periods of time. [1]

Digital systems can support an efficient, ergonomic, and transparent planning of factories and processes, but the user is confronted with a broad software landscape. Thereby software systems provide more and more functionalities such as Integrated

Factory Modelling (IFM) and digital human models (DHM), which offer the advantage of being able to access more detailed information about production and humans than a pure 3D visualization [2]. However, digital tools are mostly used separately for designing factories, logistics and for detailed planning of work systems [3, 4]. This can lead to employees being considered insufficiently or too late in the planning process. The consequence can be a time-consuming and costly replanning.

In order to take the various aspects of factory planning into account, interoperability between different systems must be created [5]. The challenges are to implement the data exchange between the stakeholders' systems and to qualify the personnel required for implementation. This requires concepts that address the challenges described with the corresponding solutions in the form of training and further education. Transfer, learning and research factories that enable a high degree of approximation to real production can support the dissemination of knowledge and experience in the use of new technologies to design ergonomic and economic workstations and processes. With the use case of a workplace redesign process in the research and demonstration factory of the Fraunhofer IFF, a concept for teaching interoperability and technologies for digital factory and work planning will be presented. It is also shown how information is exchanged between the digital and real work system to support an ergonomic and time-oriented planning and execution.

2 State of the art

2.1 Digital factory and digital ergonomics

Different planning cases with specific characteristics arise over the phases of the factory life cycle. For an existing factory, VDI 5200 defines the planning case "replanning". In the resulting brown-field project, forms of adaptation, expansion of the factory or optimization of production can be assigned. In contrast to greenfield planning, the existing production factors and factory operations must be taken into account. [6]
In the context of the digital factory software tools and included methods (e.g. CAD, CAM) can be used to generate a digital twin to examine and optimize the factory, production and work processes. [7]

Digital ergonomic tools are used to create an ergonomic design of products, work systems and processes. Such tools with digital human models (DHM) enable the consideration of humans by modeling and simulation the characteristics and abilities of humans or elements for ergonomic and economic purposes [8]. Systems with digital human models such as RAMSIS, Process Simulate with Jack / Jill, Human Builder and emaWD are widely used and support virtual analysis and design of work processes and products according to ergonomics and economic efficiency [4, 9, 10].

For a comprehensive and human-centered design of the factory, data exchange between different systems of the digital factory such as CAD and digital ergonomics as well as IoT-systems are necessary. The "Digital Factory" aims to achieve interoperability by a consistent, continuous data and information flow within factory planning [7]. Data platforms such as Industry 4.0 form the backbone of modern data infrastructures for data exchange. The concept of collaborative, open data spaces such as CATENA-X

[11] or the Nvidias Omniverse™ computing platform [12] offer an opportunity to create interoperability, but it still needs further dissemination and increasing acceptance.

2.2 The Elbfabrik as a learning factory for imparting knowledge

Learning factories are an important element in transformation processes. As a link between education and industry, they impart practical knowledge about real-life scenarios in an adequate learning setting and environment. Learning factories are practice-oriented learning environments in which learners acquire job-specific knowledge and skills using realistic production facilities and processes [13]. However, while different concepts for production and work design in learning factories are considered [14], there is still a lack of teaching modules for the combined consideration of digital factory and work planning, especially in relation to human simulation [15].

The Elbfabrik is a research and demonstration factory for sustainable value creation and serves as a cooperation platform for partners and companies [16]. Methods of virtual product development are combined with the demonstration of real production processes and illustrated in a production process for the flexible manufacture of customer-specific and variant-rich products. A specially developed IoT platform connects the demonstrators on the store floor with the MES, factory and work planning software tools. This enables status, process and energy data to be linked. The focus is on the multi-variant production of customized products and the communication of planning methods as well as optimizing and implementing such production and work systems for students, companies and the public.

3 Methodology

3.1 Didactic concept

The learning objective of the courses is the learning of the use of the interoperable toolchain to evaluate and redesign a real workplace scenario. The use case was chosen due to the industry's need for efficient rescheduling of its production facilities under consideration of the worker abilities, economic perspective and customer needs. These resulted in the design of a concept in which planners and students are trained in a realistic production environment.

The didactic concept follows the work-based learning approach and combines online preparation, hands-on experience, participant interaction and problem-based learning [17]. Since participants with different knowledge, experience and ages take place in the course, the hands-on experience is preceded by a virtual training course. The participants acquire the basic knowledge independently at home with the help of digital materials, such as learning videos, podcasts, and texts. The learning content is deepened in a learner-centered manner using a use case (section 3.2). Through active discussions, group work and further questions, knowledge is deepened and at the same time placed in an application context. The training follows the steps of a planning process in a sequential and modular structure (cp. Table 1). It’s considered to work in a group of 6-8

participants who are instructed by two experienced factory and work planners. The concept takes place in two days of training at Elbfabrik. Before hands-on experience, the participants take part in a modular online training depending on previous knowledge.

Table 1. Steps of the developed didactic concept of the use case "Replanning"

Step	Content of the didactic concept
1	*Online Training about basics knowledge:* Query of previous knowledge of the participants; presenting basic information about digital factory, interoperability, digital ergonomics, factory and work planning and IoT platform to the participants; learning videos, podcasts, and texts; learning success control (before the two-day course)
2	*Getting to know the real system*: Becoming familiar with the real assembly workplace, its provided assistance systems, the assembly process and products.
3	*Getting to know the digital toolchain used:* Becoming familiar with the MES, IoT platform and work planning system (emaWD) and their intersections / interoperability
4	*Creating the simulation model and analysis of the actual state:* Importing and modelling the assembly task in the process simulation tool emaWD by the instructors in collaboration with the participants. Practical application for data exchange (interoperability) and evaluation according to ergonomics and productivity (end of day 1)
5	*Collaborative optimization and evaluation in VR*: Evaluation of the replanned workstation of step 4 in emaVR with VIVE Cosmos VR glasses.
6	*Evaluating the replanning in reality:* Transferring the replanning results to the workstation in the technical center and evaluation of the training. (end of day 2)
7	*Online-Evaluation of training:* learning experience of the training by the participants after the workshop via an online survey tool (after the two-day course)

3.2 Use case: Redesign of assembly workstation for AGV holding devices

In the case study, a subsystem of a whole production system has been chosen, which is called "Assisted Assembly". It consists of two variants of a holding device which have to be assembled [18]. The use case demonstrates how an assembly process can be redesigned using the planning system emaWD in combination with an IoT system to ensure a continuous flow of data and information exchange.

The work process at this demonstrator is as follows: The components required for assembly are delivered from the upstream workstations by an AGV. The implemented MES sends information about the product variant to be assembled to the assistance system at the workstation so it can visualize the assembly tasks and other information to the assembly table. 16 work steps are carried out for the component assembly, in which the person performs joining operations. Once completed, the assembled product is placed onto an AGV and transported to the next workstation.

3.3 Interoperable networking of assembly table and digital mapping

The Fraunhofer IFF's IoT platform was used to exchange data between the intelligent assembly table and the different digital systems (MES, CAD, planning system). An overview of the used systems and their data flows is shown in Fig. 1.

The IoT platform enables the exchange of data about products, process execution data (e.g. progress, errors) and process evaluation data (e.g. standard times and ergonomic data) as well as the feedback of planning results between digital tools and the assembly table in the Elbfabrik. For example, the actual execution of the worker including work process sequence, execution time, movements and error rates can be captured by systems in the assembly table (e.g. camera, scanner, motion capturing system) and transferred via the IoT platform to emaWD to provide a starting point for work process simulation and evaluation. In addition to its central role as a mediation layer, the IoT platform also serves to store and provide information on the workflow as well as the tasks currently being processed and the exchange of this data with the connected MES (Hydra X and APS Fedra by MPDV) plans for order control. The environment can be created in emaWD using the information from the MES system.

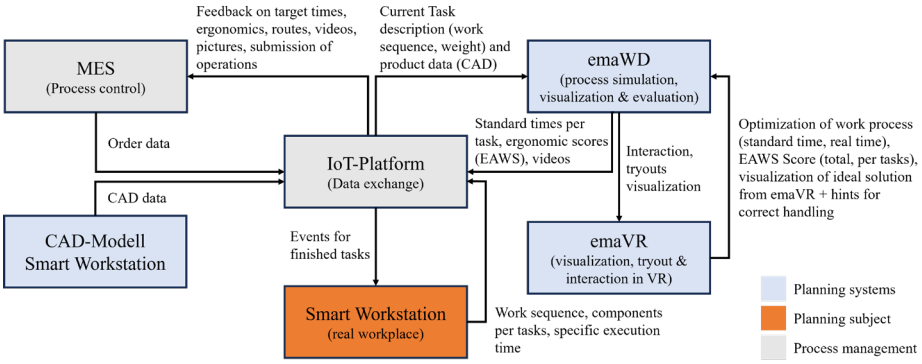


Fig. 1: Overview of the combined system, its components and data flows

emaWD is part of the ema Software Suite and is used to create a digital representation of the real assembly workplace and to simulate, evaluate and design the associated work processes according to ergonomic, economic and safety criteria [10, 19]. For that purpose, different variations of the work process are simulated using the integrated task library and motion generator, which allows the DHM to autonomously fulfill user-defined work tasks. Also, the real recorded motion data are used to evaluate the work process. In addition, the characteristics of the digital human models are adjusted in terms of age, gender, range of motion and strength regarding the specific characteristics of the participant of the workshop. The actual and simulated variations of the work process are then analyzed by using ergonomic evaluations (e.g. EAWS, visual analyses), time analyses (actual and standard time based on MTM-UAS) and productivity analyses (e.g. walking path analyzing, value creation).

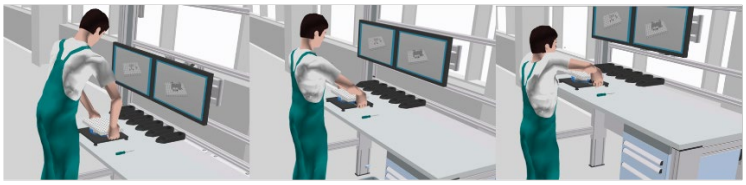
After that, a collaborative redesign of the scenario is undertaken together as part of a coupling of VR workshop and presence in the laboratory and monitor. The emaWD

and its VR application are also used for this. This allows the VR workshop to be carried out directly without further adaptation of the scenario. The target process is then evaluated and discussed with the participants compared to the initial state. As final step the digital solution is transferred to the real environment and is tested by the participants.

4 Results

The didactic concept (cp. section 3.1) and the interaction of the systems were tested as part of piloting. This includes the learning material, the real use case and in particular the consideration of the interoperability of the systems and the planning process. The results of the planning and optimization process are presented below.

Workplace height	EAWS Whole Body	EAWS Upper extremities	MTM-UAS (s)
700 mm	25.5	21.9	87.9
1100 mm	13.0	21.9	87.7
1300 mm	31.0	21.9	88.1



700 mm 1100 mm 1300 mm

Fig. 2: Results regarding EAWS and MTM-UAS for different workplace heights (left: actual work height at assembly table; middle and right design options)

The scenario was optimized by adaption to the preferred work height (1.100 mm) and rearrangement of the containers as part of an interactive VR workshop in emaWD (see Fig. 3). Placing the containers from the AGV onto the table, a significant reduction in walking distances by 12.2 m could be achieved. According to EAWS, there is a low risk of musculoskeletal disorders (EAWS: 13 points) and the standard time based on MTM-UAS could also be reduced to 66.3 s. At the same time, testing in VR verified feasibility and the arrangement was chosen so that the objects were easily accessible.

Fig. 3. Scenario execution of the VR workshop on the shop floor

5 Discussion and Outlook

A piloting of the training was realized. It was shown that data can be transferred between the IoT and digital planning toolchain. This requires an initial effort but reduces the overall effort so that processes that would otherwise be carried out manually (e.g. creation of a digital environment, process simulation) can be (semi)-automated generated. This saves time and avoids potential errors by using the presented interoperable system environment. As part of the learning concept, the importance of interoperability between various digital systems for the creation, evaluation and optimization of a real assembly use case was presented combining online preparation, hands-on experience, participant interaction and problem-based learning.

For that purpose, a process simulation using emaWD was done to create a digital representation of the real assembly workplace and to simulate, evaluate and design the associated work processes according to ergonomic and economic criteria. Various human abilities (e.g. body dimensions, range of motion, strength) were also adapted to participants abilities to evaluate this concept according to an age- and ability-appropriate work design. In addition, a collaborative redesign of the scenario with participants was conducted in combining a VR workshop with a presence in the real world in the Elbfabrik. The direct use of VR in emaWD does not require any further adaptation of the scenario. The target process was then evaluated and discussed with the participants compared to the initial state. Currently, a limitation in emaWD is that only one person can work directly in VR. At the same time, other persons can also work in the scenario but have to use the monitor version. Alternatively, the multi-user functions of the Omniverse can be used via an ema-Omniverse interface.

A next step is the evaluation of the training by different user groups. The feedback from the groups will contribute to the gradual improvement of the concept in an iterative process. In terms of content, the concept is to be expanded in the future to include additional data sources that can be connected via the IoT platform. Furthermore, the expansion of the degrees of freedom of ergonomic optimization has the potential to further increase the optimal adaptation to the person working in each case.

Acknowledgment

This research is part of the project “AEL4GW”, which is funded by the German Federal Ministry of Education and Research under grant no. 03HY126C.

References

1. World Economic Forum. Advanced Manufacturing: A New Narrative. https://www3.weforum.org/docs/WEF_Advanced_Manufacturing_A_New_Narrative_2023.pdf, last accessed 2023/11/28.
2. Burggräf, P., Dannapfel, M., Hahn, V., Preutenborbeck, M.; Uncovering the human evaluation of changeability for automated factory layout planning: expert survey. 15, p. 285-298 (2021).

3. Bracht, U., Geckler, D., Wenzel, S.: Digitale Fabrik. Springer Berlin Heidelberg, Berlin, Heidelberg (2018).
4. Paul, G.E.: Modelling and simulation of human systems, in Handbook of human factors and ergonomics, JOHN WILEY & SONS, S.l., p. 761-781 (2021).
5. Tibaut, A., Rebolj, D., Nekrep Perc, M.: Interoperability requirements for automated manufacturing systems in construction 27, p. 251-262 (2016).
6. VDI. Factory planning: Planning procedures, 2011 (VDI 5200:1).
7. VDI. Digital factory: Fundamentals, 2008 (VDI 4499:1).
8. Bullinger-Hoffmann, A.C., Mühlstedt, J.: Homo Sapiens Digitalis - Virtuelle Ergonomie und digitale Menschmodelle. Springer Berlin Heidelberg, Berlin, Heidelberg (2016).
9. Maurya, C.M., Karmakar, S., Das, A.K.: Digital human modeling (DHM) for improving work environment for specially-abled and elderly 1 (2019).
10. Spitzhirn, M., Gärtner, C., Ullmann, S., Fritzsche L.: Considering Individual Abilities and Age-Related Changes in Digital Production Planning Using Digital Human Models. In: S. Scataglini et al. (Eds.): DHM 2023, LNNS 744, pp. 1–10 (2023).
11. Catena-X Automotive Network e.V. Catena-X Operating Model Whitepaper. https://catena-x.net/fileadmin/user_upload/Publikationen_und_WhitePaper_des_Vereins/CX_Operating_Model_Whitepaper_02_12_22.pdf, last accessed 2023/11/28.
12. NVIDIA. Omniverse Platform for Virtual Collaboration. https://www.nvidia.com/en-eu/design-visualization/omniverse/, last accessed 2023/11/29.
13. Reining, N.: Lernfabriken als innovative Lernorte: Empirische Betrachtungen zu Lernen, Kompetenzerwerb und dem Einsatz digitaler Lernkomponenten (2023).
14. Dinkelmann, M., Riffelmacher, P., Westkämper, E.: Training concept and structure of the Learning Factory advanced Industrial Engineering: Enabling Manufacturing Competitiveness and Economic Sustainability. Springer, Berlin Heidelberg (2012).
15. Wolf, M., Dilena, M., Spitzhirn, M., Ramsauer, C.: Development of a Training Module for Virtual Workplace Design and Evaluation in the LEAD Factory (2023).
16. Fraunhofer IFF. Elbfabrik. https://www.elbfabrik-magdeburg.de/, last accessed 2023/11/27.
17. Murtazin, K., Shvets, O., Piho, G.: Literature Review on Work-Based Learning, in 2020 IEEE Frontiers in Education Conference (FIE), IEEE, p. 1-8 (2020).
18. Hauptvogel, M., Warnemünde, R., Bausch, W., Berndt, D.: Bedarfsgerechte Unterstützung: Flexible Assistenz für variantenreiche manuelle Montageaufgaben, p. 48-50 (2021).
19. Spitzhirn, M., Ullmann, S., Bauer, S., Fritzsche, L.: Digital production planning and human simulation of manual and hybrid work processes using the ema Software Suite. In: Proceedings of the 7th International Digital Human Modeling Symposium 7(1), August 29–31, 2022, Iowa City, Iowa, USA, p.20-32 (2022).