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A hybrid genetic and linear programming algorithm for two-agent order acceptance and scheduling problem

Mohammad Reisi-Nafchi, Ghasem Moslehi*

Department of Industrial and Systems Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran

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ABSTRACT

In this paper, the simultaneous order acceptance and scheduling problem is developed by considering the variety of customers' requests. To that end, two agents with different scheduling criteria including the total weighted lateness for the first and the weighted number of tardy orders for the second agent are considered. The objective is to maximize the sum of the total profit of the first and the total revenue of the second agents' orders when the weighted number of tardy orders of the second agent is bounded by an upper bound value. In this study, it is shown that this problem is NP-hard in the strong sense, and then to optimally solve it, an integer linear programming model is proposed based on the properties of optimal solution. This model is capable of solving problem instances up to 60 orders in size. Also, the LP-relaxation of this model was used to propose a hybrid meta-heuristic algorithm which was developed by employing genetic algorithm and linear programming. Computational results reveal that the proposed meta-heuristic can achieve near optimal solutions so efficiently that for the instances up to 60 orders in size, the average deviation of the model from the optimal solution is lower than 0.2% and for the instances up to 150 orders in size, the average deviation from the problem upper bound is lower than 1.5%.

1. Introduction

In many markets, the increasing number of manufacturers and the variety of their products have intensified competitions among them to such an extent that attracting and maintaining customers is more vital now than ever before. Therefore, this competitive situation has stimulated the manufacturers to work out new ways of satisfying their customers for the simple reason that they need to keep their income and thus improve their position in the market. One of the factors which affect the customer satisfaction is on-time delivery of goods or services. In recent years, many researchers have studied the problems related to this case, the most important among them being "simultaneous order acceptance and scheduling" or "Order Acceptance and Scheduling (OAS)" in short. In this problem, decisions about acceptance/rejection and scheduling of the orders are made simultaneously based on logical reasons such as considering production capacity before promising to the customers. Generally, this problem has been studied in the literature based on two approaches: (1) maximizing the total profit of accepting the orders and scheduling them; and (2) minimizing the total costs of rejections and scheduling the accepted orders. Studies on the former approach published before 2011 are extensively reviewed by Slotnick [1] and the investigations on the latter published before 2013 are presented by Shabty et al. [2].

Parallel to the studies on it, the OAS problem has also been extended and generalized for different applications as shown in the literature on the scheduling problem. One of these applications in the past decade was concerned with the conception of "multi-agent" or "competing agents" added to the classical scheduling; which resulted in presenting the "Multi-Agent Scheduling (MAS)" problem or "scheduling with competing agents" problem. In the MAS problem, the objective is scheduling some different sets of jobs, with each set having its own specific scheduling criterion. Considering different criteria for the job sets, which is not common in the classical scheduling, originates from the variety of customers and the orders which are referred to the manufacturers. More recently, Perez-Gonzalez and Framinan [3] have reviewed and classified the studies on the MAS problem in their survey paper. It is important to say that most of the studies have dealt with the two-agent cases because increasing the number of agents increases the complexity of such problems.

According to the points reviewed above and also due to the importance of considering different requests of customers in accepting and scheduling their orders, in this paper the two above-described problems are integrated and studied as "two-agent

* Corresponding author. Tel.: +98 3113915509; fax: +98 3113915526.
E-mail addresses: reisi.m@cc.iut.ac.ir (M. Reisi-Nafchi), moslehi@cc.iut.ac.ir (G. Moslehi).

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order acceptance and scheduling" problem. To elaborate, this study involves two agents, each with some orders, but their scheduling criteria (penalty functions) will be different. It seems that the idea of integrating the order acceptance scheduling problem and the multi-agent one was presented by Reisi-Nafchi and Moslehi [4,5] for the first time. In their studies, the objective is maximizing the total revenue of accepted orders by bounding each agent penalty function. In both of their studies the total lateness and the number of tardy jobs were considered as penalty functions of agents and the second agent accepted orders does not allow being a tardy one. In addition, in one of their study they assumed that the second agent orders have a common due date and in another one they considered that all the first agent orders have equal processing times. They showed that these problems are ordinary NP-hard and therefore they proposed a pseudo-polynomial dynamic programming for each of them. In Section 3, the differences of their problems and this paper one are described.

Due to the complexity of the studied problem in this paper, the main focus of this paper will be proposing an efficient meta-heuristic algorithm to solve the problem. Therefore, this meta-heuristic algorithm is proposed by hybridizing the genetic algorithm and the LP-relaxation of the integer programming of the problem.

In the rest of the paper, after reviewing the literature of the OAS and MAS problems, the definition of the studied problem and its complexity is described in Section 3, and some lemmas about the properties of optimal solution for the problem are presented in Section 4. Based on these properties, an integer programming model is proposed in Section 5 to optimally solve the problem. In Section 6, using the LP-relaxation of the proposed model a hybrid meta-heuristic algorithm with underlying genetic algorithm and linear programming is developed. The performance of the proposed methods is studied in Section 7 by solving some random instances, and at last conclusions are presented.

2. Literature review

As mentioned in the previous section, the OAS problem has been studied with various assumptions, one of which is considering different scheduling criteria. In the following, the studies on maximizing the total profit with two famous scheduling criteria, i.e. total weighted lateness and total weighted tardiness, are reviewed.

2.1. Total weighted lateness

The most important studies on the total weighted lateness criterion have been conducted by Slotnick and Morton [6], Ghosh [7] and Lewis and Slotnick [8]. It is important to note that all these studies have considered the problem in a single machine environment. However, the first two studies considered a one-period case and the last one considered a multi-period case. In Table 1, a summary of the studies along with the assumptions and methods is presented. What is significant in these three studies is that the optimal sequence of the accepted orders based on the total weighted lateness criterion can be obtained by the Weighted Shortest Processing Time (WSPT) order [9]. This property has significant effects on solving the problem.

2.2. Total weighted tardiness

The OAS problem with the total weighted tardiness has also been studied in different papers. A summary of these studies is presented in Table 2. As emphasized in these studies, the complexity of this problem is at least equal to the complexity of scheduling problem of minimizing the total weighted tardiness. So, its complexity is NP-hard in the strong sense.

As mentioned in Section 1, the MAS problem which was formally presented by Baker and Smith [18] for the first time is defined as scheduling some sets of jobs each with a specific criterion (or objective function), which compete to process in a machine environment. In the literature, the MAS problems have been classified into four categories [3,19]: feasibility, constrained optimization, linear convex combination, and Pareto optimization. Since the method used in this paper is similar to the second category, i.e. constrained optimization, some related studies are reviewed in the rest of this section. It must be remembered that in the constrained optimization approach the objective is optimizing one-agent criterion while bounding the other agents' criteria, which is equivalent to determining a service level for each agent.

Agnetis et al. [19] considered the three criteria of maximum of a regular function, number of tardy jobs, and total weighted completion time for the two-agent scheduling problem and then studied the complexity of different scenarios defined based on those three criteria. Ng et al. [20] showed that the two-agent scheduling problem of minimizing the total weighted completion time of the first agent jobs and preventing the second agent jobs from becoming tardy is strongly NP-hard. In a different study on the two-agent scheduling problem, Agnetis et al. [21] considered the total weighted completion time for the first agent, and the three criteria of maximum lateness, maximum completion time, and total weighted completion time for the second one as scheduling criteria. In this study, which was defined in the form of constrained optimization, a branch and bound algorithm was proposed in which the Lagrangian relaxation method was used to develop a lower bound for the problem.

Lee et al. [22] extended the studied problem of Ng et al. [20] by assuming that the jobs are deteriorating ones, and proposed a branch and bound and three heuristic algorithms to solve the problem. Liu et al. [23] studied a similar problem in which the weights of the first agent jobs are equal and the second agent objective function is the maximum of a regular function. They showed that this problem can be solved polynomially.

Mor and Mosheiov [24] considered the two-agent batch scheduling problem of minimizing the total flow time of the first agent and bounding the total flow time of the second one. In their study, it was assumed that the jobs have batch dependent setup times and that the batches of the second agent must be processed continuously. For this problem, they proposed an optimal polynomial algorithm in the case that there is not any assumption about integrality of the batch size.

Yin et al. [25] studied the constrained optimization problem of minimizing the first agent's total tardiness subject to an upper bound on the maximum lateness of the second agent. In this study, a release time was considered for each job. They proposed an integer programming model, a branch and bound algorithm, and a heuristic one to solve the problem. Yin et al. [26] investigated the problem of minimizing the total weighted earliness of all jobs by bounding the maximum earliness of a subset of jobs and developed a MILP model and a branch and bound algorithm.

In the study of Wu et al. [27], it was shown that the two-agent scheduling problem of minimizing the total completion time of the first agent subject to an upper bound on the same criterion for the second agent by considering a release time for each job is strongly NP-hard. To solve this problem, a branch and bound method, an ant colony algorithm, and four genetic algorithms were proposed in this study.

Thanks to the limitations of exact solution methods, meta-heuristic methods have nowadays found many applications in solving engineering problems, especially in manufacturing environments [28–35]. One of the most famous methods of meta-heuristic approaches is genetic algorithm which was proposed by Holland [36]. Though, various new algorithms have been presented