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Pseudo-polynomial dynamic programming for an integrated due date assignment, resource allocation, production, and distribution scheduling model in supply chain scheduling

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ABSTRACT

In this study, we consider an integrated due date assignment, production, and batch delivery scheduling problem with controllable processing times for multiple customers in a supply chain. The objective is to minimize the sum of the weighted number of tardy jobs as well as the due date assignment, resource allocation, and batch delivery costs. This model can also be applied when some parts of the jobs are outsourced. The problem is NP-hard. We propose a pseudo-polynomial dynamic programming algorithm to solve this problem, which shows that the problem is ordinary NP-hard. We performed computational tests to evaluate the proposed method.

1. Introduction

“Traditional scheduling models which only address the sequence of jobs to be processed at the production stage under some criteria are no longer suitable and should be extended to cope with the distribution stage after production. Emphasizing on the coordination and integration among various members of a supply chain has become one of the vital strategies for the modern manufacturers to gain competitive advantages” [1]. In this study, we focus on a supply chain scheduling model where four sets of decisions are considered simultaneously, i.e., due date assignment, resource allocation, production, and distribution scheduling. The decision about the due date assignment determines the revised due dates for each customer, the resource allocation decision determines the actual processing times for the jobs, the job scheduling decision determines the job sequences on the machines, and the distribution scheduling decision determines the batch deliveries. “The problems with due date determination have received considerable attention in the last three decades due to the introduction of new methods of inventory management such as just-in-time concepts” [2]. Thus, an increasing number of studies have considered the due date assignment as a part of the scheduling problem, where they showed that the determination of due dates can be a major factor in improving system performance. Therefore, decision makers may need an efficient method for quoting the due dates and job scheduling [3–6]. “In many real-life situations, customers place orders for several jobs each. Thus, they are inclined to request a single, or a common, due date for the whole order. These situations lead to common due date models, where there is a limited number of due dates, each associated with a group of jobs” [3,7]. Many studies have

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focused on the common due date assignment problem. For reviews of scheduling models that consider common due date assignment with practical applications, the reader may refer to [4,8,9].

Similar to due dates, the job processing times are considered to be fixed parameters in traditional scheduling. However, in today's more dynamic environments, a supplier may have several alternative ways of supplying and delivering products to customers. For example, suppliers may outsource part of the production to subcontractors if this allows them to quote an earlier delivery date. This type of outsourcing has been modeled by assuming that the jobs have controllable processing times such that the job processing times can be reduced by employing additional resources via outsourcing [10,11]. For recent reviews of resource allocation models, please refer to [10,12].

According to a survey by Thomas and Griffin, over 11% of the U.S. Gross National Product is spent on logistics and the logistics costs exceed 30% of the cost of goods sold for many products [13]. "Scheduling models which consider inbound production and outbound deliveries simultaneously can improve the overall operational performance of supply chains" [14]. Traditional scheduling problems do not consider delivery costs, thus addressing both the delivery costs and scheduling objective in an integrated manner is an important recent research area. "Problems addressing an objective function that combines machine scheduling with delivery costs are rather complex. However, they are more practical than those involving just one of the two factors, since these combined-optimization problems are often encountered when real-world supply chain management is considered. Yet, the body of literature on combined-optimization batch delivery problems is rather small" [15,16]. Chen reviewed these models [17].

In scheduling theory, one of the most important criteria for measuring the performance of schedules is related to due dates or deadlines. "Performance measures involving due dates model the informal criteria that are applied by practitioners. This makes these objective functions a very attractive and widely explored subject of research" [18]. In the current study, we address the minimization of the weighted number of tardy jobs with due date assignment, resource allocation, and capacity-constrained deliveries for multiple customers in a single machine environment, for which we propose a new dynamic programming (DP) algorithm. The most relevant research into the number of tardy jobs criterion, due date assignment, controllable processing time or/and distribution issues is discussed in the following.

Hall and Potts considered the problem of scheduling jobs on a single machine under the batch availability assumption with several objectives, including maximum lateness, number of late jobs, and sum of flow times [19]. One of the objectives that they addressed was minimizing the weighted number of tardy jobs plus the batch delivery costs. Slotnick and Sobel noted that the tardiness penalties may be as high as one million dollars per day for suppliers of aircraft components in the aerospace industry [20]. Steiner and Zhang addressed the minimization of the sum of the total weighted number of tardy jobs and delivery costs on a single machine based on the batch setup time for one customer, where they presented the optimal properties and a pseudo-polynomial time DP algorithm for obtaining the optimal solution [21]. Rasti-Barzoki et al. presented heuristic and branch-and-bound algorithms for solving this problem [7]. Steiner and Zhang also presented a pseudo-polynomial DP for a restricted multi-customer case, where tardy jobs are delivered separately at the end of the schedule, which they converted into a fully polynomial-time approximation scheme [22]. Mazdeh et al. considered the minimization of the sum of the total weighted number of tardy jobs and delivery costs for multiple customers on a single machine, but without considering the batch setup time, for which they presented a mixed integer nonlinear programming model and a meta-heuristic method based on simulated annealing [15]. In 2011, Steiner and Zhang presented a pseudo-polynomial algorithm for minimizing the sum of the common due date assignment costs, the weighted number of tardy jobs, and the batch delivery costs for a single customer [14]. Rasti-Barzoki and Hejazi proposed an integer programming method, a heuristic algorithm, and a branch-and-bound method for multiple customers in this problem [7]. In the present study, we simultaneously consider all of the aforementioned decisions in a scheduling model, i.e., the due date assignment, resource allocation, production, and outbound distribution scheduling.

The remainder of this paper is organized as follows. Section 2 provides the notation, problem definition, and structural properties. Section 3 describes the DP algorithm and the final section gives our conclusions as well as suggestions for future research.

2. Problem definition

The most important notations used throughout this study are defined as follows.

k	customer index
j	job index
h	resource index
$\mathcal{P}$	position index
J_{kj}	jth job of customer k
n	total number of jobs
K	total number of customers
n_k	Number of jobs for customer k
H	Number of processing (time) modes

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