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Procedia Manufacturing 23 (2018) 201–206

Procedia MANUFACTURING

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8th Conference on Learning Factories 2018 - Advanced Engineering Education & Training for Manufacturing Innovation

Requirements for designing a cyber-physical system for competence development

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Abstract

The increasing demand for individual products and shorter product life cycles leads to changing requirements concerning skills and competences of workers. Competence development during value adding processes becomes a key success criterion. In the future, new methods and procedures for education and advanced training of workers will be needed in order to handle the increasing complexity of individualized and personalized products economically. New systems for the competence development during the value adding process are required in order to achieve an economical production of individual products in an assembly system. The technology enablers for the competence development will be new communication technologies. These technologies lead to cyber-physical systems for competence development, which support the workers and enable them to produce products economically at lot size 1. For an optimal design of these systems the competence development process and the competence measurement need to be included. Competence development, competence measurement and cyber-physical systems are therefore directly linked to each other and depend on each other. For designing a cyber-physical system for competence development of assembly workers in an assembly system, these interconnections will be illustrated in order to enable an economically well-founded view.

Peer-review under responsibility of the scientific committee of the 8th Conference on Learning Factories 2018 - Advanced Engineering Education & Training for Manufacturing Innovation.

Keywords: Factory management; Industrial learning, Training; Competence development; Learning factory

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2351-9789
Peer-review under responsibility of the scientific committee of the 8th Conference on Learning Factories 2018 - Advanced Engineering Education & Training for Manufacturing Innovation.
10.1016/j.promfg.2018.04.017

1. Motivation

The increasing individualization of products leads to an increasing product variety [1] and changing requirements concerning the skills and competences of workers. As a consequence, new training and further education methods and procedures are needed [2–5]. The change from individualized products to personalized products leads to a continuing rise of complexity. The higher complexity cannot be handled with standard flow line systems. For this reason modular production systems become more and more focused which is also why here assembly systems are considered in particular [6]. Complex products are often linked products and the number of variants of the production family can no longer be predetermined, because the products are crosslinked and individualized. Such products may, for example, be personalized products co-developed and co-designed by the customer [7, 8]. Wang presented industrial examples which implemented mass personalization in their production, like the Dell industrial model, the Harley Davidson industrial model and the Red Collar industrial model [9]. Changed requirements and the increasing complexity call for new competences to enable an economically reasonable manufacturing.

Since the emergence of Industry 4.0, trade unions and labor associations have also been dealing with the topic of the “future of work”. Reflections within the unions have led to an increased discussion of scenarios such as individual mass production, self-configuring or self-organizing production systems. As a result, the learning efficiency of work environments in the age of digitization, human-machine as well as human-environment interactions and the collaborative factory work are examined. Basically, the determination of a general qualification level and of task-specific qualifications are important and so are competence development processes, as they help to determine the feasibility and profitability of human-centered operating and technology models. The aim is to design new innovative learning approaches in a participatory work environment [10]. This will allow life-long training across all work groups and skill levels [4, 11]. Workers will also be in the focus in a virtualized and information-technology centered factory, because human beings can judge and solve problems and exceptional situations due to their many years of experience [12]. This means increasing and changing requirements on the workers regarding their competences. Also the requirements on the systems, which can support and enable workers in the manufacturing of products, will increase and change. In mass personalization the customer is involved in product development via a co-design process. This means new tasks for the workforce which must be enabled to handle them with appropriate training or by the design of appropriate systems. Involving the customer in the co-design process may mean the active part of designing the product or measuring the customer for personal customization [13]. The production of personalized products in an assembly system under similar conditions as in mass production can no longer use the methods of Taylorism, so that new paradigms for production will arise. The reasons for this are discussed in detail in [3].

2. Competence development in the value adding process

Taking a deeper look at the development of Taylorism it becomes apparent that it is reaching its limits. For personalized products its no longer possible to apply the traditional methods of Taylorism as the paradigms of mass production lose their validity. Taylorism’s methods of labor division and its “one best way” approaches need to be reconsidered and their cost effectiveness be reviewed [14]. Due to an inceasing number of variants, knowledge cannot be learned in advance for every single variant. This can lead to a partial reversal of Taylorism (Reverse Taylor) or to a softening of standards in production and the usually strict division of labor [3]. The Reverse Taylor includes the following features and can be described as [3]:

- Customer-specific manufacturing supported by planning and execution standards
- Co-design process between manufacturer and customer
- Fluid competence areas of workers which change constantly over time and can be supported by CPS
- High flexibility of workers on the basis of competence measurements and adjustments during value creation

It becomes apparent that qualification and competence development can no longer take place outside the value creation and be economical at the same time. In the future due to individualized products it needs to take place in the value creation process. Using the examples of the four life cycles, i.e. order, factory, product and technology life cycles, which all come together in the production, the competences of the workers required in the future can be identified. In order to be able to manufacture individualized products in lot size 1 economically the workers must be able to move within these four life cycles in regard to their competences. Therefore, competence development must be organized within these four life cycles. This creates competence areas that are subject to constant change such as new technologies for producing personalized products. These competence areas are referred to as fluid competence areas in which workers have the appropriate skills and abilities and can handle new, unknown situations in the individual areas of the four life cycles.

3. Competence measurement and assessment in the value adding process

The mandatory basis for the specific competence development process is competence measurement [15]. It focuses on the determination of individual development needs and potentials of workers as well as the evaluation of existing and proven competences that can be recorded in the work process. Competence measurements infer the existing competences from current actions because workers' competences can be measured only while they are performing their work [15]. Continuous competence measurement enable the identification of individual competence development needs. Competence analysis includes the four steps of identifying, measuring, analyzing and evaluating competences. In order to assess the competence development of workers in value adding processes it is necessary to identify the indicators that can be used to measure and then operationalize competences first [16, 17]. A set of metrics, which will help measure in a quantified way the competence development, has to be defined [4] The competence measurement can then be integrated into value creation. The method of real-time documentation has also to be determined. Since there is no general method of measuring competences [15], the existing competence assessment procedures must first be examined concerning their suitability for measuring those skills that will be needed in value adding and possibly be adapted [15]. When the results of the competence measurement are available the third step is to establish the concept for competence analysis. With this concept the competence measurement can be transferred to a measurable value which enables a monetary assessment (analysis) of the competence development of workers. Existing approaches from financial controlling, human resource management and evaluation theory need to be examined and analyzed for their suitability with regard to competence evaluation in lot size 1 [18]. The benefits and costs of education are the basis for a monetary evalutation [19]. Its important to analyze and assess competences and the success of training measures in real time to enable optimal training and further education during value creation. In the fourth step the recorded and existing competences of the workers need to be evaluated. Competence analysis includes all procedures and instruments such as competence balance, competence assessment, competence measurement, and the evaluation of competences [20]. Today qualitative, quantitative and hybrid measurement methods are used and distinguished [15, 21]. Four different kinds of competence measurement methods are currently used in practice: competence tests based on quantitative measurements, competence passes based on qualitative measurements, competence simulations representing simulative scenarios, and competence situations such as work samples and observations in the workplace [15].

4. Systems for competence development

In order to assist workers in the production of personalized products and to enable competence development during value adding, feasible system needs to be developed or existing assistance systems need to be developed further [22, 23]. Workers will remain in the center of attention in spite of an increasing degree of automation in cyber-physical production system (CPPS) [12]. Human flexibility and creativity, their cognitive and social skills and many years of experience in assessing and resolving exceptional situations still make people indispensable in production [12, 23]. Assistance systems are already being used today to support workers in their tasks. For example, they guide the worker through the individual production steps and provide information on how to produce the product. Assistance systems may also assist to perform a certain task, e.g. to achieve the required quality or accuracy. Assistance systems are usually developed for specific applications and have sensors and actuators that enable them to perceive and influence their environment [24]. In the 5-step model according to Bauernhansl [23] assistance systems can be classified as step two on the way to Industy 4.0.

Assistance systems are generally suitable for the varied series production as the different variants are known and are stored accordingly in the assistance system. Maintaining all possible data in an assistance system is usually uneconomic and does not make sense. Therfore, a standard assistance system cannot be used reasonably for individual and personalized products where the customer is involved in the design or development process. The possible product variants are not known in advance and usually each one is produced only once. Assistance systems can therefore represent a useful support for standard products as well as for defined operational situations. However, for individualized and personalized products they are usually not appropriate. In the next steps towards Industry 4.0 assistance systems will evolve into cyber-physical systems (CPS). These are characterized by steps 3-5 in the named 5-step model, i.e. by the linking real objects and processes with information processing objects and processes via open and interconnected information networks [25, 26]. One type of CPS could be a cyber-physical competence system (CPCS), in which humans and machines will work closely together and learn from each other and knowlede can be built, prepared, shared and provided for each other, context related and closely in real-time.

5. Approach

According to Piller, the basis for individualized products is a co-design process, which defines the individual needs and services of both customer and manufacturer [13]. When choosing individualized products, the customer can select between different configuration options. The number of variants can normally be predetermined. The time of sale of the product is between the product configuration by the customer and the manufacturing of the product [7, 27]. The co-design process is a participatory process with the customer actively involved in the development process of the manufacturer. The co-design activities take place on dedicated interfaces, where the exchange of information and the coordination of each transaction must be considered. The main focus should be on fulfilling customer needs [28]. The basis for mass personalization is also a co-design process, in which the order penetration point (OPP), however, shifts further in the direction of development. Mass Personalization is focusing on individual customers and their personal needs [29]. This leads to an increasing product complexity from individualized to personalized products and to a further enlargement of dedicated interfaces. In order to remain competitive in the future, industrial companies must therefore manage the co-design process with the custormers to be able to react to their demands flexibly, efficiently and as versatile as required [8]. New approaches, such as the Reverse Taylor, have to be applied and planning and execution standards have to be redefined, so that the economical manufacturing of personalized products under the conditions of mass production becomes possible. Individual activities within the co-design process must be further defined between the manufacturer and the customer. The personal responsibilities within the co-design process could thus shift all the way to the assembly worker. This will require new competences of the workers, which may also change over time. CPS can support the competence development. The interaction between human and machine in production needs to be further focused.

A possible solution is to focus the workers and their competence development during value creation, so that they do not have to interrupt the value adding process for qualification measures anymore. CPS may support the economic realization of this solution, see Table 1. Value added competence measurements are necessary for designing these systems. Defined learning objectives can be coordinated and checked. This requires the design of new competence loops in the value creation process. Individual, task-specific and real-time planned and actual competence profiles must be measured, evaluated and developed. For the design of an economic production system for individualized products workers have to be enabled to act right in unknown complex situations and thus develop their competences in order to reach fast problem solving and a continuous improvement of the entire value creation process. CPCS could support this development process. This achieves a quick problem solving and a continuous improvement of the entire value creation process. The competence development, measurement and the used systems influence each other. In order to determine the economy of CPCS in the mass personalization, the competence development, competence measurement and the required systems for training and measuring the competences must be considered, see Fig. 1. These three factors are directly related and mutually dependent. If the competences of the workers are not as high as required for a specific task, this needs to be compensated by the systems. This makes the systems usually more complex and more expensive. If chosen systems are on a lower price limit this needs to be compensated by workers with a higher qualification. Competences need to be measured and economically assessed to find the right balance. The chosen systems also need to be economically assessed. This information enables the manufacturer to make the right decision on how to qualify the workers in the future. Synergy effects might be lost by just considering the isolated factors. Without an appropiate competence measurement competence development cannot verify competence objectives and cannot guarantee an objective and comparable measurement. Unnecessary training contents are difficult to identify, threfore a comparison of the individual planned and actual competence profiles is missing. Only a subjective perception of the results (learning outcomes) by the participants is available.

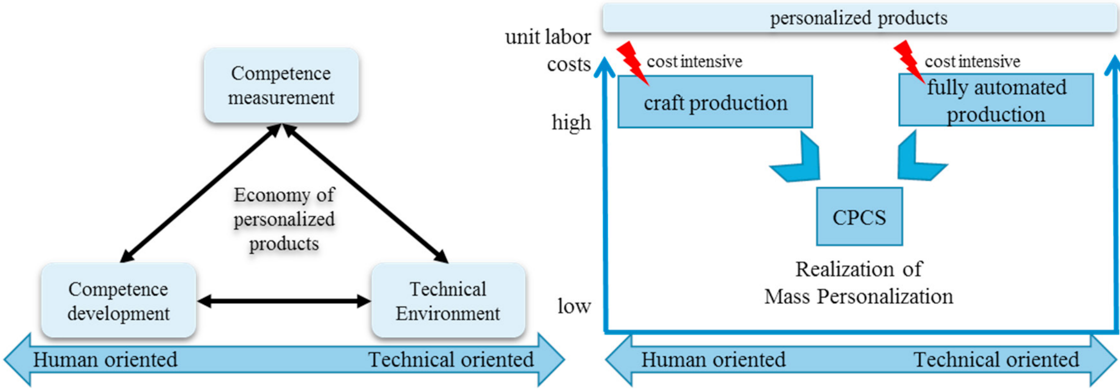

Fig. 1: Economical balance of competence measurement and development and technical environment for the realization of Mass Personalization.

Table 1. Expectations and Requirements for CPCS: economy of personalized products

Expectations	Requirements
Increasing external complexity (Mass Personalization)	Internal complexity adjusted to external complexity
OPP in direction of development (co-design process)	Crosslinking,integration and decentralization
Redefining of existing standards	Approaches like Reverse Taylor (service orientation)
Further personal responsibilities for the worker	New and changing competences can be handled
Competence measurement during value creation	Set of metrics and technical environment defined, developed and installed
Workers supported depending on their competence area	The individual competences of each worker are contiuously measured (Fluid competence areas)
New tasks and problems must be solved well and fast	Self-organzied real-time support
Competence development during value creation	Individual and task-specific support and learning
Economical production of personalized products	Well defined production system
Synergy effects can be created	Not just considering the isolated factors

6. Conclusion

For the economic manufacturing of personalized products in an assembly system competence development and competence measurement during the value creation process becomes increasingly important. CPS (CPCS) can support the competence development and competence measurement process. In summary, we assume that cyber- physical systems for competence development will make a significant contribution to the economic production of personalized products in the future. It has been shown which requirements can be derived for such systems and which possibilities may arise as a result and thus will be the basis for future work. Learning factories can support these processes and they provide the initial basis for applying new methods of competence development. This may support profitably manufacturing customized products in lot size one. Many learning factories do represent the complete value stream [11, 30]. However, they usually do not sufficiently consider the order processing and the technologies used to manufacture the given product. The didactic approaches have also to be reconsidered. Contents need to be created that allow a holistic view of the four life cycles. Learning factories can especially deliver initial findings concerning the analysis and conception of competence building processes during the value adding process. Workplace learning approaches, for example, may be investigated and adapted to the individual requirements in learning factories. The developed approaches may also be validated. Thus additional knowledge of the interrelation of modern e-learning contents and actual shop-floor issues may be created. Coaching approaches for competence development during the value adding process can be developed and tested in existing learning factories. Learning factories will be significant in advanced training, especially in the field of investigating new approaches of competence development. The necessary methods for learning in value adding industrial environments can be tested and evaluated in learning factories. They thus may be considered as laboratories for developing methods of competence development for specific value adding systems.

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