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Dynamic scheduling of parallel heat treatment furnaces: A case study at a manufacturing system

Adil Baykasoğlu*, Fehmi B. Ozsoydan

Dokuz Eylül University, Faculty of Engineering, Department of Industrial Engineering, İzmir, Turkey

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ABSTRACT

In the present work, a case study focusing on online and dynamic scheduling of parallel heat treatment furnaces at a real manufacturing company is presented. The problem under consideration in this study involves release times, eligibility constraints, due dates, sequence-dependent setup times due to heating up or cooling down the furnaces, breakdowns and maintenance periods. Moreover, dynamic events, for instance, arrivals of rush orders, cancellations of already handled jobs, changes in due dates or in lot sizes exist in the nature of the problem considered here. Such dynamic factors make the introduced problem more challenging. One more difficulty is the vast variety of products at the firm. Generating a large-scaled setup matrix is neither practical nor reliable. Therefore, based on the distinctive attributes of the products, an implicit clustering is employed. As a solution approach, a multi-start and constructive search algorithm is proposed for this problem. Finally, as a dynamic scheduling module for the heat treatment furnaces, the proposed algorithm is embedded into the enterprise resource planning system of the company that is built on JAVA. The current system contributes to the firm by online scheduling of the heat treatment furnaces, generating online Gantt Charts for managers, online transmission of work orders and digitalized performance analysis reports. Thus, as demonstrated by numeric data presented in the present paper, a decrease in energy consumption and an increase in annual income are expected.

1. Introduction

In traditional optimization problems, the problem domain is assumed to remain stationary throughout optimization process. However, majority of real-life applications are indeed dynamic due to uncontrollable and hard-to-predict events like new order arrivals, rush orders, cancellations, due date changes, changes in production constraints or breakdowns. Such events give rise to changes in the problem domain or in related problem data. In such dynamically changing problems, the aim is to keep track of the changing optima by finding high quality solutions in a short period.

The related literature of dynamic optimization [1–6] commonly adopts some well-known synthetic problems like moving peaks or bit-changing problems, which are known to be an abstraction of real-life problems. They are particularly used along with extensions of some well-known mathematical functions for benchmarking in operations research community. As one can see from the reported literature, studies focusing on applications and implementations of these techniques in real life are lacking. The present study addresses a case study of a dynamic parallel machine scheduling problem with sequence-dependent setup times, release times, due dates, eligibility constraints, breakdowns and several other intrinsic features, clarified throughout the paper.

Scheduling problems [7–10] have attracted notable attention of both researchers and practitioners. As an extension of this problem class, parallel machine scheduling problem (PMSP), which is one of the most widely practiced problems, has numerous practical applications in industry, commercial manufacturing systems and expert systems.

PMSPs are known to be *NP-hard* [10,11] and in turn, forms a considerable challenge to both practitioners in real life applications and researchers from academic community. As one of the early studies, Cheng and Sin [7] roughly classified PMSP into three categories namely, identical, uniform and unrelated parallel machine problems. Some other related surveys are also presented in Allahverdi et al. [12], Pfund et al. [13] and Allahverdi et al. [14].

However, PMSPs have further attributes to be considered for classification. As one of them, setup operation (time and/or cost), which has for long been considered negligible and hence ignored, or considered as part of the processing time [12,14], has a great impact on the efficiency of the generated schedules, particularly if those setup operations are sequence-dependent. In such cases, the occurred setup is dependent to the sequence of consecutive jobs. Although recent studies and advances pay attention to the

* Corresponding author.
E-mail address: adil.baykasoglu@deu.edu.tr (A. Baykasoğlu).

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sequence-dependent setup times, this type of PMSPs is still lacking in comparison to other extensions. A related comprehensive presentation is reported in Armentano et al. [15].

Presenting extensive literature here is beyond the scope of this study and it is not practical due to space limitation, however, some of the recent and related advances are addressed here. In one of those studies Jia and Mason [16] present a real-life case study, where multiple orders per job scheduling problem for identical machines is solved. Ying and Cheng [17] propose an iterated greedy search heuristic for a parallel machine scheduling problem with sequence-dependent setup times and release times. One interesting work is presented by Gokhale and Mathirajan [18], where a scheduling problem with identical parallel machines, eligibility restrictions, release times and sequence-dependent setup times exist in automobile gear manufacturing. An extension of PMSP with machine preference is addressed in Huang and Liao [19]. Edis and Ozkarahan [20] report a similar problem with machine eligibility restrictions. The authors propose a combined integer/constraint programming approach to solve their problem. Ruiz-Torres et al. [21] introduce deteriorating effects of jobs on machines. In the same year, Costa et al. [22] propose a genetic algorithm for worker allocation in parallel unrelated machines with sequence-dependent setup times. A survey focusing on online scheduling with machine eligibility restrictions is reported by Lee et al. [23]. Lin and Hsieh [24] employ a heuristic and an iterated hybrid metaheuristic for minimization of total weighted tardiness in PMSP environment, where sequence and machine-dependent setup times and ready times exist. In the same year Yilmaz Eroglu et al. [25], propose a genetic algorithm for unrelated PMSP with sequence-dependent setup times and with the objective of makespan minimization. Xiao et al. [26] present an interesting application in a semiconductor factory, which takes the parallel-machine capacitated lot-sizing and scheduling problem with sequence-dependent setup times, time windows, machine eligibility and preference constraints, into account. Finally, Costa [27] proposes a hybrid genetic algorithm to solve a real-life parallel machine scheduling problem, encountered in pharmaceutical industry.

In the present paper, a constructive and multi-start strategy is proposed for solving a special case of the PMSP with release times, sequence-dependent setup times, eligibility constraints, due dates and machine breakdowns. As a notable distinctive feature worth mentioning is that the presented problem particularly includes domain and parameter based dynamic changes, where domain based changes correspond to arrivals/cancellations of orders or breakdowns and parameter based changes correspond to the changes in problem data like changes in due dates, lots sizes etc., respectively. In this respect, the main motivation of the present study is proposing and implementing a constructive and multi-start algorithm at a real manufacturing system. Thus, the proposed system, contributes to the firm by generating online schedules and related Gantt Charts, online transmission of work orders and performance analysis reports.

It is worth stressing that there are several reasons to choose such a strategy. As one of them, it only deals with the revealed part of a problem environment and guaranties feasibility. In other words, at the beginning of each generation, it takes a picture of the system and runs only with the current available data. As a result, in the proposed approach, dependency to the previously found solutions is eliminated in contrast to numerous other dynamic scheduling algorithms employing evolutionary or population based approximation methods. Because, in such algorithms there is a strong dependency to previously found solutions while generating the current and upcoming populations. As extensively discussed in [28,29], loss-of-diversity problem, adaptation procedures and necessary solution string repairing issues in population based algorithms are other challenges that do not appear in the proposed algorithm. Moreover, such a strategy provides applicable solutions in short period, which is a crucial necessity for a real life application. Putting things together, a case study, where the proposed constructive and multi-start search algorithm is embedded into the enterprise resource planning (ERP) system of a manufacturing company, is presented in the current paper. Thus, the present study introduces both academic and practical contributions.

The rest of the paper is organized as follows: Section 2 is devoted to clarifying the problem considered here. A brief information about project partner and system description are provided in Section 3. The details of the case study and proposed solution approach are presented in Section 4. Implementation at the firm along with experimental results and concluding remarks are given in Section 5 and Section 6, respectively.

2. Problem statement

The considered problem in the present work includes a number of distinctive features. Firstly, it involves previously unknown and hard-to-predict future events such as arrivals of rush orders, cancellations of already accepted jobs and changes in due dates or lot sizes. Existence of such factors makes the problem dynamic and therefore more challenging. It is worth stressing that numerous publications adopt the word *dynamic* if release times exist in a problem environment. However, authors here think that, existence of only release times does not make a scheduling problem dynamic. Since the release times are known beforehand, any job is also priorly known to be scheduled just when it is released. In such a case, release times of the jobs are already revealed to a decision maker and the problem environment remains stationary throughout the processing of the scheduled jobs. However, in the present study, although previously known to be released jobs exist, additionally, there are also rush orders, whose arrivals are unexpected and remain unrevealed until they arrive at the system. Likewise, previously scheduled jobs might be cancelled with urgent decisions. Moreover, problem parameters like due dates, lot sizes, etc. might change during the processing of the scheduled jobs. In the present study, only such cases are referred to as dynamic factors. The noteworthy features of the problem under consideration are stated in the following.

2.1. Dynamic factors

Dynamic factors here are referred to as unpredictable and uncontrollable events that change the problem domain and problem data, so that already generated plans should either be revised or be re-scheduled. Two types of dynamic factors with different effects simultaneously exist in the introduced problem. The first type of dynamic factor, such as, arrivals/cancellations of jobs and maintenance/breakdowns of the furnaces yield to changes in the problem domain, where the mentioned problem is defined. Therefore, this type of dynamic factor is referred to as domain based (dimensional) change in the present work. As the second type of dynamic factor, changes in due dates, in priorities of the jobs and lot sizes give rise to changes only in the related problem data rather than causing changes in the problem domain. Therefore, this type of dynamic factor is referred to as parametric change (non-dimensional) in this paper.

2.2. Preemption

Preemption is not allowed here. Because, providing exactly the same physical conditions for two fractions of the same lot (before and after preemption) is quite challenging. Therefore, while re-