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Technical paper

A decentralized model for flow shop production with flexible transportation system

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ABSTRACT

The recent advances in technology sectors often clash with traditional organizational paradigms which can limit or make difficult an efficient implementation in the real world. In this paper we show how it is possible to exploit the advantages of innovative technologies in manufacturing when these are supported by new and efficient methods for production management. More in details, we face a flow shop scheduling problem in a shoe manufacturing system in which overtaking of jobs is allowed thanks to an innovative transportation system. Overtaking means that a job can be put in waiting state and another job can surpass it, allowing the change of the scheduling sequence. Preemption is not allowed. The objective function of the problem is the minimization of the maximum lateness. We propose a decentralized model, based on multi-agent system theory, to represent the production cells of the plant and to include the potentiality offered by overtaking of jobs at decisional level. The adoption of a decentralized approach increases the system flexibility since each machine is able to solve its local scheduling problem. Adding or removing machines to the plant will not imply a change in the scheduling algorithms. The outcomes of this work are reached firstly through a formulation of the problem with three flow shop scheduling models, secondly through a comparison of the models with respect to different performance indicators. The results highlight as the decentralized approach is able to reach comparable performances with the centralized one for a relevant number of instances. Moreover sensitivity analysis shows as in the decentralized model the computational time required to solve bigger instances increases less quickly than in the case of centralized ones. Finally, simulations of the decentralized approach clarify as the correlation of the local solution procedure is effected by the number of machines of the flow shop and the coordination mechanism is effected by the number of the jobs to be scheduled.

1. Introduction

The concept of flexible manufacturing system (FMS) was introduced in response to the need for greater responsiveness to changes in products, production technologies and markets, and has been deeply discussed in the literature [1–4]. FMSs have a high degree of complexity and they are often underused mostly due to lack in software systems and communication technologies able to effectively manage the complexity. For this reason it is common to analyze the FMS along two different dimensions: the flexibility and the complexity. The former dimension can be analyzed as internal flexibility (i.e., the ability to manage in efficient way the plant) and external flexibility (i.e., the ability to quickly respond to the market requests). The latter dimension, i.e., the complexity, is instead measured in terms of (i) plant complexity and, (ii) information domain complexity. The plant complexity is an indicator of the number of machines, products, and product models [5]. The information domain complexity is a function of total quantity of information, information diversity, and information content, corresponding to the effort to capture and to transfer in useful format the information [6].

The aim of this work is to present an application of a multi-agent systems (MAS) able to solve a scheduling production problem with a high level of flexibility and complexity within a reasonable computing time. The paper shows how it is possible to exploit the advantages coming from innovative technologies in manufacturing when these are supported by new and efficient methods for production management. Thanks to an automated transportation system, the sequence of jobs may change at each stage of the flow shop, enabling high flexibility at manufacturing level. For instance, job with different routes may be processed on the same line, and dynamic changes in scheduling parameters (e.g. in the due date of a job) can be considered during the process execution, allowing dynamic change in the sequence of jobs. In these settings higher

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system flexibility comes together with higher management complexity. In fact, if from one side the transportation system enables higher flexibility allowing schedules to be changed and given jobs to surpass other jobs during execution, from the other side the scheduling problem to be managed and solved is much more complex. As a matter of fact, the resulting scheduling problem must consider schedules in which a job surpasses another. The scheduling problem deals with the allocation of activities to time slots and/or machines. The output of the scheduling, i.e., the schedule, is a list of jobs or activities to be processed or executed in a period of time using a set of scarce resources. Historically, scientific literature proposed several techniques and tools to solve the problem within a reasonable computational time with respect to the requirements of the decisional maker. Unfortunately, it is not unusual that technological restrictions and precedence or other real constraints can increase dramatically the complexity of real problem instances. On the other hand, the technological innovations for FMSs require changes in traditional organizational paradigms. In particular, this work presents a case study where the transportation system within the flow shop plant allows the overtaking of jobs, and the decision support system is unable to consider this opportunity. This happens because very often the flow shop scheduling, where all jobs have to be processed in an identical order on a given set of machines, is solved using the hypothesis of permutation, i.e., the hypothesis considering the job sequence equal for all the machines of the flow shop. If the job overtaking is considered, the complexity of the flow shop scheduling increases dramatically because it is required to represent a different sequence of jobs for each machine.

In this work, three different models are formulated and compared:

- Centralized permutation flow shop scheduling problem (PFS): the decision about the jobs processing sequence is made once by one decisional maker who collects the plant information. The overtaking of jobs is not allowed.
- Centralized general flow shop scheduling problem (GFS): the decision about the jobs' order processing is made once by one decisional maker who collects the plant's information. The overtaking of jobs is allowed.
- Decentralized flow shop scheduling problem "cascade" (CFS): the decision about the jobs' order processing is made by several decisional makers, one for each manufacturing cell. The overtaking of jobs is allowed.

The analyzed models are formulated and tested in order to evaluate in which cases is more convenient to adopt a centralized or decentralized approach to solve the scheduling problem.

The problem instances are built considering, as a constraint, the case of some jobs having null operation time on specific machines of the shop. In all the considered cases, preemption of jobs is not allowed. A job must finish its current operation before it can be shifted in waiting state and another job can surpass it.

The objective of the work is to evaluate the goodness of the models proposed by the literature with respect to the new opportunities offered by innovative manufacturing technologies in production.

The paper is organized as follows. Section 2 presents literature review on shop scheduling problems. In Section 3, the problem with the physical plant characteristics and the production constraints are presented. In Section 4, the centralized models are formulated while in Section 5 the decentralized approach is defined. The solution approach and the comparison between the presented models are given and discussed in Section 6. Finally, in Section 7, conclusions about the best approach to use in order to reach a specific objective for solving flow shop scheduling problems are given. Ideas for future improvements follow.

2. Literature review

The flow shop scheduling problem (FSP) is a particular type of scheduling problem which considers the processing of a given set of jobs, and where all jobs have to be processed in an identical order on a given number of machines [7]. Several models and resolution methods exist in literature for representing and solving the FSP. The solution methods can be evaluated by using different performance indicators [8], mainly related shop time or due date. Shop time performance indicators are the flow time, defined as the time a job spends in the shop, and the maximum completion time of the schedule, named *makespan*, equal to the ending time of last job in the sequence, are measures related to the shop time. However, in real shops, meeting the due dates tends to be a more important criterion than minimal flow time. Time based performance indicators are lateness and tardiness. The first one can be defined as the difference between the completion time and the due date of the job; a good schedule can be obtained by minimizing the maximum lateness. The second one is defined as the maximum between the value 0 and the value of job's lateness; a good schedule can be obtained by minimizing the maximum tardiness. With respect to the transportation system, overtaking of the jobs may be considered. Job overtaking means that a job can be put in waiting state before to start or after ending an operation in a specific machine of the flow shop and the following job in the sequence can surpass it, causing a change in the jobs sequence. If this opportunity is not exploited, the problem solution considers only permutation schedules, meaning that the job sequence is the same for all machines. In this paper, a permutation FSP is analyzed by adopting the centralized approach and a general FSP exploiting job overtaking is analyzed in both centralized and decentralized approaches. For both settings proper buffers for waiting jobs have to be considered and prearranged. The permutation FSP will not consider the job overtaking. The comparison is then not punctual and it is performed with the aim to demonstrate the potentials and computational problems of the job overtaking based models in static settings. Another shop characteristic that may be considered is the possibility to interrupt a process of one job in a machine; if this is not allowed, the problem resolution creates non preemptive schedules.

Plentiful literature exists about the several aspects of the FSP. An interesting review of flow shop problems with *makespan* criterion can be found in Ref. [9]. Rajendran and Ziegler [10] present several heuristics for static flow shop where the objective function is the minimization of the sum of weighted flow time, weighted tardiness of jobs, and the setup times are considered. Ziaee and Sadjadi [11] propose different formulations for the FSP considering the minimization of the *makespan*, the flow time, and the tardiness. In particular, they propose a general formulation for FSP not limited by the permutation assumption; as a consequence, the sequence on a machine can be different from the sequence on another one. This assumption is the same considered in our paper. Allahverdi [12], proposes two very interesting works where a FSP problem with 2-machines and m-machines is tackled while minimizing at the same time the *makespan* and the flow time in Ref. [12], and the *makespan* and maximum *tardiness* in Ref. [13]. Tseng et al. [14] compare four of the most known formulations of the permutation FSPs with respect to the effectiveness performance measures, and they conclude that, in terms of computer solution time, the model proposed by Wagner [15] performs better than the models proposed by Wilson [16], Manne [17], and Liao and You [18]. A lot of methods have been proposed to implement heuristics for FSP and to test their efficiency. The most known method has been proposed by Johnson in the 1954 for the FSP with 2-machines [19]. Starting from this seminal work, several studies improved the ability to solve more complex flow shop scheduling problems using specific heuristics based on graph theory [20] or on known techniques as Lagrangian relaxation [21]