A Competence-Based Description of Employees in Reconfigurable Manufacturing Systems

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Abstract. The increasing demand for customer-specific, cost-effective products with shorter production times is shaping the industrial production environment. Therefore, both human workers and machines must react to these changes with greater flexibility and productivity. This paper shows a procedure to plan the employee ideally into the Reconfigurable Manufacturing Systems (RMS). The approach systematizes the competences of employees and enables an assessment of different expertise levels to finally realize a flexible integration of them into the constantly changing work environment. Therefore, the competencies of employees must be opposed with the needed skills so that the work processes can be executed adequate according to the product requirements. When this procedure is finally described digitally, companies will be able to realize a flexible workforce planning in the RMS, which is not possible so far.

Keywords: Human-centered reconfigurable manufacturing systems (RMS), competence-based classification, human-machine-interaction

1 Introduction

Today's production environment is characterized by individual customer requirements, shorter product life cycles, increasing cost and time pressure [1]. RMS enable to cope with this high variance of customized products with variable work processes in a flexible work system. RMS are flexible, rapidly adaptable assembly systems regarding production capacity, functionality and system structure [2,3]. Capacitive oversupply and a lack of capacity can thus be avoided [2]. Due to the variable manufacturing system, the workplaces and the work tasks change in a frequent manner for the employee [4]. In the context of this paper, a procedure for a competence-based integration of workers into a RMS is presented. The detailed digital description of human competences is part of the virtual representation ("Digital Twin") of workers, which can be used for an automated workforce scheduling.

Following the introduction, the paper is structured in four further sections. Section two gives an overview of the current state of research and the objectives we want to achieve. Afterwards, section three introduces the development of a model to describe the employees' competences to simplify personnel planning in RMS. Section four discusses possible application scenarios of the developed assessment including solutions to compensate competence gaps of worker. Finally, section five summarizes the paper and gives an outlook on further research contents.

2 Current State of Research and Research Goal

In this paragraph, five approaches for possible descriptions of machine skills and competences of human workers in a production environment are presented.

Reference [5] presents a taxonomy for the digital description of skills of automation devices in assembly. The aim is to optimize their comparison with the requirements of the work task. The assembly machinery offer their capabilities to the manufacturing system. Subsequently, other systems can search for required functions and use them to perform their working tasks. A functional analysis of both, the production process and the operating resources, leads to more flexibility in planning and application of resources. This allows an automated configuration and ad-hoc integration of equipment according to the plug & produce approach. The focus of this approach lies on the reconfiguration capability of assembly systems, for which reason the employee and his capabilities are not taken into account.

A more human-oriented way to digitally describe capabilities, but still not adaptable to the aim of the present project is considered by [6]. This approach uses an ontological representation to identify and configure team members for interdisciplinary teams in production networks based on competence profiles. They take into account competences such as problem solving, planning, technical, or language expertise as well as general and specific information of the individual team members i.e. their geographical location and phone number.

The method of [7] includes a comparison between employee qualifications and job requirements. The comparison focuses on changes caused by digitization and thus new challenges for the employee. The approach is prospective and provides companies with guidelines in the changing world of work. After applying the method, companies can derive qualification measures to prepare their employees for work in digital production.

A similar procedure was developed in the research project by [8]. The resulting procedure is used for strategic personnel development, especially in small and medium-sized enterprises (SMEs). In order to meet future challenges, SMEs can strategically align the competence profiles of their employees using the competence management tool developed. Professional, interpersonal, methodical and knowledge-based competences are the basic categories of the developed tool, into which the different tasks of the job description can be placed. The comparison of actual and target profiles on the basis of four different competence levels then shows the competence gaps that SMEs have to close. Since these approaches consider future changes in the digitized world of work, and do not take into account the requirements of an employee-matching to machine skills, it cannot be applied exactly to the conditions for employees in RMS.

A further human-centered approach is outlined by [9], in which individual capabilities of a human worker are described using a standardized taxonomy. The worker model contains two main aspects: individual human-related information and work-related capabilities. The latter contains the competences necessary for the concrete task execution, e.g. filling or joining by reforming. Three performance levels are distinguished for each competence: beginner, advanced and expert. Human-related information contains for example core capabilities or an individual fatigue level. The focus of this taxonomy is on the first conceptual presentation of a comparison between the abilities of humans and those of machines. However, the detailed level and a transferable description of human and machine capabilities are not yet sufficient for a precise matching.

In summary, it can be stated that there are already approaches that describe the employee and its competencies. However, among these there is no approach suitable for a digital description and thus an automatic planning and distribution of work tasks between men and machine. There is a lack of a standardized system for the optimal matching in the RMS. Such an approach is introduced in greater detail below.

3 Development of a Competence-Based Classification for Employees in Reconfigurable Manufacturing Systems

Argumentation of the positioning of the approach. As already described, RMS help to meet challenges such as short innovation cycles or products with many variants. By being able to react quickly and economically to sudden changes in market, RMS provide a remedy [10]. However, changes in the manufacturing system also affect other actors in the work system. The employee is a central component of it. If individual modules or functions i.e. in an assembly line change, it must be verified whether the employee is still able to fulfill his work task accordingly [4]. With this in mind, a procedure is required which simplifies the way to perform this verification.

As shown by [5], there are already attempts to describe machine skills to execute an automated resource planning. The aim of this article is to enable automated resource planning not only for production machines but also for employees in the work system. Therefore, a system has been developed which classifies, structures and assesses the competences of the worker in order to enable an easy and flexible personnel deployment planning.

The RMS is an operating resource and represents as such an element in the work system (see Figure 1). According to [11], further elements of the work system are the human worker, the work piece, the work task, the workflow, the input and output as well as environmental influences. These elements interact with each other. For example, the work task is fulfilled through the interaction of people and resources.

The replacement of individual modules of RMS results in a change of the operating resource and thus in a change of a system element in the work system. Since this interacts with the human worker, the company must verify what this change means for him/her, and whether the human worker is still able to fulfill his or her task. The analysis of the working system and the interaction of its elements help not only to achieve an optimization of the entire system, but also to meet the human criteria of good work and valid legislation. For example, the Civil Law Code enshrines the employer's duty of care [12]. Ergonomic evaluation methods of work want to provide a damage-free work for humans and evaluate physical and anthropometric aspects and has to be realized when changes become effective at the work place. With RMS in the work system, however, the demands on people with regard to the required competences can also change, which are neglected in ergonomic evaluation methods. Thus, a method is needed to do so.

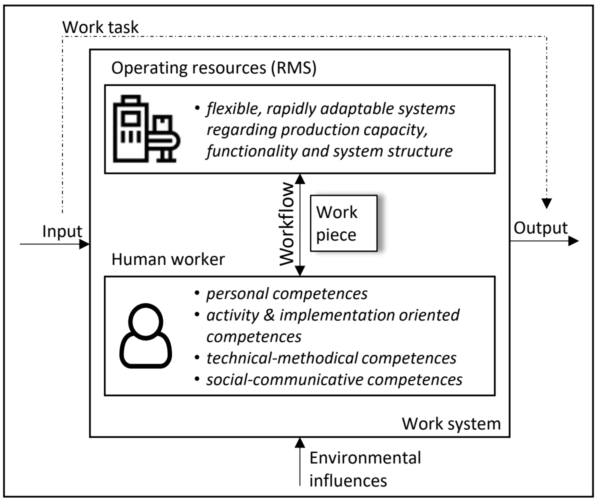

Figure 1: Human and RMS in the work system

Competence modelling and characterization approach. Humans in the working system can be described by the four types of competences [13,14]. The employee needs *personal competences*, *activity- and implementation-oriented competences*, *technical-methodical competences* as well as *social-communicative competences* in order to be able to fulfill the work task with the aid of resources (see Figure 1). Personal competences are skills to be wise and critical of oneself, to develop productive attitudes, values and ideals. Activity- and implementation-oriented competences are abilities to implement all knowledge, the results of social communication as well as personal values and ideals in a strong and active way as well as to integrate all other competences. Technical-methodical competences are abilities combined with technical and methodical knowledge, to creatively master even almost unsolvable problems. People with social-communicative competences are able to work together and interact with others, they can cooperate creatively and communicate. [14]

These four types of competences represent the basic characterization of the systematics for the competence-based employee description in the RMS (see Figure 2). The types of competences can be further differentiated. From the competence atlas according to [14], subcategories can be taken which are exemplarily shown in Figure 2 (e.g. loyalty, execution readiness, communication skills, etc.).

If a company wants to match the changed requirements with the employee's competences, specific subcategories that are required at the given workplace can be chosen from the competence atlas. The technical-methodological competences of the employee are particularly important in this comparison, as they enable the employee to implement a work task operationally. Within the scope of this contribution, these will therefore be examined in focus and detail. In the context of the application field, the assembly, activities can be seen under the technical and methodical competences recording to German standards (VDI 2860, DIN 8593 and DIN 8580) [15]. These are joining, handling, checking, adjusting, and special operations and have also been included with their individual activity modules in the depicted system. Based on the system described, the changed requirements can now be compared with the competences of the employee.

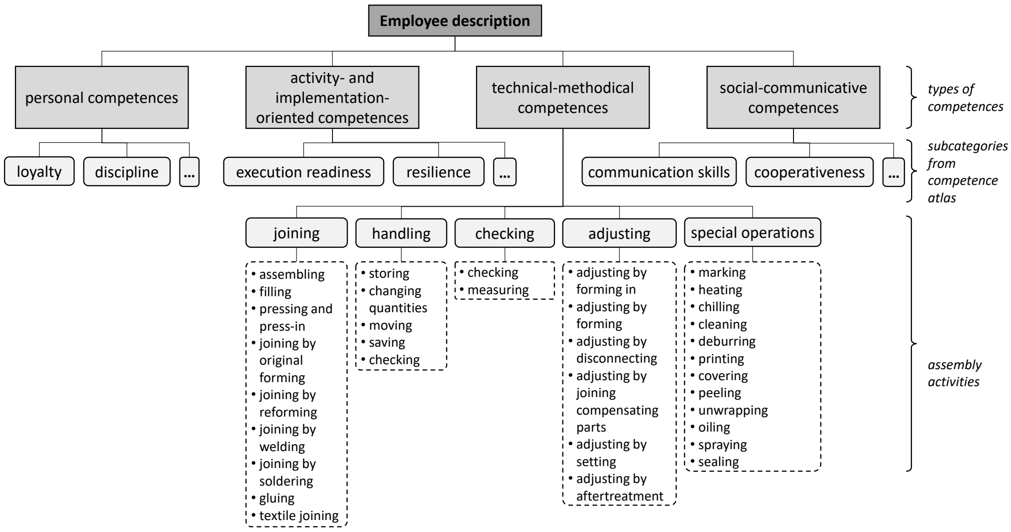

Figure 2: Systematics for a competence-based employee description

Comparison between available and required competences. In order to enable the user to assess the level of expertise additionally, the system is to be supplemented by the expertise model according to [16]. In this model the qualitative development of competences is described in three stages:

*Stage A (competences are poorly developed)***.** At level A, the employees have basic knowledge with little application experience and are able to carry out specified tasks in a familiar learning and working situation with preparation.

Stage B (*distinctive competences)***.** Multiple experience in applying the knowledge in concrete professional situations, projects or processes is existing. The employees react to new, unforeseen situations with appropriate professionalism. They have differentiated knowledge and understand tasks and problems in their familiar working environment. They choose from a repertoire of possible actions to work on and solve tasks independently.

*Stage C (strong competences)***.** Employees have broad and in-depth specialist knowledge as well as diverse experience from various contexts. They are therefore able to anticipate problems completely self-organized, intuitively and find new solutions. They master the management of complex and new tasks and make valuable contributions to the further development of their organization, their field of work or discipline.

An evaluation of the requirements of the work system and the competences of the employee is depicted in Figure 3. The grey dots present the given requirements according to the level of expertise in order to make them comparable by supplementing the competences of the employee, represented by the squares. The comparison reveals gaps that need to be closed to continue the deployment of the employee at the workplace.

Up to now, there has been no approach that enables flexible personnel deployment planning in RMS. The combination of the four types of competences, the assembly activities and the stages of expertise presented in this paper now enables an automated scheduling.

4 Possible Application Scenarios

The presented assessment (Figure 3) shows a competence gap in assembling, where the employee experiences are poor and the requirements are high. In order to ensure that the work tasks are fulfilled in an appropriate quality, the company has to close the given gap. Below, three application scenarios of the given assessment with solution approaches to close the gap are presented:

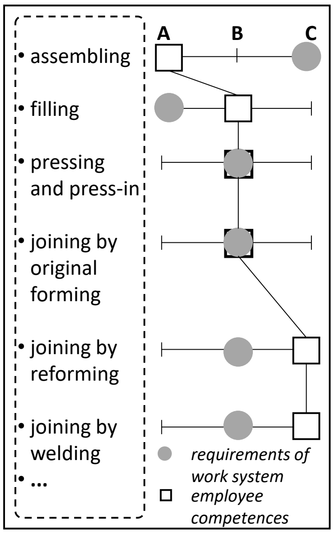

Figure 3: Comparison of the work system requirements and the employee's competences

Usage of an individual worker information system. In reconfigurable, flexible manufacturing systems, the worker has to adapt constantly to the changed work tasks, which significantly increases the complexity for the employees. According to [17], a generally valid presentation of worker information is not sufficient for a successful execution of a task. Consequently, the displayed information should be adapted to the individual experience of the worker and the production context. Therefore, an individual information system guides the employees through the working process at the best. By the usage of such a system, lower competences of the worker could easily be balanced out.

Qualification measures for employees. If the worker's competences do not match the skills required to perform the task, specific training measures can be used to provide selective employee qualification. On the job or off the job trainings would be suitable to educate the employee further. Additionally on the job trainings could bridge idle times, which is a further benefit for the company.

Development of a rotation plan. Another possibility to close the gap created would be a rotation plan. By establishing a competence matrix of all employees of a company a simple algorithm could reassign the employees to the work stations changed by the RMS. However, this would mean a high initial effort and is only practicable if the working environment and work organization allow a rotation. A balanced workload of the employees should also be taken into account, as well as the willingness of the employees to change stations frequently or flexibly.

To decide which of the three proposed solutions fits best, the needs of the employees as well as those of the company should be considered. If, for example, the employee is not willing to perform the work steps with an assistance system and is not familiar with the operation of such a system, the first scenario would not be recommendable. On the other hand, an assistance system could be too expensive for the company or the setup of such a system could be too time-consuming for the corresponding use case. The situation is similar with scenario two and three. In order to achieve a good and productive work system, it is always necessary to balance the economic aspects of a company with the availability, motivation and willingness of its employees.

5 Conclusion and Outlook

The presented assessment is an approach to a description of worker abilities. The combination of the four types of competences with the defined assembly activities and the three stages of expertise is a completely new approach and should lead in the long term to automated and flexible personnel deployment planning. In the coming years this assessment will be further developed at the Institute for Machine Tools and Industrial Management at the Technical University of Munich.

For the implementation of such an assessment, competences of the worker cannot be included on a one-off basis in the assessment, since the dynamic acquisition of competences must also be taken into account. In order to keep the maintenance effort of the assessment as low as possible, an automatic recording of the competence development would be conceivable. For example, competence development would be recorded by an individual error rate or by regular performance appraisals of the supervisor using a standardized, digital evaluation sheet.

In addition, it would be possible to integrate the presented assessment into the production cost planning by taking into account not only the conversion times of the plants, set-up costs and downtimes, but also the availability and competence level-dependent costs of the workers. An extension of the automated and optimized assembly planning of [18] would be possible.

Even if the creation of such an automated employee planning tool means a high initial effort for a company, it should not be neglected that without such a tool the flexibility trends in a digitized working environment will be difficult to meet. The developments in production lead to a constant flexibilization of work processes, therefore it is of great importance to also make the work organization more flexible in the future.

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