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# A simulation-optimization based heuristic for the online assignment of multi-skilled workers subjected to fatigue in manufacturing systems

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ABSTRACT

Manufacturing systems are often characterized by a stochastic and uncertain behavior in which frequent changes and unpredictable events may occur over time. Moreover, the customers' demands can sometime evolve drastically along time. In order to cope with such changes in the manufacturing system state, and to optimize given performance criteria, the assignment of multi-skilled workers to the machines in the system can be decided online, in a dynamic manner, whenever workers become available and need to be assigned. Indeed, the starting and completion times of jobs in such systems cannot be predicted, so that static optimization approaches turn out not to be relevant. Several studies, in the ergonomics literature, have outlined that the operators' performances often decline because of their fatigue in work. In particular, in manufacturing contexts, fatigue can increase the processing times of jobs. Several online heuristic have been published, but to the best of our knowledge, they do not cope with this consequence of fatigue. We propose to solve this dynamic multi-skilled workers assignment problem using a new methodology, which aims to provide an adaptable dynamic assignment heuristic, which is used online. Our approach takes the impact of fatigue into consideration, in order to minimize the mean flowtime of jobs in the system. We suggest computing more realistic task durations, in accordance with the worker's fatigue. The heuristic uses a multi-criteria analysis, in order to find a compromise that favors short processing times and avoids congestions. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is used to select the machine where to assign the worker. Since in our case no expertise is available, an offline adaptation process, based on simulation optimization, is used to identify the weights needed by TOPSIS, so as to better fit with the system specificities. A Job-Shop system is simulated to illustrate the proposed approach. The performance of the suggested heuristic is assessed and compared to two other workers assignment rules, which are widely used in the scientific literature because of their efficiency on the mean flowtime: SPT and LNQ. The comparisons are made under different conditions (staffing level, operators' flexibility). A sensitivity analysis is also performed to analyze the impact of the way how fatigue affects the task duration. Our experimental results show that our heuristic provides better results in every case studied. Several important research directions are finally pointed out.



## 1. Introduction

Human labor plays a key role in modern manufacturing systems. Indeed, workers, as human beings, are complex entities. Often, they each have several skills so that, they can perform a variety of tasks in the manufacturing system. In order to cope with the frequent changes to which manufacturing system are subjected to (e.g., in the customers' demands, or regarding unexpected events) and to meet productivity objectives, assigning these multi-skilled workers to machines can be complex (La Forme, Genoulaz, & Campagne, 2007). There are many companies whose manufacturing systems are subjected to a stochastic behavior (e.g. random arrival of orders and perturbations) and where frequent changes occur, for example due to fluctuation in the customers' demands. For such types of systems, the starting time and completion times of jobs can be unpredictable (and therefore the availability periods

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of machines), which can render static optimization approaches not relevant.

For such types of systems, many authors have suggested to assign the workers online, dynamically, once they become available and need to be assigned, in order to ensure a quick reaction to the changes occurring in the system state. If more than one machine requires a worker, a choice between the available machines must be made, depending on the current system state, in order to minimize a performance criterion. In this article, we will focus on the mean flowtime (MFT) of jobs in the system as the performance measure that should be optimized. However, the suggested methodology could be adapted to other performance criteria (e.g. mean tardiness of jobs).

Since workers generally get tired when they process jobs, their performance generally decline over time because of their fatigue, so that they can become slower. As consequence, the workers may spend more time than expected in processing their assigned tasks. Unfortunately, this may cause what can be called a 'deterioration' of the task processing times, which can affect tremendously the MFT. In this respect, taking the impact of workers' fatigue into consideration, when assignment decisions have to be made, is an important issue.

Although the impact of fatigue has been widely reported in the ergonomic literature (Barker & Nussbaum, 2011; Lodree, Geiger, & Jiang, 2009), to the best of the authors' knowledge, no publication seems to take the operator's fatigue into account for the dynamic assignment of multi-skilled workers. Therefore, we propose a methodology that allows the design of a heuristic that determines how to assign workers, online, while taking the impact of their fatigue into account, to minimize the MFT. This heuristic is based on several original features described in the article. In particular, we suggest computing more realistic task durations in accordance with the worker's fatigue at the time when he/she will be assigned. The choice of the machine, to which the worker has to be assigned, is supported by a bi-criteria analysis. Therefore, we use a Multi Criteria Decision Making (MCDM) approach that tries both to keep the task durations short, and to avoid congestions. For this, we use simulation optimization in an offline process, to adapt the weights used in TOPSIS with the features of the manufacturing system.

The remainder of this article is organized as follows. Section 2 recalls related research in this area and explains the novelty of this study with respect to the existing literature. Section 3 formalizes the problem addressed. Section 4 presents the proposed approach. In Section 5, a simulation study of a Job-Shop system under various conditions is presented to illustrate and compare our heuristic with popular dynamic assignment rules. The final section draws the conclusions and some suggestions for future research are pointed out.

## 2. Related research

### 2.1. Workers assignment problems

These last decades, researchers have paid an increasing attention to the workers assignment problems. These types of problems have been widely studied in the literature about manufacturing systems and it is well known that the way how workers are assigned in the system greatly affects the system performances. Reviews of research works related to workers assignment in manufacturing systems are presented in (Ammar, Pierreval, & Elkosantini, 2013; Ernst, Jiang, Krishnamoorthy, & Sier, 2004; Van den Bergh, Beliën, De Bruecker, Demeulemeester, & De Boeck, 2013; Xu, Xu, & Xie, 2011). According to these literature reviews, there exist various definitions, assumptions, contexts and methods related to the workers assignment problems, which are known for their complexity and for their NP-Hardness (Mahdavi, Paydar, Kia, & Khonakdari, 2010; Sirovetnukul & Chutima, 2010).

According to Ammar et al. (2013) and Xu et al. (2011), the majority of existing publications are concerned with problems where the set of jobs to be processed is defined in advance, with deterministic processing times. As a consequence, the task durations are known a priori, with enough certainty, and the completion dates of jobs can be computed. In such cases, how to assign workers is considered as an optimization problem. Thus, different approaches have been developed to solve such problems, given one or several performance objectives. For instance, Süer and Dagli (2005) have developed a mixed integer model to assign workers into cells with the objective of maximizing the production rate. Miralles, García-Sabater, Andrés, and Cardos (2007) have applied a Branch and Bound approach with three possible search strategies (i.e. depth first search with complete node development, best first search and minimal lower bound) to solve their assignment and balancing problems. Such problems are often called "static problems', since the data known in advance allow classical optimization approaches to be used offline, before that the assignment decisions are applied in the system.

Certain information about the production plan to be performed, such as the time when the jobs start or the task processing times, can sometimes not be totally determined for the period of study. However, this information may be known for a given limited period. For example, Gronalt and Hartl (2003) have assumed that the set of jobs to be operated each day is known in advance. The authors have highlighted the necessity of using forecasting technique to deal with this lack of precision about the production plan. In their study, the authors have used a rolling planning horizon to solve the daily problem of assigning workers and floaters in a production line.

In the same context, other works such as Sabar, Montreuil, and Frayret (2012), have emphasized the importance of coping with unpredictable or dynamic events, namely machine failures or worker absences. That is why, these authors have first proposed to assign the workers to the different machines to process a given set of tasks, which is known in advance and, when an unexpected event occurs, workers are then reassigned according to the new system state to process a new set of tasks. In this context, multi-agent based approaches have been used (Sabar et al., 2012; Savino, Brun, & Mazza, 2014).

Certain types of systems have different characteristics. Orders can arrive randomly, unexpected events can occur and the customers' demands can fluctuate over time for each product type. In such stochastic and changing contexts, how to deal with the different operators' skills is a complex problem. Given the lack of precision about the production plan to be performed, it is well known that usual optimization approaches can generally not be applied. As a consequence, several researchers, such as Ammar et al. (2013), Cesani and Steudel (2005) and Zavadlav, McClain, and Thomas (1996), have pointed out, from their literature analyses, that determining online, in real time, where the operators should be assigned can represent an alternative to react quickly to these changes. The assignment decisions are made, online, according to the current system state, with respect to a set of constraints (e.g. worker qualification and availability of machines) and, to given performance criteria (e.g. mean flowtime of jobs).

To address these assignment problems, which are often referred to as dynamic workers assignment problems, Ammar et al. (2013) and Ferjani, Ammar, Pierreval, and Trabelsi (2015) have highlighted that assignment rules called 'When and Where' are often used in the literature. The 'When-rule' indicates when the worker is considered to be available and eligible to move to another machine. The 'Where-rule' specifies the machine to which the worker is going to move once he/she is released (Kher, 2000).