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Minimizing total tardiness and earliness on unrelated parallel machines with controllable processing times

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ABSTRACT

Job scheduling has always been a challenging task in modern manufacturing and the most real life scheduling problems which involves multi-criteria and multi-machine environments. In this research our direction is largely motivated by the adoption of the Just-In-Time (JIT) philosophy in parallel machines system, where processing times of jobs are controllable. The goal of this paper is to minimize total weighted tardiness and earliness besides jobs compressing and expanding costs, depending on the amount of compression/expansion as well as maximum completion time called makespan simultaneously. Jobs due dates are distinct and no inserted idle time is allowed after starting machine processing. Also each machine is capable of processing only some predetermined jobs and operations with probably different speeds. A Mixed Integer Programming (MIP) model is proposed to formulate such a problem and is solved optimally in small size instances. A Parallel Net Benefit Compression-Net Benefit Expansion (PNBC–NBE) heuristic is then presented to acquire the optimal jobs set amount of compression and expansion processing times in a given sequence. To solve medium-to-large size cases, a proposed heuristic, two meta-heuristics and a hybrid technique are also employed. Experimental results demonstrate that our hybrid procedure is a proficient method and could efficiently solve such complicated problems.

1. Introduction

Most of research in the literature have treated tardiness and earliness as two criteria associated with completing a job at a time different from its given due date since both earliness and tardiness have affect on the system efficiency and must be taken into account. In other words, a major force of research in the scheduling field has been directed towards minimizing both tardiness and earliness penalties of scheduled jobs. Due to the extensive acceptance of Just-in-Time (JIT) philosophy in recent years, the due date requirements have been studied widely in scheduling problems, especially those with earliness–tardiness penalties. In fact, JIT philosophy seeks to identify and eliminate waste components as over production, waiting time, transportation, processing, inventory, movement and defective products [1]. Since earliness could represent manufacturer concerns and tardiness could embrace both customer and manufacturer concerns while none of them is desirable, we aim at minimizing weighted tardiness and earliness as well as makespan in parallel machines environment. A job in JIT scheduling environment that completes early must be held in finished goods inventory until its due date and may result in additional costs such as deterioration of perishable goods, while a tardy job which completes after its due date causes a tardiness penalty such as lost sales, backlogging cost, etc. So, an ideal schedule is one in which all jobs finish exactly on their assigned due dates [2]. Owing to their imposed additional costs to production systems, both earliness and tardiness must be minimized since neither of them is desirable. Baker and Scudder [3] presented the first survey on early/tardy (E/T) scheduling problems. Also this category of problems has been shown as NP-hard ones [4,5].

Machine scheduling problems fall into two main classes, single machine and multi-machine problems. Despite researches focused mostly on single machine E/T scheduling, since it is easier to solve, however parallel machine E/T scheduling problems are more practical in industrial production environments, such as mechanical industry, electronic industry and so on. The majority of earlier studies on parallel machine scheduling have dealt with performance criteria such as mean flowtime, mean tardiness, makespan and mean lateness. In accordance with increasing current trends towards JIT policy, traditional performance measures are no longer applicable. In its place, the emphasis has shifted towards E/T scheduling taking earliness in addition to tardiness into account [3]. Generally speaking,

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readers interested in earliness–tardiness scheduling are referred to a survey conducted by Baker and Scudder [3] and the recent book by T'kindt and Billout [6]. Also readers especially interested in earliness and tardiness scheduling with setup considerations are referred to the survey article by Allahverdi et al. [7].

On the other hand, from among different types of parallel machines, scheduling of unrelated ones is one of the most important and yet complicated issues in the multi-machine manufacturing environments. Meanwhile, in spite of large amount of researches on parallel machines, few of them have surveyed unrelated parallel ones or sequence-dependent setups. In general, such a problem consists of simultaneous job allocation and job sequencing to the machines with similar, but not necessarily identical capabilities. Also in multi-machine manufacturing systems, the unit-time value of different processors may quite vary because of the technology differences, energy or labor requirements, tool usage and failure rates. Therefore, the job-machine assignment is very important and may affect the total processing costs. Of papers which are published in this field, one may refer to Li and Yang [8], Kim et al. [9] and Logendran et al. [10].

The rest of the paper is organized as follows: Section 2 gives related literature. In Section 3 problem description and basic properties will be described. Section 4 explains our proposed PNBC–NBE heuristic in detail. In Section 5 evolutionary algorithms consist of two meta-heuristics and a hybrid one are described. Section 6 discusses computational studies. Finally, Section 7 includes conclusions and future researches.

2. Literature survey

Widely used performance measures in due date-related scheduling problems include maximum tardiness, total or mean tardiness, total weighted tardiness/earliness and the number of tardy jobs [11,12]. Morton and Pentico [13] and Liaw et al. [14] indicated due date-related problems for multi-machine environments are usually computationally complex and therefore most existing consequences are typically for small size problems or simple settings. Cheng and Sin [15] studied a comprehensive review on parallel machine scheduling problems with conventional performance measures based on due date, completion time, and flow time. Rocha et al. [16] studied unrelated parallel machines considering sequence and machine-dependent setup times, due dates and weighted jobs. Also, Bank and Werner [17] considered unrelated parallel machine regarding release date as well as common due date where each of n jobs has to be processed without interruption on exactly one of m unrelated parallel machines.

Earliness and tardiness criteria were studied simultaneously on parallel machines in several papers. Of them, Sivrikaya and Ulusoy [18] developed a genetic algorithm (GA) approach to tackle the scheduling problem relevant to a set of independent jobs on parallel machines with earliness and tardiness penalties. Biskup and Cheng [19] studied scheduling of identical parallel machines with minimizing earliness, tardiness and completion time penalties goals. Ventura and Kim [20] considered parallel machines scheduling problem where jobs have noncommon due dates and may require, besides machines, certain additional limited resources for their handling and processing with the goal of minimizing total absolute deviation of job completion times about the corresponding due dates. Kedad-Sidhoum et al. [21] addressed the parallel machine scheduling problem in which the jobs have distinct due dates with earliness and tardiness costs.

Toksari and Guner [22] considered a parallel machine E/T scheduling problem with common due date and different penalties under the effects of position based learning and linear and nonlinear deterioration. Lin et al. [23] compared the performance of various heuristics and one meta-heuristic for unrelated parallel machine scheduling problems with the goal of minimizing makespan, total weighted completion time, and total weighted tardiness. Hsu et al. [24] studied unrelated parallel machine scheduling problem with setup time and learning effects simultaneously, in which the setup time is proportional to the length of the already processed jobs (i.e., the setup time of each job is past-sequence-dependent) with the objective of minimizing the total completion time. They showed that there exists a polynomial time solution for the proposed problem. In similar research, Kuo et al. [25] studied unrelated parallel machine scheduling problem with setup time and learning effects simultaneously in which the setup time is proportional to the length of the already processed jobs. Their objectives were to minimize the total absolute deviation of job completion times and the total load on all machines, respectively. They also showed that the proposed problem is polynomially solvable. Mor and Mosheiov [26] showed that minimizing total absolute deviation of job completion times (TADC) remains polynomial when position-dependent processing times are assumed (i) on uniform and unrelated machines and (ii) for a bicriteria objective consisting of a linear combination of total job completion times and TADC. Bozorgirad and Logendran [27] addressed a sequence-dependent group scheduling problem on a set of unrelated-parallel machines where the run time of each job differs on different machines. To benefit both producers and customers they tried to minimize a linear combination of total weighted completion time and total weighted tardiness. Vallada and Ruiz [28] studied unrelated parallel machine scheduling problem with machine and job-sequence dependent setup times with the objective of minimizing the total weighted earliness and tardiness. The idle time is allowed in their research. M′Hallah and Al-Khamis [29] addressed minimum weighted earliness–tardiness parallel machine scheduling problem with distinct deterministic known due dates regarding allowable machine idle time. They provided the exact solution for small or relatively easy instances.

In the face of real-life situation most classical scheduling models assume that job processing times are fixed, while the processing times depending on the amount of resources such as budgets, facilities capabilities, manpower. The controllable processing time means each job could process in a shorter or longer time depends on its efficacy on objective function by reducing or increasing the available resources such as equipment, energy, financial budget, subcontracting, overtime, fuel or human resources. When the processing times of jobs are controllable, selected processing times affect both the manufacturing cost and the scheduling performance. As an applicable case for such assumption, in chemical industry, the processing time of a job is increased by an inhibitor or reduced using catalyzer. An inhibitor is any agent that interferes with the activity of an enzyme. Actually, enzyme inhibitors are molecules that bind to enzymes and decrease their activity. More applications of such a substance could be found in Wang et al. [30] and Sørensen et al. [31]. CNC machines are other high usage examples in which job processing times could be controlled by setting the cutting speed and/or the feed rate on the machines.

There is a remarkable relation between E/T scheduling problems and controllable processing times concept, since by controlling the process time of jobs, earliness and tardiness could be decreased and consequently the scheduling environment gets closer to JIT philosophy. Almost certainly, Vickson [32] has studied one of the first researches on controllable processing time scheduling problems, with the objective of minimizing the total flow time and the total processing cost incurred due to job processing time compression. Researches on scheduling problem with controllable processing times and linear cost functions up to 1990 are surveyed by Nowicki and Zdrzalka [33]. Also Shabtay and Steiner [34] have conducted a complete survey on scheduling with controllable processing times.