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Learning Factory modules for smart factories in Industrie 4.0

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Abstract

Industrie 4.0 has become more and more important for industry in recent years. A lot of companies are currently facing the challenge that plenty of technologies like the information and communication technology are indeed available but the companies, i.e. the individual employees, are not prepared for a successful use of Industrie 4.0. Therefore, learning factories can make a substantial contribution toward the understanding of Industrie 4.0. Learning factories are more frequently used to instruct students and employees. Workplace-related scenarios can be mapped through practical learning. This proceeding enables participants to transfer learned knowledge directly to the own workplace. This article presents a variety of learning modules for the smart factory in Industrie 4.0. It describes the new job profile of employees in Industrie 4.0 and thoroughly discusses the various learning modules with their individual learning targets and mapped scenarios.

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Keywords: Industry 4.0, learning factory, operating figures, human-machine-interaction

1. Introduction

Manufacturing companies are exposed to varying circumstances due to globalization and volatile markets. In general, companies react with short-cycle adaptation, a stronger customer focus and shrinking batch sizes [1,2]. The continuous advancements of information and communication technologies offer great potential to manufacturing companies. The term Industrie 4.0 embraces the use of new communication technologies and accelerates the implementation of cyber-physical systems in the manufacturing industry [1,3]. Industrie 4.0 has a big influence on employees and organizations across technical innovations in production [4]. The production work will change in that manual operations in production will decrease while steering and monitoring activities will become more important [5].

The staff needs to be prepared for the changed job profile by getting acquainted with new technologies (e.g. smart glasses). Learning factories have already been used in practical trainings for different topics within production processes during the past years (e.g. lean management and resource efficiency) [6]. Furthermore, learning factories offer a realistic environment of production systems by the use of their technical equipment. In addition, process improvements and modifications can be safely tested during production processes [7]. Therefore, learning factories offer a great opportunity for trainings and the preparation of employees for the use of Industry 4.0 [8] and should be closely linked to cyber-physical production systems [9].

This article first describes the change of job and field activity of production workers (see chapter 2). The LPS learning factory and its equipment is introduced to provide a showcase project for learning factories in general (see chapter 3). Specific Industrie 4.0 learning modules are presented in chapter 4 until an outlook for future tasks is provided in a thorough conclusion.

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2. The human role in Industrie 4.0

Industrie 4.0 differs from the approach of computer integrated manufacturing (CIM) of the 1980s concerning the human role in the production environment. Whereas CIM considered the workerless production, the human role in Industrie 4.0 is still very important and essential [5]. Nevertheless, the role will change on the different levels of a production system and these changes will occur both on the shopfloor as well as management level.

As a result of the interlinking of cyber-physical systems in Industry 4.0, the real-time depiction of all processes in a factory is now possible [10]. For this reason, employees on the production planning and control (PPC) level will be confronted with a high amount of information and data, generated by the entire infrastructure of cyber-physical systems. The challenge will be to summarize, prepare and interpret the data [11]. Besides, it can be assumed that formerly separated tasks and competences will merge [10]. This will all increase the complexity of work. Thus, planners and controllers will have to be educated and trained to deal with this complexity by using new forms of planning methods and technologies.

The increasing complexity of work will also concern the shopfloor level. As simple tasks will be more and more automated, the remaining tasks will mostly consist of problem solving. Besides, these tasks will become more and more complicated, as the complexity of machines and plants within the smart factory will increase rapidly [12]. For the human operator, mastering this complexity requires larger amounts of knowledge and competences than ever before [13]. Thus, employees on the shopfloor level have to be enabled to deal with this complexity, for example by using new assistance and knowledge services.

Regarding the human role in Industrie 4.0 in general, especially the requirements regarding the professional, social, methodical and personal competences will increase [14] (see figure 1).

In order to succeed within the fourth industrial revolution, companies of the producing sector have to prepare their employees for these competences. In order to deal with the high complexity and diversity of challenges in this development, learning factories offer great opportunities for an efficient and sustainable development.

Regarding the important competences, the following learning objectives can be derived (see also figure 1):

- Dealing with high amounts of data and information
- Using new methods and technologies, which will be key elements of work in Industry 4.0
- Becoming comfortable with new forms of organizational structures regarding processes and personnel issues
- Becoming comfortable with the new human role in production processes

Figure 1 shows the connection between challenges posed by Industry 4.0, the appropriate relevant competences as well as the resulting learning objectives. The following chapters present one possible approach of an Industrie 4.0 learning factory.

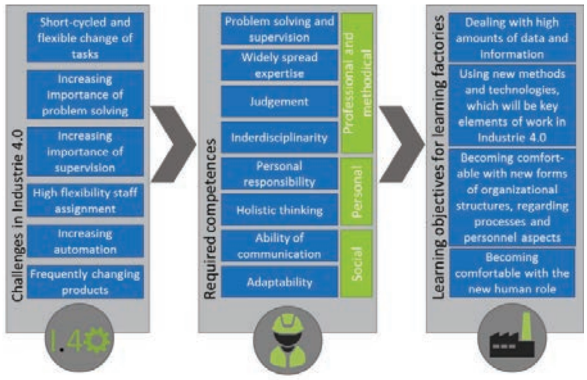

Figure 1: Challenges of Industrie 4.0 and corresponding learning objectives for learning factories (following [14])

3. Infrastructure and goal of the LPS learning factory

The LPS learning factory has the technical equipment of a small and medium-sized enterprise (SME): lathe machines (manual and CNC), drilling machines (manual and CNC), machining center, drilling tools, band saw etc. Two fully equipped assembly lines with seven stations each are being developed at this moment. The manufacturing execution system which is implemented and collects data from the machines via OPC-UA is fully functional and set up for a day-to-day application [15]. The described setup of the LPS learning factory allows the simulation of different kinds of learning modules within a real-world manufacturing environment, hence offering a perfect learning environment for students and industrial participants [16].

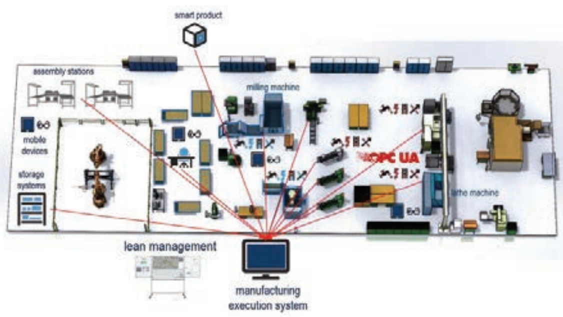

Figure 2: Infrastructure of the LPS learning factory

Figure 2 shows a 3D model of the learning factory and the possibilities of interaction between the components (machines, MES, server, workers, etc.) and future components (assembly lines). The goal of the LPS learning factory is to be able to simulate as many use cases of a real production system as possible. This can only be achieved by also including assembly lines with real-world products. One assembly line will focus on just one product and the possible improvements within the process and the implementation of new technologies to advance towards an Industrie 4.0 assembly station. The other assembly line is designed in a more flexible manner so that new ideas that are developed by the participants during different learning modules (MTM, lean management, assistant systems) can be instantly implemented. The participants can implement smart glasses, MES, mobile devises, 3D printers, etc.

4. Learning modules for Industrie 4.0

The different learning modules for Industrie 4.0 which are being developed at the Chair of Productions Systems are shown in figure 3.

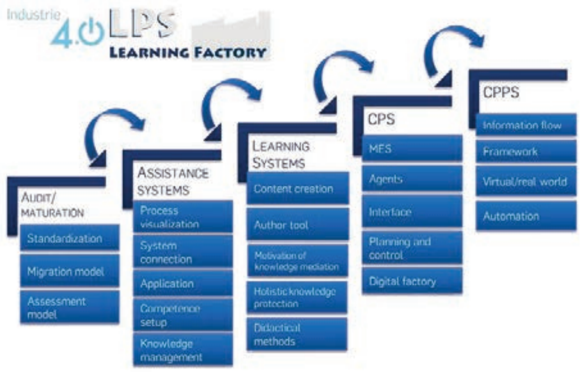

Figure 3: LPS-learning modules for Industrie 4.0 [8]

The developed modules, once fully employed, will give an insight into the five functional areas of Industrie 4.0: assistance systems, decentralization & services, crosslinking & integration, data acquisition & processing and self-organization & autonomy [17].

The module 'audit/maturation' is still in a very early phase of development since the research project has just started. The idea is to support companies systematically with the transformation to an Industry 4.0 company. Every company has to develop its own schedule of how to create the design fields of technology, organization and staff. Therefore, a maturity model is necessary. It maps the latest Industry 4.0 status of the production and supports the transformation to a higher maturity level. An Industry 4.0 audit demonstrates the current status of the respective company. It also clarifies if technology, organization and staff have the same development status. For instance, a company could have already installed a Manufacturing Execution System (MES) for their production control without adapting the organization structure or without dedicated trainings for the employees. With the help of the maturity model, the transformation can be done systematically by simultaneously considering the three design fields of technology, organization and staff [8].

The second, third and fourth module are described below. The fifths module is going to be the most complex module as it consists of all the learning contents out of the other modules.

4.1. Manufacturing control in Industry 4.0

Industrie 4.0 makes it possible to interlink all elements related to manufacturing processes. The main target is the connection between the real physical world and the digital factory. This is facilitated by new technical possibilities for manufacturing control [18]. Until now, the manufacturing control has been exercised by manual spreadsheets or detailed planning in MES. Multi-agent systems for an intelligent networking of real and digital factories allow a real-time data gathering for an automatic manufacturing control support and autonomous runs of material flow simulations [19].

Agents are small autonomous software units with a specific task to fulfill a particular aim. An important feature of these agents is the communication skill. In the SOPHIE system, the agents are implemented with the JAVA development framework JADE. The first task is to handle proprietary interfaces for special software systems (e.g. MES or spreadsheets) needed for planning processes to collect data. Each interface agent contains a converter to map the proprietary data model to an open XML-based data format. For this project, the CMSD (Core Manufacturing Simulation Data) structure was chosen [19].

As soon as the agents have received the necessary data, the information can be communicated between them. This has several advantages: Firstly, the information can be visualized for all employees. Furthermore, an automated data processing is possible based on a uniform data syntax and semantics. For the manufacturing control process, different scenarios have to be compared. This can be automated with simulations. Therefore, a special simulation agent was implemented who can communicate with the data providing agents to update the models. After different simulation runs, the results can be communicated back to other agents or the traditional planning system. This new opportunity is included in a learning factory model. The learning target is to familiarize participants with the function of simulation-based manufacturing control. The participants should become acquainted with necessary technical requirements (material flow simulations, MES, agent systems), interfaces (data of digital and real factories) and applications of the SOPHIE system.

For this purpose, a traditional manual manufacturing control for production systems is presented as a first step. It is obvious that the manual planning is very time-consuming. Because of machine failures, it is necessary to continuously reschedule manufacturing orders, which makes the manual planning very difficult and complex. The deficiencies are discussed in a reflection and implementation phase.

In this context, the new SOPHIE system is presented as an Industrie 4.0 solution. During the implementation phase, it becomes obvious which technical devices and tasks are necessary for the assignment. This is shown by a few examples like the interface definition of simulation data. In a second step, the SOPHIE-system is applied.

In this case, the participants learn how Industrie 4.0 changes particular tasks and what kind of benefits result from the SOPHIE solution. As part of a special example, the participants realize that if they use material flow simulations for manufacturing control aspects, there will be no need for manual use. The savings of manual accountability such as the timing of which order shall be produced on which machine bring about interface and data model definition as a new task.

4.2. Assistance system in Industrie 4.0

The work environment of workers on the shopfloor level is becoming more and more complex. Employees have more responsibilities, have to operate more machines at a time and have to know more about the production processes. If errors occur at machines, which may stop the whole production line, workers have to be able to carry out the troubleshooting themselves instead of waiting for the maintenance crew to fix the problem. The two criteria, time and the complexity of machines and processes, require more assistance for the workers on the shop floor level. Today's technology, such as cyber-physical systems, mobile end devices and intelligent services enable the possibility to develop such assistance systems. But at the same time training modules have to be developed to sensitize companies as well as the new generation of engineers to the possibilities and also the risks of assistance systems. It is not enough to just show them what today's assistance systems are capable of. They have to be able to identify processes that are worth assisting, convey the necessary measures and possible potentials and accomplish the change process with the necessary consideration of labor laws [20].

Such a training module is being developed at the LPS learning factory. With the mentioned requirements in mind, the module will put the participants in different day-to-day situations within a production process. They will have to improve the processes and, at the same time, they have to consider customer demands, key performance indicators (KPIs) and labor laws. At the end of the first unit, the participants discuss their first ideas for the implementation of an assistance system after which they receive more theoretical input. As soon as the second unit starts, some workers are equipped with mobile devices (tablets and/or smart glasses) with installed assistance services (APPsist-system). The objective of the second round is to identify more possible potentials for assistance systems and to measure the influence of the already embedded assistance systems. Among others, the following questions are raised: is the worker faster, can the worker handle more tasks, is there an influence on the KPIs, how ergonomic is the equipment for the worker, etc.

4.3. Learning on the shopfloor level by using digital learning scenarios

The continuous increase of productivity, flexibility and quality demand within production processes is a key factor for securing the competitiveness of the German manufacturing industry [21]. In addition to technically innovative production solutions, the worker is a central key success factor [22]. The increasing complexity of manufacturing machines results in a clear need for support of machine operators within Industry 4.0.To manage the work processes adequately, the machine operator needs special knowledge about the work processes [23]. Focusing on these fact, there is a clear demand for a modern learning system which can solve these problems by the use of digital media. The workplace-integrated learning system will provide learning content for the worker. This leads to a new kind of learning to match the new requirements of knowledge-based manufacturing [24].

This new learning system is built up in a learning factory model. The main target for the participants is to learn how this modern form of workplace-integrated learning works and which possibilities this system offers.

The learning factory module consists of different learning steps. In order to reach the learning target, a turn-based training concept is used. In a first round of the training, the participants will try to manage a complex task within the production. Every participant will get a specific role within the fictional company, for example accountant or production worker. Afterwards there will be a discussion on how the workers have managed this complex situation. In a second round, the participants change their role, so the upcoming situation is unknown for everyone. Every worker will get a tutorial for their specific role provided by a mobile terminal. There the playback service of the DigiLernPro system is used. After the learning process, the participants try to manage the same complex tasks, which are completed by another discussion. In a third phase of the training concept, the concept of the DigiLernPro system is explained. The DigiLernPro system consists of a very simple periphery to make the system very affordable. To reach a fully functional system, only a convertible, a server and a Wi-Fi system is needed. An external camera as well as an external microphone can be used in addition to these three parts.

The convertible is used for the visual and local-independent presentation of the created learning content as well as for the instructed recording of the learning content. The created learning content is centrally stored on the server. The WiFi system is used for the communication and data transfer between the different parts of the system. The employee, who gets access to the learning content, logs in to the system with his own account. This user account contains the individual competence profile, which helps to edit the learning content in consideration of the personal preferences of the employee. In addition, the individual state of knowledge is recorded to create an adapted content to the individual experience of the employee [25]. Within this phase, the participants will learn how they could create content on their own, how the author tool works and which didactic concept is used to provide the learning effect within the tutorial.

4.4. Integrated framework

In order to have a holistic approach to Industrie 4.0, the described modules have to be joined in one framework. Figure 4 shows the basic extendable framework of the LPS learning factory. This framework provides the basis for a learning environment to teach future workers in Industrie 4.0. On a technical level, this means that the learning factory needs to be fully interlinked to provide the systems with all data that is produced within a cyber-physical production system. On an organizational level, the environment must be very flexible to change from a classic SME to an Industrie 4.0-compliant SME. On a personnel level, participants of such learning modules have to able to make enhancements to the presented work stations, infrastructure, organizational setting, etc.

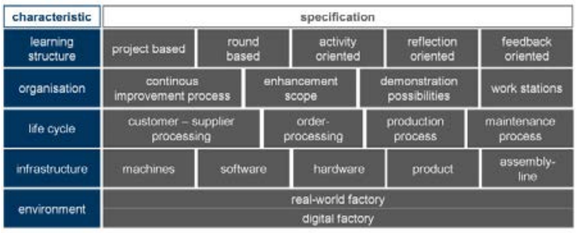

Figure 4: extendable learning framework of the LPS learning factory

The modules will be aligned along an objective to show the interdependence of the different topics. The participants will see that workers have to be assisted in order to improve key performance indicators (KPIs). In order to give intelligent assistance, digital services need more information about the process (operating process, maintenance process, machine data, production data, human-machine interactions, machine manual, etc.) to push the network integration within the factory as well as the workers' obligation to communicate knowledge into a digital knowledge basis. This also affects organizational aspects such as workers' rights. Autonomous production planning and control agents will also require a wide network integration in order to use real-time data for simulations. This digital integration will affect the employees' work and their work space. That is why the modules will encourage an integrative approach where employees of all levels (shop floor and planning and control) will be trained to propose new innovations to their companies in order to level up its technological standard towards Industrie 4.0.

5. Conclusion

The continuous increase of productivity, flexibility and quality is a key factor for the German producing industry. The ongoing digitalization and interconnection of production processes will challenge the German companies. The complexity of Industrie 4.0 leads to new technology, workplace and business model enhancements. The role of the worker within the production environment remains very important.

In order to introduce the topic of Industry 4.0, different learning modules are being developed. Within the next few years, the workshops will be extended along the most recent research results. Different research project of the LPS (Chair of Production Systems) in the field of Industrie 4.0 will be implemented in a special Industrie 4.0 learning factory workshop.

These workshops show the different Industrie 4.0 maturity levels and lead to a holistic comprehension of the topic for every participant. In the future, other topics may well be integrated into learning factories, for example product-service systems (PSS) offering holistic customer solutions instead of solely products or services. Offering PSS will definitely lead to changes for production-oriented companies (e. g. [26,27]). To support employees and companies for the PSS integration and the use of new interconnected methods like service value stream, learning factories serve as a perfect way to provide and enhance successful learning processes.

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