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A Training Concept Based on a Digital Twin for a Wafer Transportation System

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***Abstract*— Due to the increasing automation and digitalization level in modern semiconductor wafer facilities and the associated growing system complexity, the demands for the maintenance staff for highly automated systems are continuously increasing. In order to maintain line stability, qualified maintenance personnel are essential for fast and secure troubleshooting the highly automated transportation system of a semiconductor plant. However, the transfer of knowledge to new maintenance personnel for coping with malfunctions is a big challenge. This is also a contribution in the digital transformation in this context for training of people at highly digitized workplaces by introducing a virtual training for (new) employees. This training supports new maintenance personnel to gain practical experience in operating a modern human-machine interface without disturbing the existing productive system. Initial results indicate that this approach supports the transformation process in a targeted manner. For future work, we aim to examine other performance metrics and their impact over time.**

Keywords—transportation system, virtual training, digitalization, digital twin, cyber range

I. INTRODUCTION

The semiconductor industry is an industrial sector with great growth potential, as people are increasingly looking for electronic solutions to improve their standard of living, for example through the use of modern means of communication such as smartphones, laptops and tablets. The shift towards renewable energies also requires circuits and sensors that are essential for this change. The worldwide demand for innovative circuits is therefore leading to a boom in the semiconductor industry. Hence, existing factories are automated as far as possible by using fully automatic transportation systems and various robotic systems which automatically take over the simple and repetitive production processes in the factories. However, even these novel automated applications must be monitored, controlled and maintained by humans (e.g., maintenance workers). Hence, the boom in the industry leads to a growing system complexity and demands for the maintenance staff for highly automated systems [1]. To maintain line stability in the semiconductor plant, qualified maintenance personnel is essential for fast and secure troubleshooting of the highly automated transportation system. According to [2], the digital transformation is leading to a dynamic change in the world of work, which is characterized by high variability of working conditions and a high frequency of change. This places extensive demands on the operational actors on site, not least on the employees themselves.

Industry 4.0 technologies are changing workplace activities at the expense of routine tasks and future work content will be more demanding, more varied and more complex [3]. As the digital transformation has increased the use of software products in the daily business, training and how we transfer knowledge needs new ideas and methods to cope with the diversity and complexity of the digital work places. For example, our initial analysis revealed that for new employees working with transportation systems, it is very difficult and time consuming to take over many varying tasks to maintain the system and its components. The process is further complicated by the fact that expertise can be gathered mainly by experiential learning (e.g., in shifts). Mistakes caused by the employees could lead to worsening of a traffic jam on the transportation system and even to wafer breakage resulting in serious economic damage.

Therefore, this paper addresses these challenges by developing a training concept for new employees (maintenance workers) in semiconductor industry that applies a hands-on and dynamic training simulation using a virtual environment [4]. The objective of the training concept is (1) to support new employees for learning the basics of the software user interface of the monitoring and control system, (2) learning to recognize specific patterns in the system, and (3) learning how to deal with certain errors.

We propose a concept that is divided into a theoretical introduction and a simulation based on a digital twin to apply and foster the knowledge. The simulation enables trainees to manifest the knowledge using experiential learning [5]. In this paper, we focus on the approach, the design and the key performance indicators of the training from the perspective of

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a manufacturer. Also, we provide initial results which show that the digital twin training receives highly positive feedback throughout the workforce.
With this paper, we contribute to the understanding of digital transformation and how the process can be empowered with a training based on a digital twin of a very complex wafer transportation system. The findings in this paper can be beneficial to other organizations who are currently in the process of digital transformations and are searching for opportunities to include empowering measures to the involved humans. Furthermore, this paper can be of use to researchers working in the area of education and training in industry who are looking for new cases to support the onboarding and knowledge transfer of new employees.

This paper is structured as follows: Section II describes the background and motivation of this paper. Section III summaries related work in the area of digital twin training. Section IV describes the approach of investigating digital transformation in a workplace. Furthermore, Section V outlines the digital twin training concept and discusses initial results. Section VI concludes the paper.

II. Background and Motivation

The worldwide demand for innovative circuits is leading to a boom in the semiconductor industry. Therefore, existing factories are automated as far as possible by using fully automatic transportation systems and various robotic systems which automatically take over the simple and repetitive production processes in the factories.
However, even these novel automated solutions must be monitored, controlled and maintained by humans. Infineon Technologies Dresden (IFD) had already established a conveyor-based transportation system in its 200 mm production facility in the 1990s which supplies its cleanroom areas with the production lots within the manufacturing bays to the different equipment. The goal of this work was to establish a new virtual training method based on a digital twin for the existing 200 mm conveyor based automated material handling system (AMHS) with a length of 12 km, which is monitored and maintained around the clock by various maintenance teams.

At the end of the 1990s, during the installation of the new conveyor based transportation system, the demands on the maintenance personnel were still comparatively low and limited to simple maintenance work on the individual components e.g. solving simple lot stops by mechanical actions. However, due to the advancing automation and the associated growing system complexity, the demands on maintenance have been continuously increasing over the years. This is also reflected in the workplace at the transportation system at IFD.
The most important goal was to avoid any deadlock situation in the factory causing high traffic slams or so-called “wafer in progress” (WIP) waves of the production lots. This kind of situations will cause cycle time losses, bottleneck situations or even complete line stops. Those failures can have a high impact to the productivity of the factory.

In the years 2010 to 2015, IFD automated the 200 mm factories by introducing a complex IT-landscape which allows to implement and control numerous of robotic systems, which are the interfaces to the wafer transportation system. This massively reduced the workload for the operators in production, so that significantly fewer personnel were needed for higher throughput during the production ramp-up, which also led to significant cost benefits and thus to an improved market position and much more customer orders. For the staff at IFD, this results in a clear shift of work from simple loading and unloading of machines in the different manufacturing bays to much more monitoring tasks and trouble shooting at the automated systems.

Among the requirements identified in the past for on-site troubleshooting in the flexible automated production environment [6]–[11], the proper handling of cyber physical systems, for example in remote operations and monitoring, as well as handling other software such as the different IT- and dispatching systems is now an important factor in modern industry 4.0 maintenance tasks.

The advanced technologies offer versatile application scenarios. For example, digital twins are already being used in augmented reality and virtual reality scenarios for training [12], [13]. For the use of digital twins, various different scenarios could be identified, including production process simulation, as well as fault warning and maintenance among many others [14].
The progressive digitalization of production enables the operators to immediately recognize malfunctions and sometimes even to solve diagnostic tasks and troubleshooting by using remote control functions. This was connected with numerous training courses and instructions by experienced operators in order to meet these requirements. Due to the increasing complexity of automation systems and the large number of existing data streams caused by digitization, the simple workstation at the transportation system has changed over the years to a highly specialized control center where the employees not only have to maintain the conveyor system, but also have to react quickly and safely when malfunctions occur while understanding all interfaces to the other automation and digitization solutions to ensure line stability. Modern human machine interfaces such as IFD's operator control and monitoring systems offer advanced possibilities for remote diagnosis and troubleshooting of malfunctions on such a transportation system.
Employees with many years of experience in the company were able to acquire this knowledge over the years flanked by numerous internal and external training courses.

III. Related Work

The digital twin is characterized as a virtual counterpart of a physical entity (e.g., of a system, product or vehicle) [15]. The virtual environment is a digital simulation of the physical environment that the physical entity is part of. The approach in our paper uses a digital model that is a digital representation of the physical entity as specified in [16]. The authors in [17] provide a systematic review of digital twins for maintenance work. They categorize maintenance work into reactive, preventive, condition-based and prescriptive work. Our approach contributes to reactive maintenance as it provides a training that transfers knowledge on how to identify patterns of failure as well as breakdowns.

Furthermore, research has proposed various digital twins that are used for training. To the best of our knowledge, we did not identify similar publications from the semiconductor industry. Only, the authors in [18] evaluate a training program in a wafer factory in Malaysia. In this paper, we provide a digital twin training that can be part of a holistic training program for the semiconductor industry.
In other industries, we identified learning environments for engineering education [19] as well as virtual reality or augmented reality for safety training (e.g., [13], [20]). Cyber ranges (e.g., [21]), i.e. virtual environments for the simulation of information technology and operational technology infrastructures, have been proposed to be used for simulation of digital twin training.

Learning factories have shown to be useful for conveying theoretical and practical knowledge in a production environment [22]. The approach presented in this paper can be used as a simulation of a product and contribute to the training of new employees. It could be integrated into a learning factory, that supports the learning of infrastructure, organization and life cycle in a learning framework (see [23]).

IV. Approach

A. Investigation of the digital workplace

The first step towards improving highly digitized workplaces in a semiconductor factory at IFD was made starting with a detailed study of the area of interest. This investigation was conducted by experts from the fields of industry (IFD), information technologies (AIT) and research centers like the Dresden University of Applied Sciences with regard to labor science aspects, and the Zittau/Görlitz University of Applied Sciences with a socio-economic view of the jobs. Some of the results how digitization can improve administrative business processes and that digital twins are important for training have been already shown by Schneider et.al. [24], [25]. One important goal was to get a deep understanding about the influence of the digitalization to the existing workplaces in the factory and to get out factors for further improvement of the work in this fields. Furthermore, all problems or risks driven by the new technologies should be eliminated and the increasing complexity in the actual business should be reduced as far as possible. Other factors are to assure the healthiness of the employees as well as the motivation in the different jobs. All those factors will also help to improve the competitiveness of the company. There are various theories in the literature for the information-gathering procedure [26]–[29]. In addition to handing out and collecting questionnaires, the interview technique has proven to be particularly helpful. Using this method, distinction is made between several types of interview. Thus, it is first roughly divided into individual and group interviews. For further specification, interview forms are usually named according to their collection method, such as narrative interview or observation interview [28].

In order to gain a good understanding of the work processes at the highly automated workplaces, a comprehensive workplace analysis was carried out. Hereby, the aim was to identify workplace-specific information such as the main tasks of maintenance workers, training measures for newly hired staff, common challenges for maintenance workers, and the infrastructure for information and communication technology (ICT) of this workplace. Processes of all employees working in the area of the transportation system were analysed and compared with the existing work instructions and competencies of the employees, and an actual/target comparison was carried out in addition to recording the respective times and task shares.
Furthermore, this analysis also determined the current and the maximum level of digitization to be achieved. The level of digitization was determined using methods described by Tomanek and Schröder as well as Keil et al. [30], [31]. The level of digitization is calculated from the sum of all information transmissions multiplied by their degree of value creation divided by the maximum degree of value creation.

$$\textit{Level of digitization} = \frac{\textit{Sum of all information transmissions} * \textit{their degree of value creation}}{\textit{Maximum value added}}$$

The result of this analysis showed that the current workplace already had a digitization level of about 30% at that time and that there is a potential to double it up to a level of 60%. The execution of an exemplary troubleshooting on the highly complex wafer transportation systems was shown as an example within Figure 4.

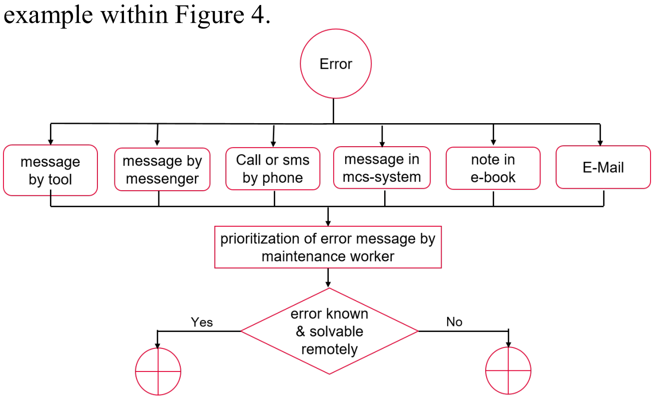

Fig.4: Example for troubleshooting at the transportation system

Figure 4 shows that any troubleshooting activity requires complex processes, which also needs a high level of competence and clear knowledge management in the factory. In addition, it must be ensured which employees have the necessary expertise and can be further deployed for this purpose. The goal is to keep a maximum proportion of all employees certified on as many systems as possible, so that the highest achievable flexibility is guaranteed. However, since the work requires very different levels of knowledge, the establishment of a cyber range training is an essential success factor in order to be able to achieve this on a shift-by-shift basis, especially when new employees have to be trained.

B. Investigation of the communication and responsibility structures

Furthermore, the current communication and responsibility structures as well as the share of tasks that can be performed directly using remote control were examined. Especially the latter part of the tasks is very important for the work, because these parts can be done from outside or from any available workstation in the line without the work due to high travelling times. Especially the high travelling times are a problem for the employees of the transportation system, because a lot of time is lost due to less value adding searching for the faults occurring in the respective systems instead of directly eliminating faults in the production. The analysis showed that fault elimination via remote control is already very high and at more than 90% for the operation of modern transportation systems such as in the 300 mm line at IFD. In the 200 mm line, this is unfortunately only possible to a much lower extent due to the older generation of this system.

The workplace analyses showed that there are intellectually diverse tasks in which the employees are holistically involved in the solution process. Due to the responsibility in making their own decisions when solving problems and the dependence of the entire production on its success, the aspects of significance and autonomy at this workplace must also be emphasized. Therefore, the tasks at this workplace can in principle be evaluated as very positive from an occupational scientific point of view.

The analysis showed also significant advantages of a highly specialized, digitalized and automated workplace. Nevertheless, three essential needs for improvement at the workplace were identified:

- Use of a Task Management for better coordination;
- Introduction of a knowledge management system as interface between human capital and the manufacturing execution system;
- Virtual trainings for new employees, whose implementation in the context of this work will be discussed in the following.

C. Implementation of a digital task management system

The first improvement for the management of the daily work was the implementation of a digital task management system. Using a special display which visualizes the actual errors and preventive maintenance tasks helped to improve the coordination of the work among the maintenance team. Now it is possible for all responsible persons to see the distribution of the work of the whole team. The second idea was to link the existing knowledge management system of the diverse functions in the shift to the manufacturing execution system. The idea is that such a link will be created after the implementation of the virtual training system when the demonstrator is finished and used not only for trainings, but also for certification of new employees.

D. Virtual Training Simulation

Based on this initial analysis and the identified lacks for improvement, the project was launched to establish the third and most important issue, the virtual cyber range training for the employees working on the operation and maintenance of the wafer transportation system at IFD. To generate a highly realistic training, we conducted continuous interviews with the maintenance staff at the work place of the transportation system over a period of 12 months to identify the main needs for training the staff.

Observational interviews were conducted in all shifts of the transportation system maintenance staff in order to understand the relevant training contents and procedures for dealing with malfunctions. This methodology was chosen because the determination of qualification requirements and contents for the development of training and education units is an area that is particularly suitable for work analyses based on observation interviews [32]. In addition, the Teach-Back method was used to ensure that the facts were recorded as accurately as possible. The principle of this method is that new findings are described in own words to the experienced party. Through communication, misinterpretations and loss of information can be prevented [33].

The main goal of this training is to enable new employees to improve their skill level at handling the operator control and monitor software by solving maintenance tasks such as traffic jam clearance in a virtual environment without the risk of endangering the productive system.

V. Training Concept using a Digital Twin

The main aim of the training is to improve the highly digitized work area of the maintenance staff working on a state of the art wafer transportation system. Therefore, we aimed to establish a hands-on training simulation that uses a digital twin in an industrial cyber range for new employees (further called trainees), specifically maintenance workers in the control rooms. With this training, it is expected that new employees (1) are getting to know the most relevant basics of the software user interface the monitoring and control system, (2) are learning to recognize specific patterns in the system, and (3) are learning how to deal with certain errors.

Based on training requirements and background established in a workshop in the wafer facility of IFD, the initial concept was specified. Based on the requirements gathered during the different workshops and interviews of the employees in the following weeks, the training objectives and contents were specified in detail.

Particularly, the training is intended to bear a resemblance to a realistic, everyday setting in the control room where a new maintenance worker is faced with the already existing monitoring and control software of the transportation system. We therefore leverage technology that is usually used in cyber exercises [21] and has been known as an approach to leverage active learning (e.g. [34]).

The goal of the training was to familiarize new worker with the setting in the work environment, as well as with the different possibilities and responsibilities that come with utilizing the monitoring and control software. For this training, a digital model is developed that imitates a dynamic software system that visualizes all features of the existing 200 mm transportation system. The overall objectives of the described training include:

1. getting to know the software interface of the monitoring and control system,
2. learning to recognize specific patterns in the system, and
3. learning how to deal with certain errors.

The training concept consists of two main parts. First, the trainee is introduced to the fundamentals. Second, the training continues with a virtual training using a digital twin. These parts will be explained in more detail in the following.

Theoretical Introduction

The introduction serves to gain an understanding of the operating and monitoring system for the transport system and is provided as presentation. The introduction is structured in three parts.

First, the graphical user interface (GUI) is presented in a section of the transportation system that is realistically designed. The interactive design allows autonomous exploration of all three viewing levels mapped in the virtual demonstrator. The different viewing levels include increasingly detailed visualizations of the components. In addition to the extensive documentation, photos of the components in the production line are also provided. Figure 5 shows an excerpt of a lesson on color codes and different target states of conveyor components and their respective meaning. By learning the color codes, a maintenance worker can quickly recognize a certain change in state of an element within the system, react adequately and intervene if necessary.

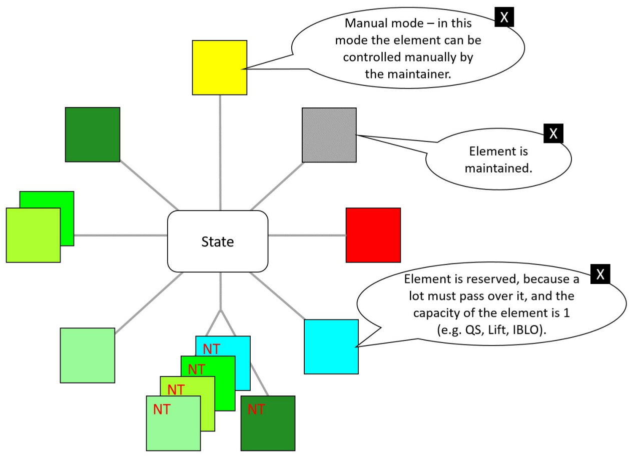

Fig.5. Example element color codes and meanings.

Second, an overview of the respective intervention and diagnostic functions of the different components of the monitoring and control system are provided and explained. Since negligent use of the functions carries a high risk of accidents with high property damage, the consequences of interfering with the operational system were highlighted.

Third, a selected number of error messages with typical error images in the form of a visual representation or through typical sensor outputs corresponding to errors were recorded and displayed. We have selected five commonly occurring errors and presented them in the theoretical introduction.

Virtual Training with the Digital Twin

The main aim of the virtual training is to enable the application of the learned knowledge via experiential learning [5]. Two training modes are supported: general practice and certification.

As maintenance workers utilize the control and monitoring system constantly throughout their workday to observe the state of the transportation system in the production, an efficient navigation in the training software as well as the correct matching of conveyor states and their meanings are asked. They monitor changes in the transportation system, evaluate occurring errors, redirect lot transportation when needed, and also use the control system as a map to quickly access a specific section of the transportation system in cases of manual intervention (e.g., when equipment is physically damaged).

To be able to operate the control software, the trainees (i.e. the new employees) need to be aware of different conveyor elements and their visual counterparts, know the meanings behind color representations, and be familiar with the functionalities supported by the system.

The training consists of 17 tasks and was prepared in cooperation with maintenance teams. The tasks are getting successively more difficult throughout the training. These range from simple navigation tasks, the detection of target/actual deviations based on sensor information, to pattern recognition and resolution of a deadlock scenario on the transportation system. Each task has one or more associated questions for validation of the learning outcomes. The task descriptions along with the respective evaluation types (i.e. how the answer or reaction of the trainee is recognized by the application) are listed in Table 1.

#	TASKS	EVALUATION TYPE
1	Navigation-Challenge	Click events (sequence)
2	Find destinations of certain lots	Input field(s)
3	Investigate certain lot characteristics	Input field(s)
4	Detect conveyor status (1/3)	Input field(s)
5	Detect conveyor status (2/3)	Input field(s)
6	Detect conveyor status (2/3)	Input field(s)
7	Research latest error ID’s	Input field(s)
8	Response to certain sensor malfunctioning	Click event
9	Identify specific component (1/3)	Click event
10	Identify specific component (2/3)	Click event
11	Identify specific component (3/3)	Click event
12	Search-Request	Input field(s)
13	Support colleagues on-site by hindering access to specific conveyor elements	Click event (executed function)
14	Investigate the location of lots in the conveyor based on profibus input/output information	Multiple-choice (radio buttons)
15	Re-route Lots in the conveyor system	Internal state evaluation
16	Recognize pattern of error	Multiple-choice (radio buttons)
17	Solve a deadlock-scenario – use solution introduced in the pre-training	Internal state evaluation

Table 1: Examples of the task catalogue

To solve the tasks, the trainee has the task description and a realistic simulation of the transportation system in the proof-of-concept implementation, called transportation system maintenance training simulation and certification tool (INTERACT). By simulating the functions and properties of the conveyor elements, the user's understanding of the system is supported. Figure 7 shows an example of a task and the information of the element that is required to solve it.

To develop a highly realistic digital twin, we iteratively validated the demonstrator by the shift and subsequently communicated to the specialists. This made it possible to transfer the GUI of the real operating and monitoring system as well as different behavior rules of the transportation system and the interface to the manufacturing system for this training demonstrator. The digital twin was designed as a web-based application that can be integrated into the intranet of the factory but also (if needed) accessed from the Internet.

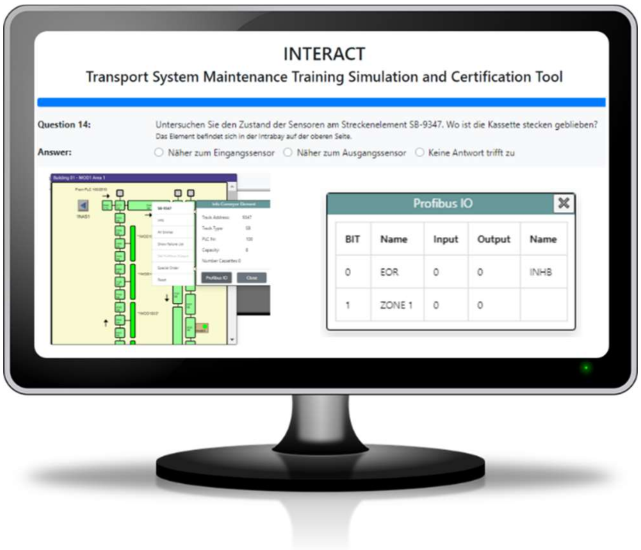

Figure 7: Mockup of the virtual training demonstrator

Evaluation Concept
The evaluation concept consists of several iterative steps.

Iterative Evaluation during Training Development.
The findings were processed, iteratively validated by the shift and subsequently communicated to the specialists working on the software programming to establish the demonstrator, taking over the concrete technical implementations. This made it possible to transfer the GUI of the real operating and monitoring system as well as different behavior rules of the transportation system and the interface to the manufacturing system of the whole wafer facility.

Evaluation of maintenance personnel
Additionally, to the iterative development, an evaluation with the maintenance personnel in the shifts was conducted. Thus, two target groups were addressed, as we want to gather feedback from experienced and newly employed personnel (who know about the requirements of new employees). In this regard, two research questions were aimed to be answered (RQ):

RQ1: Can the participants familiarize themselves with the Digital Twin training?
RQ2: Are they able to solve the challenges correctly in the Digital Twin?

The procedure was planned as follows:

- *Step 1 – Introduction:* In the introduction, trainees were presented an overview of the evaluation, goals and the next steps (Steps 2 - 4).
- *Step 2 - Theoretical introduction:* Step 2 addressed the research question 1. The idea was to give the trainees a theoretical introduction to the system (see Section V).
- *Step 3 - Training demonstration:* After the introduction in Step 1 and 2, the trainees opened the training demonstrator. They conducted the training for as many times and how long they wanted and before attempting the certification. The idea was that the trainees will experience a highly realistic situation that future employees will also experience.
- *Step 4: Survey:* After the training demonstrator, the trainees were asked to fill out a short questionnaire. The questionnaire consisted of 20 questions. The survey of the maintenance personnel is added to the appendix (see Section VII.A).

The initial results of the evaluation are summarized in the following part of the paper.

Initial Results and Discussion
A particular challenge was to ensure the acceptance of the employees of the affected workplace. Therefore, feedback was collected for each exercise during development to improve the virtual training. The first feedback for the virtual training presented was very positive in three out of five shifts. In addition, a rather reserved reaction from one shift as well as some critical comments from another shift provided valuable feedback on some small further improvements that are scheduled. Based on this results, we strive to achieve a highly realistic training that has a high acceptance rate. The second feedback phase was performed after implementing the initial feedback to finalize the training units. Through the final feedback, it became clear that training measures on this digital twin-based training system for new employees would have been very helpful and desirable some time ago to improve the onboarding process and to enhance human capital. One shift concluded, that they would have been very happy if they could have had this training even 20 years before.

The results showed that main key performance indicators in a semiconductor factory like time to market, cycle time and the overall equipment efficiency could benefit from the results. Another very important non-technical key parameter is employee satisfaction which will be strongly influenced by the virtual training. The cyber physical training will reduce the stress factor for new employees because there is no risk anymore to scrap wafers by wrong actions during critical maintenance operations which must be always fixed in a short time and any corrective actions can be done without risks. It will also reduce the whole training period because many different scenarios can be tested with the virtual system instead of using the productive system. Our estimation is, that the training time for new employees could be reduced for several months. Other facts are, that the system helps to reduce the monotony in times with lower failure rates where the time can be used for deeper trainings and special tests on a non-productive system. At least the skill ratio for all maintenance people, even for well trained workers can be enhanced. With the newly acquired know-how, errors can be eliminated faster and more reliably in the future and the uptime of the entire system can be significantly improved. Therefore, it will help to achieve a better overall equipment efficiency, higher throughput and speed, lower costs and higher quality.

Through the training materials and the final test based on extensive on-the-job studies, the knowledge of many employees from different shifts could be captured. Since knowledge does not only accumulate differently in individuals, but also in different shifts due to temporal boundaries, the catalog of knowledge for the training of new employees represents a first cross-shift knowledge comparison. For the new employee, this has the advantage that a knowledge transfer is possible which is not dependent on the relationship between the learner and the mentor. In addition, the errors that have occurred on the transportation system used to dictate which knowledge is transferred to new employees at what point in time. From now on, this process is more time independent. For the first time, the virtual cyber range training enables a qualitatively consistent briefing of new employees. In addition, the virtual training allows practical experience to be gained on a digital twin without endangering the productive system. The integration of photos of real error images into the representation of the digital twin of the operating and observation system as well as the explanation of cause and effect relationships enables the targeted formation of first mental models of the learners. Furthermore, the trainings can be used for the certification of the employees by the shift leader and can be linked with the knowledge management system of the factory. For the first time, the sandbox scenario of a virtual training can be used for teaching purposes at any time without the risk of damaging to the productive system.

Due to the inevitable distance of a virtual training to the physical transportation system, there are nevertheless limits to the training. Online training cannot teach the target torque of a conveyor component or the replacement of worn parts of the transportation system. As expected, the teaching medium is therefore primarily capable of promoting the transfer of knowledge in remote diagnosis and repair with the help of an operation and monitoring system. In order to qualify the employees to handle all tasks on the 200 mm conveyor, existing practical training courses are therefore still essential. A further limitation is found in the scope of the training, since only a section of the complex transportation system is simulated to train new employees. The benefits from modeling the entire cyber-physical system would not be commensurate with the associated effort.

VI. Conclusion and Outlook

Within this work, it was the first time after many years of progress in factory automation that a deep and extensive study of a highly automated workplace was performed with different experts in the field of automation, information technology, economy and psychology. An important output of the analysis was the lack of knowledge especially for new people in a shift who are responsible for those highly automated systems on a wafer transportation system. Instead of implementation of more and more new technologies it was necessary to prepare the maintenance experts for the correct applications of the systems and a fast and secure handling of upcoming problems and errors. Especially on highly complex systems such as a fully automated transportation system, the need for a realistic training is very high and in the past it could be only acquired by employees through many years of experience in their special fields. Any operating errors or not immediately executed failure scenarios or wrong troubleshooting on such systems can lead to high economic damage and must be avoided. The established virtual cyber range training for the automated material handling system first as a digital twin and then to make it available to the employees responsible for the focus area as a virtual training method has been offered and implemented for the first time. Important success factors are that the digital twin had to be set up in such a way that it was as similar as possible to the productive system and that the applications for the maintenance employees were as close to reality as possible. This was also one of the biggest challenges in the context of this work, as it was often not easy for the IT programmer to map all scenarios 100% compared to the reality. In places where the programming was not in stock to represent everything realistically, additions had to be made with some commentary lines and explanations in the virtual training. Through a continuous optimization process by constantly asking well experienced shift supervisors and constantly obtaining feedback from the shifts as well as experts from the transportation system in the normal shift, it was possible to establish and transfer the virtual training to production. Using the first simulation based training system, the maintenance staff have now the opportunity to train and also to test themselves. Furthermore, the training can also be used for direct certification of new employees. The work on this system created for the 200 mm line at IFD as a virtual training can also be used in the future to create other virtual trainings e.g. for 300 mm lines and many other complex automation or digitized systems in other industrial sectors.

VII. Appendix

A. Training Evaluation Survey

The original survey was conducted in German. In the following, the transcribed script of the survey is summarized. Most answers use the Likert scale, a scale from 1 to 5, for the rating. The answers follow the following scale: (1) not at all, (2) slightly, (3) moderately, (4) very and (5) extremely. In each answer, the scale is typically combined with an adjective such as “not at all content” or “extremely content”.

Questions regarding your experience

1. How many years of experience do you have in maintaining the transportation
2. system?
   ☐ Less than a year
   ☐ 1 to 5 years
   ☐ 5 to 10 years

☐ More than 10 years

3. Were you aware of the semantics of the different visualizations and features of the software? (Yes/No)

4. How much time did you need to qualify for the utilization of the software?
Please give an estimate. (Open text)

5. How content are you with the previous training methods for the maintenance of the transportation system? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not content at all*" and 5 to "*extremely content*")

6. To which user group do you belong to?
☐ Regular shift (*German: Normalschicht*)
☐ Shift supervisor (*Schichtleiter*)
☐ Maintainer in shift (*Instandhalter in Schicht*)

General questions about the training

7. Could the new training, in your opinion, bring added value for new workers in transportation system maintenance? (Yes/No)

If you have any additional remarks or comments, you can enter them here: (Open text)

8. How much time could be saved with the new training? Please give an estimate (e.g., number of workdays or other advantages). (Open text)

9. Do you have experience with a similar training/learning system for maintenance tasks? (Yes/No)
If you have any additional remarks or comments, you can enter them here: (Open text)

Questions about the theoretical part – the introductory slides

10. How understandable is the content of the introductory slides? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not understandable at all*" and 5 to "*very understandable*")
If you have any additional remarks or comments, you can enter them here: (Open text)

11. On as scale from 1 to 5 (where 1 is "*not understandable at all*" and 5 is "*very understandable*"), how would you rate the descriptions and depictions of the following concepts?
    a. View levels in the software
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
    b. Types of transportation track elements
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
    c. Color codes (e.g., red = error)
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
    d. Main functions (e.g., *info*, a*ll entries*, etc.)
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
    e. Errors (e.g., t*ransfer timer ended*, etc.)
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
    f. Deadlock error
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

12. Are the animations and visualizations of the above mentioned concepts (11.a - 11.f) helpful? (Yes/No)

13. How content are you with the time spent on going through the full introductory slide set? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not content at all*" and 5 to "*extremely content*")

14. How content are you with the insights that new maintenance workers can gain with the introduction? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not content at all*" and 5 to "*extremely content*")

15. Does the content of the theoretical introduction give sufficient information for a newcomer to be able to answer the questions in the INTERACT application? (Yes/No)
If you have any additional remarks or comments, you can enter them here: (Open *text*)

Questions about the practical part – the INTERACT application

16. How would you rate your experience with the application? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not good at all*" and 5 refers to "*very good*")

17. How realistic is the representation of the software user interface in INTERACT compared to the real software? (The answer can be chosen on a scale from 1 to 5 where 1 is "*not realistic at all*" and 5 is "*very realistic*")

18. How realistic is the simulation of the behavioral aspects (functions and color changes) of the software? (The answer can be chosen on a scale from 1 to 5 where 1 is "*not realistic at all*" and 5 is "*very realistic*")

19. Would you recommend the application for utilization in other maintenance sectors? (Yes/No)

20. How content are you with the time spent on working through a training instance? (The answer can be chosen on a scale from 1 to 5 where 1 refers to "*not content at all*" and 5 to "*very content*")
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

21. If you have any other remarks or improvement suggestions regarding the training, please enter them here. (Open text)

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