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Learning Factory on Global Production

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Based on the fundamental principle of teaching psychology that retentiveness increases if students actively apply learning topics rather than only attend oral or visual presentations, the concept of learning factories becomes more and more popular. Academic education in the field of production science is imparted by means of real-world manufacturing facilities. By applying the manufacturing process of a real product, students or professionals incorporate the learning contents effectively and gain consciousness about their practical implications.
Most learning factories are focused on lean manufacturing, lean administration or resource efficiency. As today manufacturing is not only subject to a single factory, but a network of globally distributed production sites, at the wbk Institute of Production Science, currently, a learning factory dealing with the topic of global production is developed. On the one hand, the curriculum of the Learning Factory Global Production (LGP) involves the specifics of local production sites with different location factors, such as different degrees of automation, cost structures and qualification levels, and their effects on the reconfigurability of the production systems. On the other hand, the interaction of the production sites in a globally distributed production network and the strategic configuration of the network are also subject to the curriculum.
The manufacturing processes are exemplified by the assembly of an automotive e-motor with transmission in the learning factory on global production. The learning factory is realized in cooperation with the Robert Bosch GmbH.

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1. Introduction

Modern globalization shows a global expansion of the manufacturing industry and production networks [1]. The differences in factor costs such as labor and energy costs, which are still significant, motivate the globalization of production. In addition, the markets for consumer and industrial goods have shifted from the developed industrial countries to developing economies [2,3]. As a result, not only large corporations, but also small and medium enterprises (SME) operate in globally distributed production networks. Particular stages of the production processes are performed at globally allocated sites. Simultaneously, globalization leads companies into an unprecedented competitive field with shortened product life cycles, rapid fluctuations in demand and increasing numbers of product variants [1].

However, in 2012 the industrial production in Germany comprised about 7.9 million employees, representing approximately 20% of the total employment [1]. This proves the importance of the manufacturing sector for the German economy.

In addition to modern production principles, qualification and skills of human resources will be of particular interest as a critical success factor in global competition [4]. Identifying dynamic changes and taking technical and organizational adjustment measures are differentiating assets of modern production [5]. The education and training of students, employees and executives leads to a continuous improvement of a company‘s business performance [6]. Traditional methods for the development of staff competences have shown to be unsuccessful in the past due to a lack of implementation and transfer skills [7]. More and more educational institutions and companies qualify students or employees and managers in practice-oriented learning environments, so-called learning factories. This approach has much potential, since not only inert knowledge is taught through lectures, but also skills are being developed that qualify for self-organized problem-solving [8].

Due to the increasing importance of the qualification of human resources and the global expansion of the manufacturing sector, particularly, a learning factory for production-related issues of global production has an enormous potential. At the Institute of Production Science

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(wbk) a learning factory for global production is currently implemented structurally, technically and didactically.

2. Theoretical Background

Over the past ten years, numerous learning factories have emerged, not only in Germany, but all over the world. This development reflects the trend towards new, practice-oriented learning environments for education and training. Learning factories can be found both in academic, research-oriented institutions and industrial companies. In addition, consulting companies offer a range of training and development platforms. Learning factories in many cases have been realized in cooperation of academic and industrial partners.

However, the issues of global production, e.g. the planning of site-specific production systems or the design of global production networks, is not focused in any of the existing learning factories.

3. Learning Factory on Global Production

3.1. Scope and Objective

The Learning Factory on Global Production at the Institute of Production Technology (wbk) serves as an innovative training platform for the challenges of a global manufacturing company. The learning factory is based on three key issues of global production:

- What should be produced?
- Where should it be produced?
- How should it be produced?

Figure 1: Key questions of global production

Consequently, production-related issues such as site-specific factory planning and production in global production networks are in the focus of the learning factory.

Target groups are primarily students and professionals. Yet, in addition to its educational and training purposes, the learning factory will also serve as a research demonstrator with regard to scientific issues of global production in the future, which are investigated at the Institute of Production Science (wbk).

3.2. Object of Investigation

A fictitious production network of a real product serves as object of investigation of the learning factory. The production network consists of three production sites which are globally distributed (cf. Figure 2). The lead factory of the production network is located in a high-wage country. In addition, two assembly plants in low-wage countries complete the network. At the lead factory all production steps are allocated. The production steps of the other assembly plants are limited to the scope of final assembly and quality control. However, the lead factory, in contrast to the assembly plants, is not physically realized in the learning factory at the Institute of Production Technology (wbk), but is virtually integrated into the scope of consideration.

In addition to the site-specific design, evaluation and optimization of the assembly plants, the complexity of the supply chain between the production sites and the associated planning and optimization tasks have to be modelled as realistically as possible for the course participants. Within the seminars, the course participants are faced with the challenge of adapting the production systems of the two assembly plants with respect to the local conditions such as factor costs, qualification of staff, legal factors, etc.

For each production step, different process alternatives are available for the participants. In the seminars, the goal is to design, evaluate and optimize production systems by means of state-of-the-art methods and procedures, such as line-balancing, methods-time measurement (MTM) etc. The developed solutions are discussed and potential approaches for optimization are implemented by the workshop participants.

Another important goal of the learning factory is to raise the students' awareness of the complexity of global production networks. Thus, the seminars include problems such as the planning and optimization of the production network and supplier management. These tasks not only include make-or-buy decisions, but also the determination of production capacities and production programs. Suitable material and component suppliers are selected and the material flows between the production sites of the fictitious network are planned. In order to understand the complexity of the designing process of production networks, various key performance indicators (KPIs) are compared and discussed by the participants.

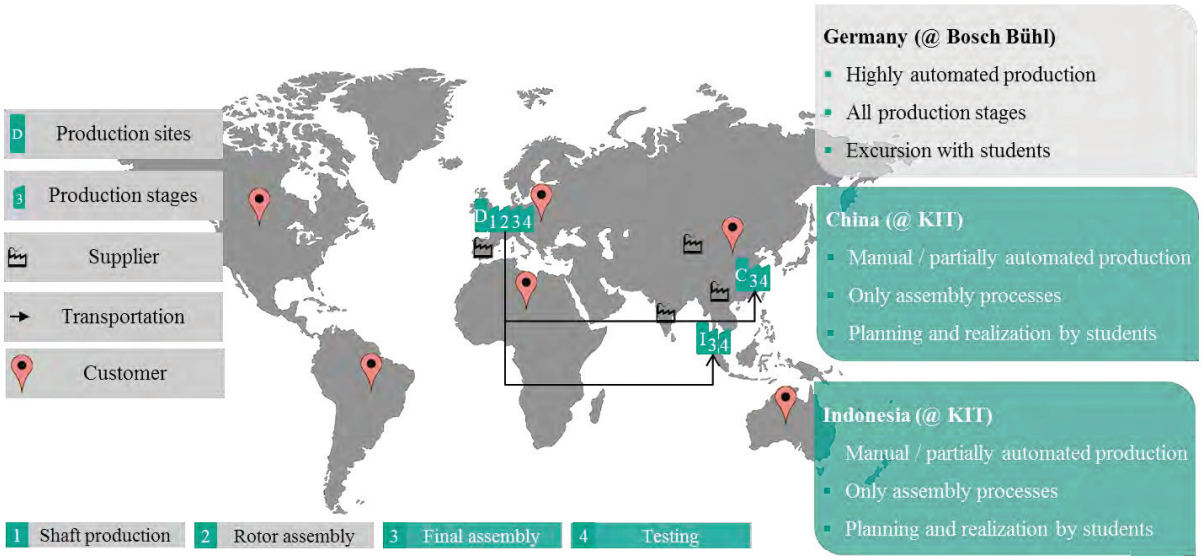

Figure 2: Object of investigation of the Learning Factory on Global Production

3.3. Demonstrator Product of the Learning Factory

For a realistic evaluation of production issues in the learning factory the identification of a suitable demonstrator product is essential in order to illustrate the desired educational contents. The product selection sets strict conditions for a learning factory. On the one hand, the viable manufacturing and assembly processes limit the degrees of freedom for possible course contents. On the other hand, their complexity has still to remain manageable.

In order to optimally cover the addressed course contents, the following characteristics are demanded with regard to the potential demonstrator product:

- Real industrial product
- Wide range of variants of the product
- Ability of easy assembly as well as disassembly (recycling of semi-finished products)
- Low material costs
- Possibility of automated and manual workstations
- Simple machine operation by seminar participants
- Close cooperation with manufacturer of the real product

Finally, a DC motor with gearbox by Robert Bosch GmbH was selected as demonstrator product for the Learning Factory on Global production (cf. Figure 3), which fulfils the aforementioned requirements.

The selected product is a direct current motor of the AHC product family of Bosch. The electric motor consists of a case with clamped permanent magnets and bearings, a wound rotor, a brush carrier and a flange-mounted gearbox (cf. Figure 3). Based on a standardized motor, particularly, the various types of gearboxes and brush carriers lead to a high variety of variants with a manageable fabrication complexity. The numerous screwing, pressing and joining processes can be automated in a scalable manner. The process chain of the motor is illustrated in Figure 4. Due to a close cooperation with Bosch as a partner of the Learning Factory on Global Production, the supply of semi-finished products and the access to resources and process know-how is realized.

Figure 3: Bosch DC motor as demonstrator product of the learning factory

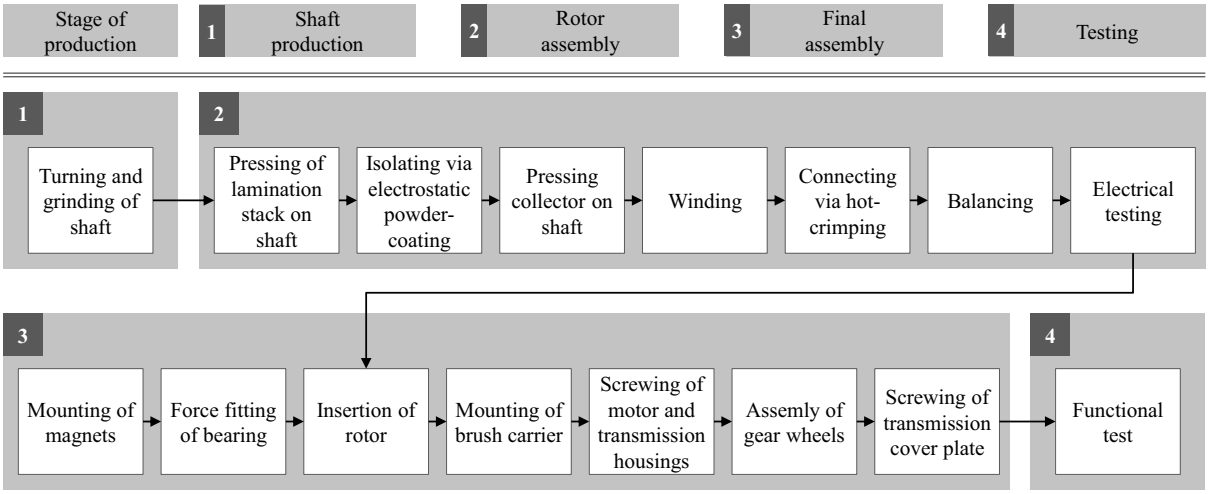

Figure 4: Process chain of the demonstrator product

3.4. Considered Process Chain of the Learning Factory

The process chain to manufacture the considered motor consists of the mechanical production of the shaft, the assembly of the rotor, the final assembly of the motor and the gearbox as well as a final functional test (cf. Figure 4).

Production stage 1 and 2 require cost-intensive equipment. Production stage 1 consists of precise turning and grinding machines to manufacture the shafts within small tolerances. Production stage 2 comprises multiple-turn coiling via flyer winding, crimp welding for the manufacturing of the rotor contacts as well as negative balancing by milling.

In the hardware of the Learning Factory on Global Production at the Institute of Production Technology (wbk) only production stage 3 and 4 are covered, as a result of the cost-intensive plant technology and high qualification requirements of stage 1 and 2. Yet, production stage 1 and 2 are virtually incorporated into the production network of the learning factory. For this purpose the Bosch plant in Bühl is virtually integrated in the Learning Factory as an additional production site. The plant in Bühl delivers single parts and semi-finished goods (coiled rotors) to the learning factory.

For a variable implementation of the production chain flexible workstations with different characteristics have been constructed, closely corresponding to the requirements of the industrial realization at Bosch. On the one hand, the equipment comprises several manual screwing, pressing and joining stations. On the other hand, screwing and pressing processes can be conducted by semi-automated stations with integrated quality control. Moreover, both the joining processes and the material handling between the workstations can be realized by means of flexible 6-axes-robots. Thus, the workshop participants have manifold degrees of freedom to design the production system of the learning factory in accordance with the location-specific conditions and constraints and to configure the hardware self-reliant.

3.5. Learning Modules

The modules of the Learning Factory on Global Production focus on issues of facility planning in accordance with the location-specific conditions and the production in a global production network. Within these two key aspects the workshop participants are confronted with close-to-reality problems.

The key aspect of site-specific facility planning focusses on the education of methods with regard to the creation, assessment and optimization of site-specific production systems as well as the planning of methods for dynamic adjustments (e.g. scalable degree of automation). Participants should gain knowledge to adapt site-specific production systems to local conditions as well as to dynamic changes of the environment (e.g. volatility of demand, increase of labor costs). Furthermore, the implementation of adequate methods for quality control in the context of global production is within the scope of the curriculum of the learning factory.

The second key aspect of global production involves methods and approaches to plan and optimize global production networks. In addition to a data-based assessment and an optimization of network configurations, the participants learn methods for capacity planning and production program planning in global production networks. Furthermore, the participants gain understanding of the complexity of supply chain issues by means of suitable simulation examples. Topics about supplier management, e.g. supplier evaluation and selection, will be also integrated in the learning modules.

In addition to specific problems of global production, fundamental knowledge of integrated production planning (e.g. lean production and value stream analysis) will be also taught to the participants.

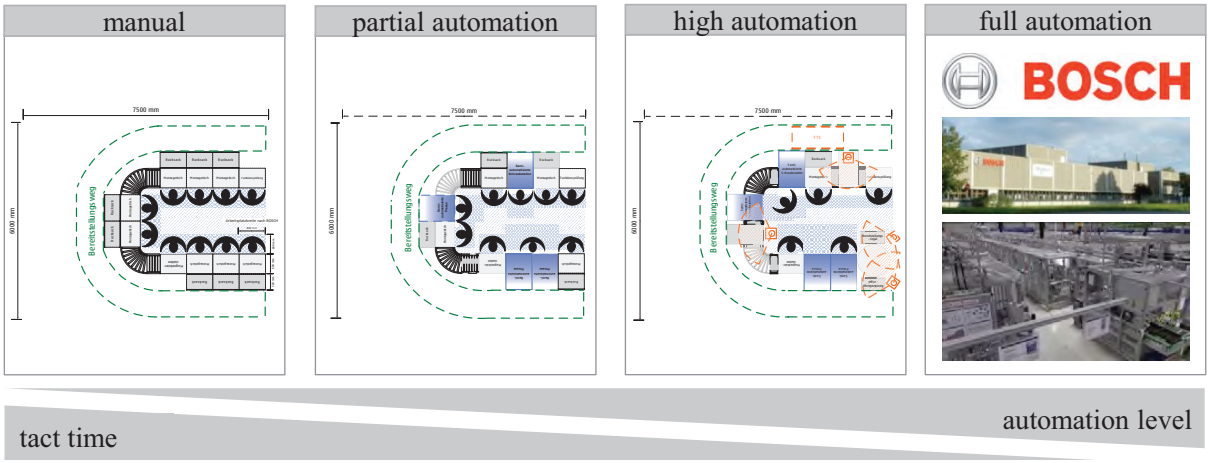

Figure 7: Demonstration of scalable automation in the production system of the Learning Factory on Global Production

In summary, the following learning modules are focused in curriculum of the Learning Factory on Global Production (cf. Figure 5):

- Site Selection
- Sourcing
- Location-specific Production
- Scalable Automation
- Quality Assurance in Global Production
- Production Network Planning

The workshops in the realistic production environment of the learning factory will be complemented by e-learning modules. Before the workshops the participants learn about the theoretical background of the respective learning modules by e-learning in self-study. Furthermore, physically not representable contents of the curriculum are taught based on e-learning modules. A modular organization of the learning contents guarantees a tailored conception of training sessions.

Site Selection	▪ **Topics:** Knock-out process for site selection
Sourcing	▪ **Topics:** Supplier evaluation and selection
Location-specific Production	▪ **Topics:** Flow principle, line-balancing, factory logistics, workplace design
Scalable Automation	▪ **Topics:** Factory planning with scalable automation, ramp-up and robustness assessment of automation technology
Quality Assurance in Global Production	▪ **Topics:** Six Sigma project regarding quality defects in global production
Production Network Planning	▪ **Topics:** Modelling, assessement and comparison of alternative configurations of the production network

Figure 5: Overview of the learning modules of the Learning Factory on Global Production

3.6. Exemplary Learning Module: Scalable Automation

One focused topic within the curriculum of the Learning Factory on Global is the planning of scalable production systems. The selection of the optimal degree of automation of the equipment in accordance with the location-specific conditions is a key challenge in the scope of a reconfigurable production system. The participants experience realistic production scenarios, which are characterized by dynamic changes of environmental influences (e.g. increase of labor costs or demand).

In these scenarios the participants deal with scalable adjustments in the degree of automation within a production system (cf. Figure 6). The impact of the participants' decisions on key figures of the production systems (e.g. unit costs, OEE, process time) is analyzed. Thus, the participants learn to identify the demand and the time of a potential adjustment of the degree of automation. Furthermore, the effects within the ramp-up phase of automated equipment are experienced and evaluated by the participants. Within the scope of the Learning Factory on Global Production several scales of automation are realized, while a fully automated production line is only subject to the Bosch plant in Bühl (cf. Figure 7).

Automation can be applied not only for the execution of production processes, but also for the material handling and logistics of the workstations. The respective automated equipment comprises semi-automated workstations (e.g. screwing and pressing stations) as well as robots for the material handling and the logistics.

Figure 6: Manual and semi-automated workstations of pressing processes in the Learning Factory on Global Production

4. Cooperation with Bosch

With the Robert Bosch GmbH, a valuable partner could be found for the implementation of the learning factory. The Bosch plant of the division Electrical Drives in Bühl produces the DC motors, which were selected as demonstrator products of the learning factory. The professional support of Bosch regarding the product characteristics and the production processes have been very helpful for the planning of the learning factory.

The conjoint effort of the learning factory is the development of planning knowledge for site-specific production structures. Furthermore, scalable automation solutions are commonly developed and tested within the learning factory.

In the context of the learning modules the highly automated plant in Bühl serves as a virtual site and represents a high-wage location within the production network. Many aspects of the real conditions of the plant Bühl are integrated in the case studies of the learning factory.

Furthermore, the participants of the learning factory gain insight into a highly automated production at a high-wage site through on-site modules in Bühl. The participants deepen their knowledge by active involvement in the factory (e.g. by value stream analysis, cycle time analysis, etc.) and learn about the challenges of automated equipment (e.g. availability issues).

5. Conclusion and Outlook

Production in global production networks is gaining more and more importance for companies of all sizes. The planning and management of globally distributed value chains is a complex task. In order to prepare future engineers and experts for these challenges, the Learning Factory on Global Production is established at the Institute of Production Science (wbk) at KIT. By means of the assembly of the demonstrator product of a DC motor, the course participants deepen their knowledge of production planning and the management of globally distributed networks. In a balanced mix of theory and practice, theoretical contents are applied in a real industrial environment. The workplaces in the learning factory can be implemented in various scales of automation. In addition, the highly automated site of Bosch Electrical Drives located in Bühl is virtually integrated into the learning factory to map a production network with three production sites.

Within the next months, the didactic concept as well as the training materials of the learning factory will be elaborated in detail. Besides, the automated workstations will be further refined (e.g. with respect to the integration of robotics).

6. Acknowledgement

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