Workforce Rostering for Tomorrow's Industry: The Workforce Scheduling Dilemma in Decentrally Controlled Production Systems

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Extended Abstract

Summary. The workforce rostering for tomorrow's industry needs to be reconsidered. The development of new types of production control mechanisms, like decentralized production control, impacts the effectivity and efficiency of workforce rostering methods, too. Simultaneously, social trends, like the growing demand of flexible working time models and labor shortages, take their influence on the rostering process. We are facing these requirements by developing a new rostering method which is appropriate for decentrally controlled production systems, the consideration of individual preferred working times independent of rigid shift systems and the simultaneous targeting of production-related performance variables. Therefore, we apply a simulation-based optimization approach which is based on a genetic algorithm.

Keywords. Industry 5.0, working time models, sim4pep

1. Motivation: The Worker as an Important Part of Production

The headline „Tesla's problem: overestimating automation, underestimating humans" (Büchel and Floreano 2023) with corresponding article demonstrates an typical error in reasoning of the Industry-4.0-paradgim under criticism (European Commission 2021a; 2021b): In the Industry 4.0 approach, there was a very strong focus on technology. However, the human worker will continue to play an important role in future production systems. So, the human worker has to be integrated into the overall industrial concept and is still needed as a production resource.

At the same time, however, workers are a production resource that is not available in unlimited quantities. The shortage of skilled workers, which is occurring not only in Germany (DIHK 2021) but also throughout Europe, clearly shows this (Cedefop 2018). The worker shortage is no longer something that will happen in the future but it has already begun and continues to grow (Cedefop 2018). It has consequences not only for individual companies, but also for the economy as a whole, such as falling tax revenues and, in the long term, a decline in innovation and competitiveness (DIHK 2021).

In addition, there is another effect: A change in values of work ethic in society. Employees' demands on flexible working time models are increasing as the work-life balance becomes more and more important (see, e.g., Veal 2023; Messenger 2018). Recent examples illustrate this trend, such as the recent research project for a 4-day week in the UK (see, e.g., Ellerbeck 2023). This trend in society will also be hard to ignore for production areas.

Last but not least, there is a work organizational reason to reconsider workforce rostering in tomorrow's industry due to new types of production control mechanisms. A key driver, e.g., is the decentralized production control (DPC) which leads to the dilemma of workforce scheduling and rostering in decentrally controlled production systems (Schwemmer and Schmidt 2023).

We describe this dilemma in more detail in section 2.1, followed by a short summary on the state of the art in section 2.2. To solve the described dilemma of section 2.1, we summarize our proposed solution strategy in section 3 and give some general gained results in section 4. We close with a short conclusion in section 5.

2. The Dilemma of Workforce Scheduling and Rostering

2.1. Description of the Dilemma

Automation is one way to face the increasing labor shortage. However, it changes the nature of workers' tasks to become more supervisory and coordinating (Ganschar et al. 2013). It transforms not only the qualification requirements but also the required working times for the workers in the production system. Despite increasing automation, in most application areas, the human will be still a key factor in tomorrow's production systems (Ganschar et al. 2013).

When proposing changes of workforce management, one has to keep the overall production related trends in mind: Logistical control concepts for production processes continue to develop. The idea of autonomization leads to increasing dynamic decisions on job sequence and machine assignment. Decentralized communication between machines and production tasks allows dispatching decisions to be made at short notice when they are due. This concept can be summarized as one of the main paradigms of industry 4.0: DPC.

A main consequence of the concept of DPC is that there is no need for detailed baseline schedules in advance anymore (Schwemmer and Schmidt 2023; Schwemmer et al. 2022). This, in turn, has a strong impact on the planning of workforce requirement and deployment times for production employees. Without detailed production schedules, there is no information about when which employee (or, more abstractly considered, which qualification) is needed. Thus, the employee requirement times cannot be determined deterministically in advance. However, this information is a fundamental basis for designing the workforce roster in established methods. Since people are not machines and are not available 24 hours a day in the production system, the duty rosters must be announced several days or weeks in advance to ensure adequate availability – not only from an organizational but also from a legal point of view. (Schwemmer and Schmidt 2023; Schwemmer et al. 2022)

Figure 1 show the referred contradiction between planning of workforce roster and control of production system to which we refer as the workforce rostering and scheduling dilemma for decentrally controlled production systems (Schwemmer and Schmidt 2023; Schwemmer et al. 2022). This dilemma requires new methods of the organization of workforce resource planning.

Figure 1. Dilemma of workforce rostering and scheduling in industry 4.0 (based on Schwemmer and Schmidt 2023)

2.2. State of the Art

As we show in a literature review (Schwemmer et al. 2022) and to the best of our knowledge, there are only publications dealing with related or reduced problems but there is no method handling the dilemma described by the combined consideration of the following aspects:

- Merging both "scheduling decisions of machines and jobs on a detailed shopfloor-level" as well as "the roster generation for employees" on the same level of importance,
- the consideration of human and machine as separate but equally important and limited resources,
- the planning of deployment times completely independent of shift grids and individual for the employees,
- the inclusion of working time preferences from production employees,
- the background of a decentrally controlled production systems with changed processing times and qualification requirements of manual production tasks as well as
- the stochastic influence of disturbances.

For example, the results of the research project "KapaflexCy" (Bauer 2015) requests available workers via a "shift doodle" app for additional shifts or shift extensions at short notice but only after the demand planning at machine level has been completed and the rostering system is also based on a fixed rigid shift pattern.

3. A Simulation-based Optimization of Workforce Rosters

In order to develop solution approaches to the described dilemma in section 2.1, we see the changing work of working models as opportunity to match volatile requirements with time-flexible preferred working times. To deal with the mentioned requirements, we are currently working on a simulation-based optimization model which determines the workforce attendance times by forecasting demand and operating times in the production system (see Figure 2). Our developed method also involves the desired working hours for all individual workers. The goal is to efficiently deploy the bottleneck resource of skilled workers in complex, decentrally organized systems with simultaneous application of more flexible working time models for the employees.

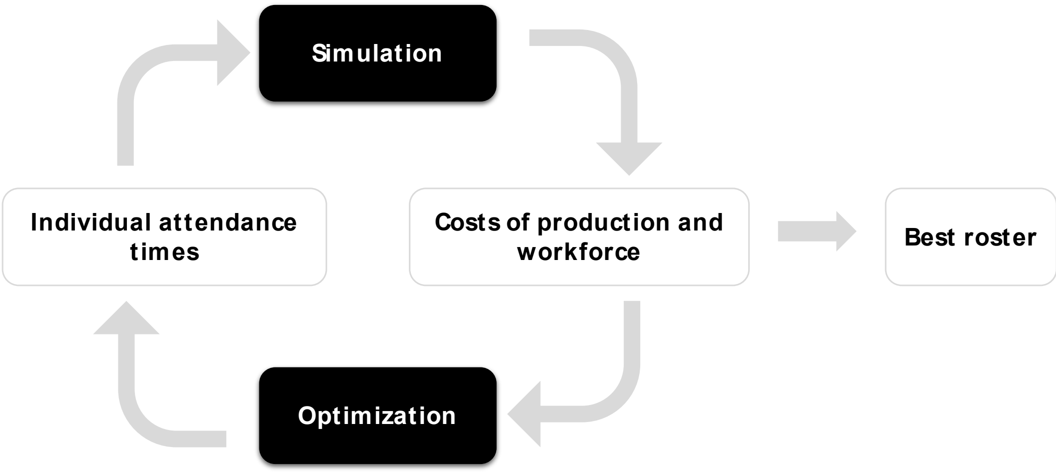

Figure 2. Simulation-based optimization for forecasting worker attendance times

The simulation part models the production system and its behavior of job processing. It is a discrete-event simulation model that takes different stochastic production scenarios into account. These stochastic scenarios occur, e.g., due to human-induced variations in manual processing times or due to production disturbances like breakdowns. Due to these fluctuations, there may be differences in the dispatching of production tasks between the stochastic scenarios. This effect is reinforced by decentralized production control, whose dispatching autonomy can lead to different allocation and sequence decision depending on the stochastic scenario. The autonomy is especially given as we use multi-mode job shop scheduling problems as basis instances where different processing options are available for the production tasks.

The optimization part consists of a genetic algorithm (GA) that optimizes deployment intervals for the workers based on the demand determined from the simulation and the desired working hours of the employees to generate a complete roster. We consider working time regulations by the integration of a repair algorithm for deployment intervals within the GA. This ensures that all generated solutions always comply strictly with working time legislation.

Only the rostered attendance times of the individual workers are considered as the solution. The simulated scheduling decisions at shop-floor level are still to be made by the decentralized control system when they are due in the production system.

The evaluation of found solutions (workforce rosters) is based on a cost value. It includes not only the working time costs but also the degree of deviation from desired working times from the employees' point of view. Additionally, it contains costs for job delay that are incurred when workers are not available at times when they are required.

4. Main Results

We evaluated the method by a comparison with classical two-shift and three-shift systems in a simulation study. Due to the lack of benchmarks for this problem class, we use well-known job shop instances (e.g., Behnke and Geiger 2012; Brandimarte 1993) which we have extended to include the employee component. As main result, we can show significant improvements compared to rigid shift systems in all three categories of the objective function:

- the total amount of working time costs is reduced,
- the share of desired to undesired working hours for the individual workers is increased and
- the total amount of job delay costs is reduced.

Generally, the developed method achieves an improved synchronization between capacity supply and demand of the human production resource. We gain a higher degree in utilization of the employees without affecting production targets (i.e., due dates of jobs).

It is important to understand, that only the rostered attendance times of the individual workers are considered as the solution. The simulated scheduling decisions at shop-floor level are still to be made by DPC when they are due in the production system. Accordingly, it is not guaranteed that a solution generated with the approach corresponds to the general or global optimum. The quality of the found solution depends on the scenario that occurs in reality and the decisions made by the DPC in the real production system.

Finally, it should be noted that a large number of objective function evaluations and, thus, a large number of simulations will be necessary for the determination via our approach. Consequently, the methodology has a significantly increased computational effort in comparison to classical two-shift and three-shift systems.

5. Conclusions

The development of new types of production control mechanisms like DPC as well as trends as turbulent markets and supply shortages, labor shortages, or flexible working time models impacts not only the production scheduling but also the workforce rostering. As a consequence, workforce rostering in tomorrow's industry needs to be reconsidered.

In our research project sim4pep, we are dealing with the planning and control gap with regard to workforce attendance times which is caused by the dilemma in decentrally controlled production system described in section 2.1. Simultaneously, we are taking into account the changes in the world of working time models by treating the replacement of rigid shift times in the context of the emerging time-flexible working models for employees as an opportunity for the described dilemma. A simulation-based forecasting process in cooperation with a genetic optimization rosters workforce attendance times. The rosters are also based on the desired working hours of the workforce while also meeting the needs of the production system.

With our research approach, we hope to contribute to the feasibility of modern production concepts like Industry 4.0 (and 5.0) as well as to the improvement of working conditions for production workers in terms of flexible and individually desired working hours.

There are many promising future research topics on this approach like an extension for the synchronization of existing rosters in case of last-minute changes (e.g., sick leave), the evaluation of the method on a real system, or integration of further psychological and work science aspects.

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