Towards Capability-Based Worker Modelling in a Smart Factory

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Abstract – **New technologies and the emphasis on digitalization in industrial companies lead to major changes in production environments. A significant reorganization of production processes is one of the results. This takes place in different production areas and transforms companies into so-called Smart Factories. One of the most important questions in this context is how this transformation affects the involved employees in production and how they have to adapt to their new working environment. Therefore, it is necessary to examine the consequences for human workers and to raise awareness within the involved companies so that they can manage these changes successfully.**

To measure and evaluate the consequences, a way to describe human work and capabilities in different scenarios has to be developed. Such capability-based descriptions have yet only been used for elements of production systems, for example assembly systems. In this paper, we propose a new model to characterize the capabilities of a human worker based on these approaches.

Keywords – **Human factors, human resource management, man-machine systems, production planning, scheduling**

I. INTRODUCTION AND NEED FOR ACTION

Megatrends like the ongoing globalization and demographic change in western countries pose challenges for manufacturing companies and favor the rising integration of digital elements in production systems so that factories steadily grow smarter [1]. Smart factories are characterized by connecting stand-alone production units to global production networks with the objective to assist human workers and machines executing their tasks [2]. This is possible with the extensive use of intelligent objects and sensors, which allow communication between the network systems and their elements [2].

As a result, work routines are changing for the production workers, since production systems become more and more automated and autonomous in fulfilling their tasks. Employees have to perform less routine tasks and focus more on creative tasks and problem solving [1]. This change requires to adapt the worker's qualification so that they can act more as decision makers instead of being the operating personnel, only [3].

In order to decide which qualification measures or assistance systems have to be provided to empower the worker for their new role, it is necessary to describe and evaluate his current and future capabilities and competences in detail. This allows production planning to consider the individual features of the single worker, adapt the planning to their personal needs and preferences and successfully integrate a human worker in a smart factory.

Therefore, an approach that allows a standardized description of the highly individual set of capabilities and competences of a human worker in a smart factory must be developed. The concept of how this approach should be set up and possible use cases which can be addressed with the help of this model are presented in this paper.

The paper is structured as follows: Section II gives a short overview of the current state of research and the research goal we want to accomplish. In section III, we propose a capability-based worker model that can be adapted to different use cases, which we present in section IV. Finally, section V summarizes the paper and outlines future research work and the evaluation of our model.

II. CURRENT STATE OF RESEARCH AND RESEARCH GOAL

In the field of skill and capability-based description of production units, significant research has been done in the past few years. Especially in the context of assembly systems planning this is an important prerequisite to enable automated scheduling of production orders.

Reference [4] proposes a taxonomy for automated assembly units with which they enable plug & produce applications in automated assembly systems [4]. Their taxonomy is oriented on German standards and guidelines as DIN 8593, which describes classes of manufacturing and assembly processes.

A capability-based planning and scheduling for adaptable manufacturing systems is presented in [5]. They propose a machine-independent way to describe the scheduling problem. Therefore, the same vocabulary for describing the capabilities of the machines and the production plans is necessary [6].

These and similar approaches only take the description of the production units into account. They do not offer a taxonomy for describing a human worker within the production environment.

Approaches going in this direction mostly come from the context of personnel scheduling. As an example, [7] developed a concept to describe the learning and forgetting of processes in order to evaluate the impact of the competence of the worker on the production targets. However, [8] presented an approach for the efficient assignment of auxiliary workers based on their competence profiles.

These approaches address the human workforce but do not offer the combination and an overall taxonomy for describing both machines and human workers. Therefore, our goal is to develop a model, which considers the capabilities of the workers and allows an integration into production planning. The concept of this model and possible use cases are described in the following sections.

III. CONCEPT FOR A CAPABILITY-BASED WORKER MODEL

A key feature towards smart factories is the generation and processing of data to create information and knowledge about the manufacturing steps involved. This increases transparency and flexibility of the manufacturing process. For this, useful data models are required for all involved processes and resources. The primary goal of the modelling approach presented here is a comprehensive and consistent worker description that includes all required information needed to integrate a human worker entirely into a smart manufacturing system. To achieve this goal, the worker model has to contain two main aspects: individual human-related information and work-related capabilities. The biggest challenge is to utilize semantics that are also suitable to describe other factory resources such as machines and robots.

Fig. 1 presents an overview of the proposed model. In this section, the two different components of the model will be explained in detail.

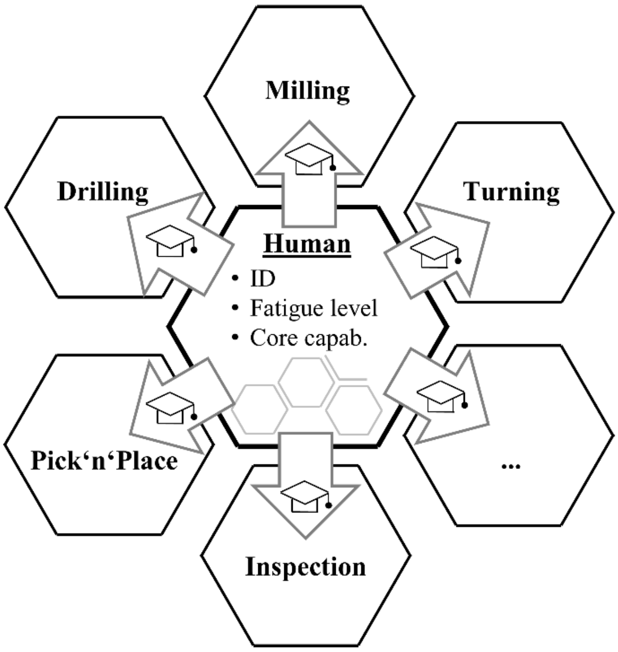

Fig. 1. The model includes individual human-related information as well as acquired work-related competences.

A. Human-related information

The human-related information is the origin of the model and is used to represent the human aspects and its properties. A human, in contrast to machines, possesses certain capabilities that are not primarily related to his role as a worker in a factory. We refer to those as *core capabilities*, such as grabbing & releasing, and seeing. Work-related capabilities such as *inspection* that are acquired by training, education, and other professional qualification measures are not considered as *core capabilities*. They are described by *competences* that are explained later. The characteristic for each *core capability* varies for every human. I.e., some humans have a very good eyesight whereas others require glasses. We utilize parameters for those individual refinements. A scale and classification is system-dependent and should be defined for every use case individually.

Additionally to *core capabilities*, the human aspect includes a *fatigue level F* that represents the exhaustion of a worker. It is based on the effort to perform the assigned workload and is generated as the weighted sum of the single *competence fatigue levels* f_c, as shown in (1):

$$F = \sum_c w_c \cdot f_c \quad (1)$$

The weight factors w_c can vary for every worker to meet his individual conditions and preferences. Therefore, the *fatigue level F* offers means to quantify the accomplished workload for each worker individually.

B. Competences

Competences represent capabilities that are required to perform work tasks. In contrast to *core capabilities*, they are not inherent and have to be learned. Through professional qualification measures, they become a part of the human worker’s abilities and therefore a part of its model description. *Core capabilities* are the foundation for every worker to perform its work tasks according to its *competences*. I.e., in order to perform an (visual) *inspection* task, the worker requires the capability to see. Therefore, *core capabilities* and their corresponding parameters formulate a base from which specific *competences* are derived from. By this coupling, changes within the core capabilities have an effect on the competences.

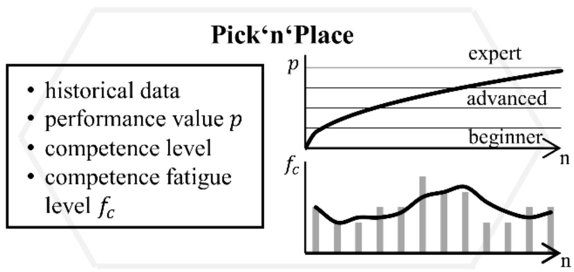

Fig. 2. Overview of the competence part

One part of the competence description is the storage of historical manufacturing data, such as the required time to perform a task. It is important to mention that these data provide an objective meaning to enforce the rule of utilizing the same semantics to model human workers and machines. Further processing of these historical data generates a performance level p that is used to determine the worker's *competence level*. Here we use the *competence levels* defined by [9] that range from 0 (no competence) to 4 (expert in the task, worker is able to teach others). The levels in between are: 1= worker has knowledge about the task. 2 = worker is able to perform the task in the sufficient quality but not in the correct time. 3 = worker is able to perform the task in the sufficient quality and time [9]. Due to its connection to manufacturing data, the *competence level* changes over time automatically and offers an opportunity to classify the worker's experience objectively. The calculation of p as well as its mapping to a *competence level* depends on the use case and will not be considered in this paper.

The effort to perform an action relies on parameters, such as the weight of workpieces for a pick-and-place task. Hence, the workload varies and has a dynamic impact on the worker's (physical) condition. The *competence fatigue level* f_c represents that impact. The manufacturing system stores a pre-defined *fatigue value* for each performed task regarding the task parameters. Along with that, deferred data processing generates f_c. Hereby, it is possible to track a worker's workload systematically. The lower diagraph in Fig. 2 illustrates this approach. The proposed method is deployed for all the *competences* a human utilizes to perform his work independently. Therefore, it is possible to analyze a worker's workload more detailed.

IV. USE CASES FOR THE CAPABILITY-BASED WORKER MODEL

The transformation from conventional to smart factories is changing production environments. Changes like this occur in different manifestations depending on the individual company's situation. Therefore, the model for a capability-based worker description must be able to cope with these situations and has to be applicable to the company-individual use cases.

To show this adaptability we are introducing three important use cases in manufacturing companies to underline the range of possible applications for the model. We specify those use cases in the following sections.

A. Use case 1: Flexible Worker Deployment Scheduling

Worker deployment scheduling defines the process of assigning the right employee at the right time at the correct workplace in order to fulfill the needed task in the required quality. This ensures that the company is able to produce their products on time [10]. The process is only functioning efficiently if a company has enough flexibility; meaning employees with fitting competences, to process the ordered product portfolio. Traditionally the executive managers on the shopfloor, which in most cases is the foreman or supervisor of the considered production area, is responsible for the daily scheduling of his team. He is the one who decides if employees can go on vacation or take the shift off. To do so, they use different tools depending on the size of the production area and group, as well as whatever software is available in the company. Especially in small and medium sized enterprises, the foreman or supervisor often schedules based on his inherent experience and knowledge about the employees, their capabilities as well as the production system in general. In this context, the use of qualification matrices reduces the complexity of this task. Depending on the organization of the production and on the shift models of the company, the employees' influence on the flexibility of their assignments varies.

Especially nowadays, where production environments and the inherent processes are more dynamic and companies are in a transformation to become smart factories, the need for flexible scheduling is constantly rising. To cover this demand, new technologies like smart- and mobile devices, as well as connected production systems are integrated. Therefore, modes of work, e.g. the work-time models or the place of work, need to become more flexible too [11].

The overall goal of worker deployment scheduling in a smart factory is to ensure a well-balanced employee portfolio within the production systems. This means that on the one hand a workforce with the right skillset or capabilities must be available for deployment at all times. On the other hand, this group should maintain a level of uniformity to prevent extensive differences between the workers concerning their competency levels, their classification and their payment.

The worker deployment scheduling serves as input for the production planning as it states the available human resources. This means that in order to finish the planned production program, the workers must have the right capabilities and be able to perform them with the needed minimum competence level, as introduced in section III. If the required level of competence is not available, e.g. the present worker has level 3 instead of 4, it is still possible to facilitate the production program but it will take longer than planned. Therefore, the deployment scheduling provides information, which can be considered for the production planning to gain better planning quality. To follow this approach it is necessary to know every worker in detail and to document their capabilities and competence levels in a way the production planning systems can process them. The model described in chapter IV therefore favors three developments:

1. Demands for qualification can be identified to ensure a homogenous worker pool.
2. The production planning considers the worker in-

dividual fatigue level, to ensure that all workers are able to perform during their shifts. If for example the last vacation of a certain worker is already long ago, production planning can inform the worker if it would be possible for him to take some free time during the following planning cycle.

3. Workers are granted more flexibility and freedom in planning their own assignments. As the scheduling becomes more flexible, shorter planning cycles are possible and therefore workers can change their work times more frequently.

B. Use case 2: Adaptable Production Planning

Two of the major challenges for future manufacturing systems is to adapt quickly to market changes and the ability to process individual customer requirements [12]. Whereas the objective of the worker employment scheduling is to guarantee that a factory with all its resources is always able to perform optimally, a production planning system is aiming at assigning specific tasks to the available resources in order to accomplish manufacturing of specific products. There has been lots of research towards adaptable manufacturing systems within the last decade for different domains. The primary focus lies on the development of architectures and methods to enable reconfigurability of machines [13] [14] [15] and controlling software [16] [17] [18] [19]. Only a minor part of research in that area is considering human workers as an integrated part of the manufacturing system [20] [21].

Some common approaches use capability-based methods to describe products separated from factory resources [22] [23]. This decoupling enables the ability to plan the production of a specific product in different factories and vice versa using capability-based matching algorithms [6]. Due to this flexible setup, it is possible to integrate human workers as a special type of a factory resource. One prerequisite assumption of capability-based production planning is the use of mutual vocabulary to define the product and factory resources [5]. Hence, it is necessary to use the same semantics to describe factory resources like machines and robots as well as shop-floor workers. Therefore, we use the capability-based competences of the worker description introduced in section III.

One challenge when integrating a human worker into a manufacturing planning system is the consideration of its dynamic character. In contrast to machines, the performance, quality, and availability for production may vary over time. For example, the required time for a worker to perform a specific task depends on its experience [24]. The planning system can regard this by utilizing the previously presented competence levels. Long-term analyses of their underlying historical data, such as manufacturing time or error rate, can provide means to optimize the workflow, reduce idle times, and increase efficiency.

In addition to the competence level, the planning system can utilize the presented fatigue level (as discussed in Chapter III) to balance a worker's specific workload. Workers with a low fatigue level are assigned to more exhausting or more frequent tasks. Whereas, a high fatigue level should lead to the worker being assigned to tasks which help in his recovery process. Hereby, the planning system is able to distribute the required workforce equally over all available factory resources over time.

C. Use case 3: Qualification in the Smart Factory

Based on production time and the number of defective products, demands for further qualifications of workers are derived. During the worker deployment scheduling and the production planning bottlenecks concerning the availability of production stations and competences are identified. If, for example, a worker, who does not have the needed level of competence, causes multiple delays in the production process, the management should initiate qualification measures to solve this issue and prevent further delays.

V. Discussion and Conclusion

In this paper, we proposed a concept for a capability-based worker model, which allows the combined consideration of machine and human worker capabilities in production planning. To do so, a consistent and standardized taxonomy to describe the worker must be developed. Our concept is a first step in this direction and is based on capability-based approaches in automated assembly planning. The differentiation of core capabilities and competences allows a more thorough description of human-inherent information. The advantage of this concept is the possibility to track historical production data and use them to determine current competence levels in order to optimize production planning. With this tracking, it is possible to assess the workers individual fatigue level and react to it in time to optimize the overall workload distribution.

The next step in our work is to detail the model and the taxonomy for the description of capabilities as well as competences. After that, evaluating the approach will be focused. This is especially interesting as it offers deeper insights if the descriptions are detailed sufficiently to allow the integration in production planning systems.

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