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Permutation flow shop scheduling with order acceptance and weighted tardiness

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ABSTRACT

In this paper we study the permutation flow shop scheduling problem with order acceptance and weighted tardiness (PFSS-OAWT) faced by firms that have a number of candidate orders to be selected and scheduled on a flow shop production line. The objective is to maximize the total net profit with weighted tardiness penalties. We formulate the PFSS-OAWT problem as an integer programming (IP) model. A heuristic algorithm named Simulated Annealing Based on Partial Optimization (SABPO) is developed for solving the IP model and obtaining near-optimal solutions. Computational studies are carried out on solving 160 problem instances with different scales (small, medium, large, and very large). The experimental results show that the SABPO algorithm exhibits good optimality for small-sized problems and robustness for medium/large-sized problems compared with benchmarks.

1. Introduction

In most flow shop scheduling models, an implicit assumption is that all jobs (or orders) must be processed through the production system without rejection. However, many companies with make-to-order systems might decline some orders if they cannot be managed effectively in the production schedule due to limited capacities or resources and therefore encounter a more complicated problem that integrates the job scheduling with the order acceptance decision. Flow shop scheduling with order acceptance decision, which aims at maximizing the total net profit of accepted orders, has been a subject of research attention for many years. A substantial number of studies based on a single machine/workstation can be found in the literature, and these assume that the accepted orders go through only one machine (or workstation) with known processing time (see, e.g., Pourbabai [1]; De et al. [2]; Slotnick and Morton [3,4]; Ghosh [5]; Lewis and Slotnick [6]; Rom and Slotnick [7]). However, in practice, a processing line often contains multiple stages (serial machines/workstations) through which different jobs/orders will be processed within different processing times. An example is that of a company providing laundry services with fixed stages for fulfilling customers' orders, e.g., picking up clothes, pretreatment, classification, washing and drying, smoothing and delivering, etc. Tardy deliveries will incur penalty costs that may lead to lower or even negative profits and possible loss of trust by customers. In today's production systems, similar lines are easy to find in different industries, all of which involve the complex problem of how to select the candidate orders and synchronously schedule the selected orders on a multi-stage processing line with the objective of maximizing total profit. However, the combination of order acceptance with flow shop scheduling on multiple machines/workstations produces a substantially more complicated problem than that with single machine/workstation, or a pure flow shop scheduling. Nevertheless, few studies can be found on the combination in the existing literature.

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In this paper, we formally address this problem as permutation flow shop scheduling with order acceptance and weighted tardiness (PFSS-OAWT for short), and we formulate the problem as an integer programming model. We provide some analysis of the solution to our problem along with a heuristic algorithm called simulated annealing algorithm based on partial optimization (SABPO) to obtain near-optimal solutions. Computational experiments are conducted by solving 160 generated problem instances with different sizes (small, medium, large, and very large), which validate the effectiveness and efficiency of the proposed algorithm.

2. Related work

Since first proposed by Johnson [8], the flow shop scheduling problem has been extensively studied for several decades (see the review by Ribas et al. [9]). The classical flow shop problem typically aims at minimizing the completion time/make-span for cases where n jobs are executed through m stages. If all machines process their jobs in the same sequence, the process is called a permutation flow shop schedule; otherwise, it is a non-permutation schedule (Potts et al. [10]). Conway et al. [11] proved that for the classical flow shop problem, there exists an optimal schedule with the same processing sequence on the first two machines as well as on the last two machines. Thus, one can consider only permutation schedules for the three-machine flow shop problem that minimizes the maximum flow-time. However, if the number of stages in a flow shop is greater than three, it is very easy to construct an instance whose optimal solution must be a non-permutation schedule (Potts et al. [10]; Sviridenko [12]; Ladhari and Haouari [13]). Moreover, for other types of variation in flow shop problems, e.g., problems related to release times or weighted tardiness, the optimal permutation schedule may not be superior to the non-permutation schedule even in the case of fewer than three machines (Lageweg et al. [14]; Cheng et al. [15]). Although the non-permutation schedule may provide shorter make-spans than the permutation schedule in some cases, the permutation schedule is usually closer to the practice and it has been studied in the literature (Ladhari and Haouari [13]; Lageweg et al. [14]; Cheng et al. [15]). Usually, the processing times for different jobs at different stages are different and precisely known, though they may sometimes be treated as fuzzy numbers (Chanas and Kasperski [16]; Niu et al. [17]) or deemed to be time-dependent of their starting times. Called deteriorating processing times, these appear in industries such as maintenance, fire fighting, cleaning assignments, etc. (Cheng et al. [18]; Wang et al. [19]; Yang and Wang [20]). Meanwhile, in some industries with learning activities, the processing times may also be affected by the learning effect (Wang and Guo [21]).

Pourbabai [1] first proposed a job selection model to assist manufacturers in determining how to accept (or reject) the candidate orders and in what quantities such that the net operational profit considering weighted tardiness penalties can be maximized. This model was extended in Pourbabai [22] to fit the Just-In-Time production system. The author assumed that the production system is constructed based on group technology and therefore the multiple processing stages of a job can be aggregated as a single stage processed at one workstation. Gupta et al. [23] considered the problem of simultaneous selection of a subset from n projects and the determination of an optimal sequence for the selected projects so as to maximize the total net return. De et al. [2] examined a single machine scheduling problem with random processing times and deadlines that considered job selection, which can be regarded as an extension of the model in Gupta et al. [23]. Stadje [24] proposed a single-machine model for the problem of job selection and sequencing, assuming that the machine is non-repairable and might incur breakdowns with a predictable probability.

Slotnick and Morton [3] proposed a single-period order acceptance model for a single-stage system, with the objective of maximizing total profit with weighted lateness, where the delayed delivery of an order will result in a penalty and earliness will contribute to the profit. To solve the model, they investigated an optimal algorithm, i.e., branch-and-bound, and two heuristics, i.e., beam search and myopic algorithms, and reported that the myopic algorithm can yield high-quality solutions. Lewis and Slotnick [6] extend this work to the multi-period case with weighted lateness, assuming that job selection will affect future orders, i.e., the rejected customer will never return. Slotnick and Morton [4] further extended their model to the weighted tardiness version, which considers delayed penalties but not rewards for earliness. Oğuz et al. [25] generalized the Slotnick–Morton version of the order acceptance problem by taking the sequence-dependent setup times and deadlines into account, and developed meta-heuristic algorithms to solve large-sized problem with 300 orders.

Order acceptance models also emerged in other environments. Ivănescu et al. [26,27] studied order acceptance problems in batch process industries. They proposed a hybrid policy using simulated annealing techniques to estimate the direct effect of accepting an order on resource utilization. Batch process industries are characterized as a no-wait job shop with overlapping operations, in which a variety of different products may follow different routings through the plant [28,29]. Ebben et al. [30] proposed a workload-based order acceptance model for over-demanded job shop environments. They used aggregate information, e.g., the required total processing time and the available capacity aggregated over all resources, to determine the acceptance of an order. Yang and Geunes [31] presented a job selection and scheduling model with controllable job processing times, in which the processing time of a job can be compressed at a specific cost if necessary.

Martínez and Arredondo [32] presented a revenue management model with order acceptance to maximize the total profit based on capacity reallocation, in which the capacity limitation is rigid and tardiness is not allowed. There are also several studies considering the penalties caused by rejected orders, another worthwhile topic that will not be discussed in this paper. Interested readers can refer to Engels et al. [33], Hoogeveen et al. [34], Seiden [35], Epstein et al. [36], Miao and Zhang [37], Nagy-György and Imreh [38], Zhang et al. [39], etc.

As the above review shows, although there are some models for job shop scheduling problems with parallel machines/routings in batch process industries, studies on flow shop scheduling (multiple processing stages) with order acceptance