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Optimizing the sum of maximum earliness and tardiness of the job shop scheduling problem

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ABSTRACT

The sum of the maximum earliness and tardiness criteria is a new objective function for the job shop scheduling problem introduced in this work. A mixed integer linear programming (MIP) formulation of the job shop scheduling problem with the new objective function is developed. We design a set of experiments where we validate the MIP model on different problem sizes.

This is one of the most difficult problems in combinatorial optimization, with even modest sized instances being computationally intractable. Getting inspiration from a number of advances in solving this notoriously difficult problem, we develop a new approximate optimization approach, which is based on the imperialist competitive algorithm hybridized with an efficient neighborhood search. The effectiveness of the proposed approach is demonstrated through an experimental evaluation.

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1. Introduction

Effective production is one of the most critical issues in today's competitive environment. Companies are under pressure to meet customer needs and requirements to maintain customer satisfaction. Production planning and scheduling have a great impact on increasing the efficiency of the plants. Scheduling is a decision making process that concerns the allocation of limited resources among competing tasks over time with the goal of optimizing one or more objectives (Pindeo, 2015). Proper scheduling leads to increased efficiency and capacity utilization, reduced time required to complete tasks, and consequently, increased profitability for the organization (Vinod & Sridharan, 2008).

Allahverdi, Ng, Cheng, and Kovalyov (2008) categorizes scheduling problems according to shop environments, including single-machine, parallel machines, flow shop, no-wait flow shop, flexible flow shop, job shop, open shop. Job shop scheduling is a branch of production scheduling, which is known as one of the most complex combinatorial optimization problems (Kundakcı & Kulak, 2016). The classical job shop scheduling problem consists of scheduling N jobs into M machines. The problem has several constraints. Each job has a number of operations that must be processed in a sequence, and once an operation is started, no preemption is allowed. Each machine can handle only one operation at a time and a job cannot be processed by two machines simultaneously. The aim of the job shop scheduling problem is to find a schedule to process all jobs in a manner that optimizes given performance objectives.

The job shop scheduling problem has been widely investigated in the last decades. The main focus has been on various optimization criteria, e.g. makespan (Lian, Jiao, & Gu, 2006), and the development of new optimization algorithms. Earliness and tardiness are another very applicable criteria in job shop environment that have been widely studied recently (Kuhpfahl & Bierwirth, 2016; Thiagarajan & Rajendran, 2005). Previous research has addressed this problem by minimizing the sum (or weighted sum) of earliness and tardiness of jobs. This formulation, however, does not work well in scenarios where certain jobs have large values of earliness or tardiness (Moslehi, Mirzaee, Vasei, Modarres, & Azaron, 2009).

For instance, consider the case where jobs are delivered in batches. The batch might suffer great delays when a single job of the batch is not finished in time, since all jobs have to finish before the batch is delivered. In addition, when other jobs of the batch are finished too early, the manufacturer has to plan storage while waiting for the other jobs of the batch to finish. Ideally, the difference between the maximum earliness and tardiness of jobs in a batch should be as small as possible.

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The sum of maximum earliness and tardiness criteria was first introduced for optimizing schedules of production systems that have large values of earliness and tardiness (Amin & Moslehi, 2000). The original study formulated the maximum earliness and tardiness criteria as a single machine scheduling problem (Amin & Moslehi, 2000). Our approach extends this work to consider the job shop scheduling environment with multiple machines. This clearly introduces more complexity into the problem, and requires appropriate optimization methods to deal with the high computational cost incurred.

The job shop scheduling problem is a notoriously difficult combinatorial optimization problem. Due to its practical importance, numerous exact procedures have been developed in the past decades, with the majority of the methods using branch and bound (Mahnam & Moslehi, 2009; Moslehi, Mahnam, Amin-Nayeri, & Azaron, 2010; Tavakkoli-Moghaddam, Moslehi, Vasei, & Azaron, 2006). However, these approaches become computationally intractable for large instances, and even fail to obtain optimal schedules within acceptable time limits for small instances.

To address this problem, we introduce new approximate optimization method, namely a hybrid imperialist competitive algorithm (HICA), which is based on the imperialist competitive algorithm introduced by Atashpaz-Gargari and Lucas (2007). We hybridise ICA with three neighborhood search operators which intensify the search around high-quality solutions. The neighborhood search procedure complements the global search that is part of ICA, ensuring the right balance between exploration and exploitation.

Here, we customize the original algorithm to solve the job shop scheduling problem, and introduce a new algorithm operator that deal with permutations in the discrete space. The new algorithm is compared against six state-of-the-art methods in job shop scheduling optimization.

In essence, the contribution of this paper is threefold: (i) we introduce a new objective function, namely the sum of maximum earliness and tardiness criteria for the job shop scheduling problem, and (ii) we propose a novel way to optimize this complex combinatorial problem.

2. Motivating example

In many real applications of the job shop scheduling problem, the maximum earliness and tardiness is the most important criteria. To illustrate this point, consider a small firm that produces a specific equipment with three equally important components shown in Fig. 1.

Table 1
The sequence of operations required for each component, processing times for each operation, and dues dates of each component.

Component	Machine sequence	Processing times	Due date
c_1	Drilling, grinding	1, 1	5
c_2	Milling, grinding	1, 1	2
c_3	Grinding, drilling, milling	2, 1, 1	6

Each component consists of a predetermined sequence of operations, each of which has to be processed for a given period of time on a given machine. Table 1 depicts the sequence of operations required for each component, processing times for each operation, and due dates of each component.

Two operations have to be performed to complete component j_1; they are drilling and grinding. Component j_2 has to be processed on the milling machine and grinding machine. Finally, component j_3 requires grinding, drilling and milling machines in the given sequence. To assemble the components and deliver the equipment on time, all components must be finished on the predefined dates. Delays in any of the components cause delays in the delivery of the final product, hence it is important that there is no tardiness. At the same time, if any of the components is completed early, it has to be stored in the warehouse, which creates space problems.

In previous work, this problem has been formulated as minimizing the total sum of tardiness and earliness of all jobs, which follows the just-in-time philosophy (Sung & Min, 2001). In modern production strategies, both tardiness and earliness are penalized. Jobs which are tardy incur a tardiness penalty such as customer discontent, loss of goodwill, contract penalties, and loss of sales, while jobs which are completed before their due dates have non-desirable effects such as inventory carrying costs, storage and insurance costs, the opportunity cost of the money invested in inventory, and product deterioration.

However, minimizing the sum of tardiness and earliness may fail to optimize storage utilization, as illustrated in the following example. Consider the two solutions shown in Fig. 2 of the problem described in Table 1. While the sum of earliness and tardiness for both sequences is the same, the sum of the maximum earliness and tardiness of the sequence on the right is better. This means that if the sequence on the right is implemented, the warehouse will be occupied for a shorter time. As a result, considering the sum of maximum earliness and tardiness as optimization criteria leads to better solutions in terms of warehouse usage.

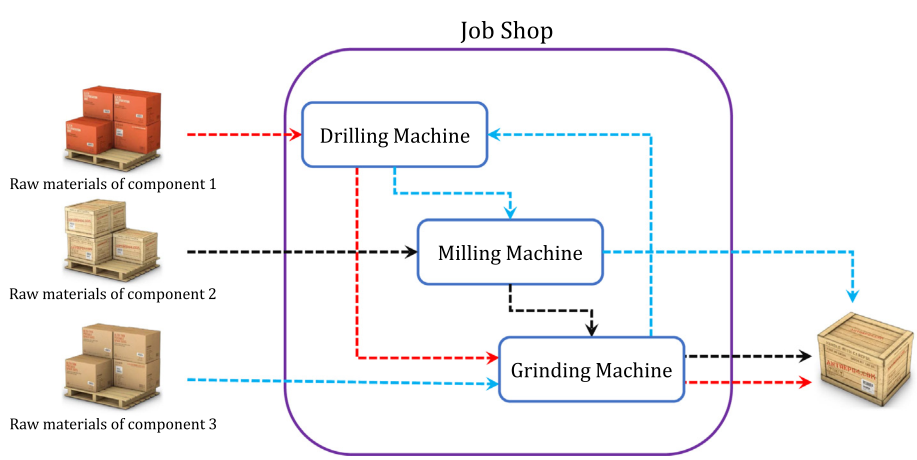

Fig. 1. An example of the job shop scheduling problem with three components (jobs).

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