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Staff scheduling in job rotation environments considering ergonomic aspects and preservation of qualifications

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ABSTRACT

Demographic change is a well-known influencing factor challenging social security systems in industrialized countries. In a manufacturing context, companies need to cope with an increasingly heterogeneous workforce in terms of qualification and impairments, as well as an increasing average age. The development of more standardized processes and the trend to move towards shorter lead times, paired with demographic changes in the workforce, reveal a strong importance of staff planning.

A short-term staff planning system which generates job rotation schedules taking into consideration workers' qualifications, the workplace's ergonomic exposure, and the most recent allocations of each worker is sought to ensure the right worker is allocated to the right work place at the right time. The arising complexity of such scheduling problems is met in this paper by using a linear programming based heuristic, which solves the scheduling problem gradually for each rotation round and generates a holistic job rotation schedule for an entire workday.

The presented approach to short-term staff scheduling is implemented in a VBA-based software prototype and was tested in the final assembly line of a German automotive manufacturer.

1. Introduction

Along with Italy and Japan, Germany is one of the countries with the oldest population [1] and according to the most likely future scenario, the German population will not only get older, but also decrease significantly over the next decades [2]. Therefore, German companies need to prepare for this demographic change by considering the challenges that an increasingly elderly workforce presents to their workforce planning.

The commonly believed hypothesis that the general performance of a workforce decreases with increasing age, is disproved in recent studies which find no significant correlation between age and performance [3]. However, research in this field assumes that workforce characteristics are becoming more heterogeneous within an ageing workforce, e. g. in terms of impairments [4]. Additionally, the occurrence of illness-related absence from work is found to increase with an increasing age of the workforce. Musculoskeletal disorders (MSD) are identified as the most significant cause of illness, followed by other illnesses such as cardiovascular diseases and psychological illnesses [5].

One of the essential business sectors within the German economy is the automotive industry [6]. With respect to age distribution, it is predicted that the average age among the workforce in this industry will increase from 40 (2011) to 44 within the next five years. By 2021, more than half of the workforce will be older than 45, whereas this group represented only 38% in 2011 [7]. Manufacturing processes within the automotive industry are characterized by repetitive and physically demanding work tasks at high frequencies, especially in final assembly lines. When executing final assembly tasks, the hand-finger system as well as the whole human body are primarily exposed. Such a working environment may lead to more frequent occurrences of MSD in the long run [8].

Increasing product variety as well as shorter product lifecycles of produced car series call for new requirements for the manufacturing process. The workforce does not only have to adapt to changes faster than before, but workers also have to be able to execute a wider range of working activities which requires diversified qualifications [9]. These aspects amplify the challenges demographic change poses on workforce planning and qualification procedures [7].

To lower or prevent occupational injuries and absenteeism from work, three general approaches have been identified by [10]. Firstly

Abbreviations: MSD, musculoskeletal disorders; BEQR, Balanced Ergonomic Qualification preserving job Rotation; EAWS, European Assembly Worksheet; IEA, International Ergonomics Association; WBE, whole body exposure.

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(1), working activities can be redesigned in terms of tools or workplace modifications and the manufacturing process at the early stages of product development. In addition, (2) the use of personal protective equipment, such as specific clothing, can help with injury prevention. Moreover, (3) utilizing administrative means, e. g. job rotation, may lower or prevent occupational injuries and absenteeism from work. According to Lussier and Hendon, job rotation can be defined as "[. . .] performing different jobs in a certain sequence, each for a set period of time" [11].

When analyzing the three outlined approaches, it was found that the application of engineering solutions (1) are often too expensive to be fulfilled, and when considering MSD, not many effective solutions are available for protective equipment (2). Utilizing administrative means (3) offers the most cost-efficient solution for the challenges in this field [12].

Through the use of administrative means, working activities can be organized in a way that reduces the monotony of the assembly process. Particularly in the automotive industry, job rotation is a broadly used concept to reduce fatigue and unilateral exposure of body regions [13]. However, there is typically no specific focus on the changing needs of elderly workers. In the last decade, companies such as BMW have begun addressing the challenges in the automotive assembly process stemming from demographic change by testing measures to cope with the future situation of elderly workers [14].

Nevertheless, a holistic approach which considers physical exposure and continuous preservation of the workforce's qualifications, as well as incorporates the situation of individual elderly workers into models to generate job rotation schedules is currently still missing [15]. In this paper an integer linear programming (ILP) based heuristic is developed, which eases the outlined aspects and fills the gap in current research entitled the Balanced Ergonomic Qualification preserving job Rotation (BEQR) method. The remainder of this paper is structured as follows: In Section 2, the relevant theoretical foundations are outlined followed by an overview of current literature on short-term staff planning. The implementation of the BEQR method, including the developed heuristic to solve the ILP, is introduced in Section 3. Finally, an application example in the final assembly line of a German automotive manufacturer illustrating the planning advantage of the BEQR method is presented in Section 4, followed by the discussion of the results in Section 5.

2. Literature review

According to Ellström (1997) the term qualification in a professional environment refers to the competence that is actually required by the work task and/or is implicitly or explicitly prescribed by the employer [16]. A job rotation environment with varying work tasks leads to multi-skilled employees who can handle large product variety [17]. In contrast, related qualifications become obsolete when the job rotation interval for a specific workstation is too long. Therefore the workforce has to practice respective working activities on a regular basis, which claims a trade-off between the benefits of long and short-term job rotation intervals [18].

Staff scheduling aims to align a company's available workforce with work tasks in the most beneficial way and can also be referred to as personnel scheduling or rostering. In the context of manufacturing, the mapping of the available workforce with different work tasks may be referred to as allocation and is typically based on workforce qualifications and the task requirements with respect to time and capacity constraints [19,20].

The definition of the term "ergonomics", provided by the International Ergonomics Association (IEA), strives for improvement in two main fields: the optimization of human well-being and the optimization of the overall system performance [21]. Furthermore, ergonomics can broadly be clustered into three main focus groups. The field of physical ergonomics (1) focuses on anatomical or biomechanical human characteristics. Relevant topics within this field are working posture and the prevention of work-related MSD. Organizational ergonomics (2) deals with the optimization of sociotechnical systems, including decisions regarding work design. Lastly, cognitive ergonomics (3) considers the interaction between humans and their working environment, such as human-computer interaction.

Looking at the design of work systems, ergonomics can also be distinguished based on the point in time of implementation. Schlick et al. introduce the terms "prospective ergonomics" and "corrective ergonomics" [22]. Accordingly, **prospective ergonomics** means that ergonomic findings are included ex ante while designing work systems. **Corrective ergonomics,** on the other hand, is used when ergonomic aspects are regarded ex post, i. e. after working systems are created. Short-term staff scheduling systems, which take ergonomic aspects into account, can be categorized as organizational corrective ergonomics.

Various ergonomic risk assessment metrics have been developed in recent years featuring differences in their focused working activities and levels of detail. These metrics typically aim at evaluating physical workloads by means of screening tools. The outcomes of the evaluations can then be used to improve the assessed working activity ergonomics [22]. Based on the screening procedure of the Automotive Assembly Worksheet (AAWS), the European Assembly Worksheet (EAWS) was designed. The EAWS assesses movements a worker executes while performing work tasks at shop floor level, and thereby revises the AAWS for an increased field of application [23]. According to Schaub et al., the EAWS is currently implemented at several German and European car manufacturers and automotive suppliers [22].

In particular, the EAWS evaluates the following:

- working postures and movements with low additional physical efforts
- action forces of the whole body or hand-finger system
- manual materials handling
- repetitive loads on the upper limbs

The evaluation of each topic results in point values indicating the extent of the physical exposure the worker has to cope with. In order to identify potential risks regarding MSD when executing tasks, these generated point values are summed and can then be associated to a color scheme which is illustrated in Fig. 1 [22].

The green section represents physical loads ranging from 0 to 25, indicating a minor risk for the person performing the task. The yellow section, which ranges from 26 to 50, marks a possible risk whereby an entire structural redesign of the respective task is recommended in order to minimize the workforce's physical exposure. However, should a redesign not be feasible, the implementation of other corrective ergonomic actions such as minor physical modifications (e. g. adjustments to tool equipment) or organizational changes (e. g. adaptions to short-term staff scheduling) is recommended. The red section contains all tasks featuring a high likelihood of getting MSD, which should therefore be modified. However, the risks to which the workforce is exposed are not linked to "critical values" at which certainly and instantly an injury occurs, since the measures are based on the average worker. Individual physical conditions and working techniques also have an influence on such risk [22].

In the following, current approaches in the field of short-term staff planning dealing in particular with job rotation and staff scheduling problems are reviewed. The approaches are preselected for their relevance regarding the considered topic. Therefore, the