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Single-machine batch delivery scheduling with job release dates, due windows and earliness, tardiness, holding and delivery costs

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ABSTRACT

This paper deals with a single-machine scheduling problem in which jobs are released in different points in time but delivered to customers in batches. A due window is associated with each job. The objective is to schedule the jobs, to form them into batches and to decide the delivery date of each batch so as to minimize the sum of earliness, tardiness, holding, and delivery costs. A mathematical model of the problem is presented, and a set of dominance properties is established. To solve this NP-hard problem efficiently, a solution method is then proposed by incorporating the dominance properties with an imperialist competitive algorithm. Unforced idleness and forming discontinuous batches are allowed in the proposed algorithm. Moreover, the delivery date of a batch may be decided to be later than the completion time of the last job in the batch. Finally, computational experiments are conducted to evaluate the proposed model and solution procedure, and results are discussed.

1. Introduction

Although single-machine scheduling problems have been broadly studied with different objective functions in past decades, most of these studies have been focused on the simple form of the problem and less attention has been paid to single-machine batch delivery scheduling problems. Batch delivery is a common characteristic of many real-life systems in which jobs are ultimately delivered to customers, leading to a decrease in the total delivery cost.

Batch delivery scheduling problems were first introduced by Cheng and Kahlbacher [1]. They have studied a single-machine batch delivery scheduling problem with the objective of minimizing the sum of the total weighted earliness and delivery costs, where the earliness of a job is defined as the difference between the delivery time of the batch it belongs and the job completion time. They have shown that the problem is NP-hard in the ordinary sense but polynomially solvable for equal weights. Hermann and Lee [2] have considered a single-machine scheduling problem where all the jobs have a given restrictive common due date and the objective is to minimize the sum of earliness and tardiness penalties and delivery costs of the tardy jobs; the authors have assumed that all early jobs are delivered in one batch at the due date without any cost, thus referring to holding costs as earliness penalties. They have shown that the problem is NP-hard, and proposed a pseudo-polynomial dynamic programming algorithm to solve it. Moreover, Cheng et al. [3] have studied single-machine scheduling with batch deliveries to minimize the sum of the batch delivery and earliness penalties, where the earliness of a job is defined as in [1]. They have formulated the problem as a classical parallel-machine scheduling problem; as a result, one can straightforwardly extend the complexity results as well as algorithms for the corresponding parallel-machine problem to this problem.

Wang and Cheng [4] have considered a parallel-machine batch delivery scheduling problem with the objective of minimizing the sum of flow times and delivery cost, where the delivery cost is a non-decreasing function of the number of deliveries, and shown that the problem is strongly NP-hard. They have developed a dynamic programming algorithm for the problem and two polynomial time algorithms for the special cases where the job assignment is predetermined or the job processing times are all identical. A similar problem with a single machine and unequal job weights has been investigated by Ji et al. [5]. They have shown that the problem of minimizing the sum of the total weighted flow time and delivery cost on a single machine is strongly NP-hard, and developed a dynamic programming algorithm for the problem and two polynomial time algorithms for the special cases where the jobs have a linear precedence constraint or the weights are agreeable with the processing times. Moreover, Mazdeh et al. [6] have developed a branch-and-bound algorithm for the same problem with the assumption that the delivery cost is a linear increasing function of the number of deliveries. For the special

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case in which the maximum number of batches is fixed, they have shown, through experiments carried out with problems up to 20 jobs, that their algorithm is superior to that of Ji et al. [5] in terms of efficiency.

Hall and Potts [7] have provided dynamic programming algorithms for a variety of scheduling, batching and delivery problems arising in a supply chain, where the objective is to minimize the overall scheduling and delivery cost, using several classical scheduling objectives. Single-machine scheduling with batch deliveries and job release dates has been investigated by Mazdeh et al. [8]. They have allowed forming both continuous and discontinuous batches, and proposed a branch-and-bound algorithm to minimize the sum of flow times and delivery costs under the assumptions that the release dates are agreeable with the processing times and the jobs for each customer are to be processed in the shortest processing time order. The authors have shown, through experiments carried out with problems up to 40 jobs, that their algorithm is more efficient than the dynamic programming algorithm of Hall and Potts [7] for solving the problem. Hamidinia et al. [9] have introduced a novel complex single-machine batch delivery scheduling problem with the objective of minimizing the sum of earliness, tardiness, holding, and delivery costs. They have presented a mathematical model of the problem, and proposed a genetic algorithm-based heuristic to solve it.

Furthermore, in the literature there are some references where batch delivery scheduling and due date assignment problems are considered. Shabtay [10] has studied single-machine scheduling with batch deliveries and earliness, tardiness, holding, batching and due date assignment costs, where the due dates are controllable. The author has proved that the problem is NP-hard, and presented a polynomial time algorithm for the special cases where the job processing times are all identical or the acceptable lead times are all equal to zero and the holding penalty is less than the tardiness or due date assignment penalty. Yin et al. [11] have studied a single-machine batch delivery scheduling and common due date assignment problem with the option of performing a rate-modifying activity on the machine. Considering the objective of minimizing the sum of earliness, tardiness, holding, due date and delivery costs, they have presented polynomial time algorithms for the special cases where the jobs have equal modifying rates, the processing times are all identical or the jobs and modifying rates are agreeable. Recently, Yin et al. [12] have studied single-machine scheduling with batch delivery and an assignable common due window, where the objective is to minimize the sum of earliness, tardiness, holding, window location, window size, and delivery costs. They have shown that the problem is polynomially solvable by a dynamic programming algorithm under a reasonable assumption on the relationships among the cost parameters.

Although a variety of batch delivery scheduling problems has been investigated in the above mentioned papers, the researchers have worked with two most common assumptions as follows: (1) the delivery date of a batch is equal to the completion time of the last job in the batch, and (2) there is no capacity limitation on the size of a batch and the delivery cost is a non-decreasing function of the number of batch deliveries.

This study provides an extension to that of Hamidinia et al. [9] by taking into consideration job release dates and due windows. The problem considered here is a single-machine scheduling problem where jobs are released in different points in time but delivered in batches to their respective customers or to other machines for further processing. Each job must be delivered within its due window; otherwise, a penalty is incurred. It is assumed that the delivery cost for a batch, which is different for each customer, is independent of the number of jobs in the batch. The objective is then to schedule the jobs, to form them into batches and to decide the delivery date of each batch so as to minimize the sum of earliness, tardiness, holding, and delivery costs. The major limitations of the work of Hamidinia et al. [9] concern the following implicit assumptions made: (1) continuous batch forming, and (2) non-delay scheduling. The first assumption states that the jobs forming a batch are processed continuously, that is, no job belonging to another customer is processed between them. The second assumption implies that the machine is not kept idle while a job is waiting for processing, that is, unforced idleness is prohibited. Moreover, Hamidinia et al. [9] have simply assumed that the delivery date of a batch equals to the completion time of the last job in the batch. In this paper, however, we show that, even when all jobs are released at time zero, it may be advantageous to form discontinuous batches, to have periods of unforced idleness, and to deliver a batch at a time later than the completion time of the last job in the batch. Furthermore, Hamidinia et al. [9] have proposed a mathematical model of their problem, which is clearly a special case of the problem considered here, and claimed that it cannot be solved by off-the-shelf optimizers even for small test problems. Although they have argued that this failure is due to the problem complexity, we show that the erroneous formulation is the main reason. In addition to presenting an appropriate mathematical model, we establish a set of dominance properties and propose a solution method by incorporating them with an imperialist competitive algorithm (ICA). The proposed solution procedure schedules the jobs, forms them into batches and decides the delivery date of each batch.

The rest of the paper is organized as follows. In the next section, the problem is described and formulated. Section 3 is devoted to the derivation of some dominance properties. In Section 4, the proposed solution method is described, followed by Section 5 providing computational results. Finally, Section 6 gives a summary as well as future work.

2. Problem formulation

2.1. Problem description

The problem considered in this paper is a single-machine scheduling problem in which jobs are ultimately delivered to customers in batches, leading to decrease in the total delivery cost. There are N jobs belonging to F customers that have to be processed by the machine; each customer j has n_j jobs and $N=\sum_j n_j$. The machine is continuously available and can process at most one job at any point of time. Preemption is not allowed, and there is no setup time. Associated with each job i belonging to customer j, which is denoted by job (i,j), is a release date r_{ij} at which it becomes available for processing on the machine, a processing time p_{ij}, and a due window $[d_{ij}^l, d_{ij}^u]$ where d_{ij}^l and d_{ij}^u are the earliest and latest due dates, respectively; the job is on-time and thus no penalty is incurred if delivered to the customer within the due window, while it will incur an earliness penalty if delivered before d_{ij}^l and a tardiness penalty if delivered after d_{ij}^u. Distinct due windows represent a generalization of distinct due dates and are relevant in many practical situations because of uncertainty and tolerance [13]. Moreover, associated with each job (i,j) is also a unit tardiness cost α_{ij}, a unit earliness cost β_{ij}, and a unit holding cost h_{ij}; the job will incur a holding penalty if not delivered to the customer at its completion time. The cost of delivering each batch to customer j is denoted by D_j. It is assumed that this cost is independent of the number of jobs in the batch and that there is no capacity limit on each batch delivery. Although this assumption may appear restrictive, it may be reasonable under the situations where all the jobs of each customer can be delivered by one truck at a shipment, and consequently, regardless of whether a truck is fully loaded or not, the delivery cost remains