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Resource-constrained unrelated parallel machine scheduling problem with sequence dependent setup times, precedence constraints and machine eligibility restrictions

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ABSTRACT

This study addresses an unrelated parallel machine scheduling problem with resource constrains, sequence-dependent setup times, different release dates, machine eligibility and precedence constraints. This problem has been inspired from the block erection scheduling problem in a shipyard. Majority of the traditional scheduling problems in parallel machine environment deal with machine as the only resource. However, other resources such as labors, tools, jigs, fixtures, pallets, dies and industrial robots are not only required for processing jobs but also are often restricted. To formulate this complicated problem, a new pure integer mathematical modeling is proposed and makespan is employed as the objective function. Since the problem is strongly NP-hard, exact approaches are intractable for large size problems. Thus, two new meta-heuristic algorithms including genetic algorithm (GA) and artificial immune system (AIS) are developed to find optimal or near optimal solutions. In addition, the parameters of these algorithms are calibrated by using Taguchi method. The performances of the proposed meta-heuristics are evaluated by a number of numerical examples. The computational results demonstrated that in small scale problems both algorithms are effective and efficient, but in large scale problems the suggested AIS statistically outperformed the proposed GA.

1. Introduction

The scheduling problem is an important issue that has a great influence on increasing the productivity of manufacturing and service systems and it concerns to simply assign a set of limited resources to a set of jobs with respect to operational constraints such that the optimal usage of available resources is obtained. The classical deterministic parallel machine scheduling problem can be defined as follows: there are a number of independent jobs to be processed on a range of identical machines. Each job has to be carried out on one of the machines during a fixed processing time, without preemption. So, the aim is to achieve the schedule that optimizes certain performance measure (Mokotoff, 2004). The parallel machine scheduling problem (PMSP) can be classified into three main categories: identical machines (Pm), in which the processing times are the same across all machines, uniform machines (Qm), where machines have different speeds but each machine works at a consistent rate, unrelated machines (Rm) when machines can work at different rates and when a given machine can process different jobs at different rates (Lin, Pfund, & Fowler, 2011).

In the past years many researchers has been investigated parallel machine scheduling problem by considering various operational constraints. However, the first study on parallel machine scheduling problem has been conducted by McNaughton (1959) in the late fifties. Other researchers such as Horowitz and Sahni (1976), Cheng and Sin (1990) and Glass, Potts, and Shade (1994) are also pioneer in considering parallel machine scheduling problem. Later Ghirardi and Potts (2005) considered unrelated parallel machine scheduling problem to minimize the makespan. They developed a Recovering Beam Search algorithm for the given problem that requires polynomial time. Lin et al. (2011) compared the performance of various heuristics with a genetic algorithm (GA) for unrelated parallel machine scheduling problems by considering three objective functions including makespan, total weighted completion time and total weighted tardiness, separately. Rodriguez, Lozano, Blum, and García-Martínez (2013) proposed an iterated greedy (IG)

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algorithm for the large-scale unrelated parallel machine scheduling problem. They believed that their proposed IG had better performance in comparison to existing meta-heuristics. Yilmaz Eroglu, Ozmutlu, and Ozmutlu (2014) proposed a GA with local search for the unrelated parallel machine scheduling problem with sequence dependent setup times for minimizing the maximum completion time.

Parallel machine scheduling problem has been one of the topics of interest for many researchers in the past few decades. Although there is a rich literature on this field, but most of these studies considered the machine as only resource which is restricted. However, in real life manufacturing systems other resources such as machine operators, tools and equipment are constrained and it is irrational to consider that there are always enough resources for processing a job. It is clear, the resource-constrained parallel machine scheduling problem (RCPMSP) is more difficult than the simple PMSP. In RCPMSP, an operation can be processed while the required machine and other resources are available during the process of operation. In these problems, besides the schedule of jobs on machines, the schedule of jobs on other resources and their interactions should be considered.

There are only few papers that have considered the additional resource constraints in their scheduling problems. Ventura and Kim (2000) addressed identical PMSP with additional resource constraints and developed an integer programming model to minimize the total absolute deviation of job completion times about common due date. They claimed this problem can be found in the burn-in operation in the final testing stage of semiconductor manufacturing and proved that the problem can be solved in polynomial time when there exists one single type of additional resource and the resource requirements per job are zero or one. Later Ventura and Kim (2003) considered an identical PMSP with unit processing times, non-common due dates and additional resource constraints. They developed an integer programming model and used lagrangian relaxation approach to obtain tight lower bounds and near-optimal solutions. Chen (2005) proposed a heuristic method to minimize makespan in an unrelated PMSP with different die types as a secondary resource constraint. The author supposed that, a setup that includes detaching one die and attaching another from the fitted die type is incurred if the type of job scheduled is different from the last job on that machine. Later Chen and Wu (2006) considered the same problem in order to minimize total tardiness. An effective heuristic based on threshold-accepting methods, tabu lists and improvement procedures have been developed. Huang, Cai, and Zhang (2010) investigated a scheduling problem on parallel dedicated machines in which the setup times are sequence-dependent and the setup operations are performed by a single server. They proposed an integer programming model, some lower bounds and a hybrid GA to solve the considered problem. Edis and Ozkarahan (2011) investigated the resource-constrained identical PMSP with machine eligibility restrictions. For the considered problem, three optimization models; an integer programming (IP) model, a constraint programming (CP) model and a combined IP/CP model have been developed. A mixed integer programming model and a hybrid GA have been proposed by Costa, Cappadonna, and Fichera (2013), for unrelated PMSP with sequence-dependent setup times and limited human resources. They assumed that the setup operations are performed by the workers with different skill levels. One of the latest investigations on parallel machine scheduling problem with additional resource constraints has been proposed by Torabi, Sahebjamnia, Mansouri, and Aramon Bajestani (2013). They addressed unrelated PMSP with non-zero ready times, sequence dependent setup times and the auxiliary resource constraints in a fuzzy environment in order to simultaneously minimize three objective functions including total weighted flow time, total weighted tardiness and machine load variation. They proposed a multi objective practical swarm optimization to tackle this problem. However they supposed that there is only one stock for each secondary resource and this simplification reduces the complexity of resource constrained unrelated parallel machine scheduling problem. In reality a job may need more than one unit of each secondary resource during its process. A comprehensive survey on parallel machine scheduling problem with additional resources has been presented by Edis, Oguz, and Ozkarahan (2013).

The parallel machine scheduling problem literature is vast. However, the literature on PMSP with precedence constraints is quite limited. Hurink and Knust (2001) considered identical PMSP with precedence constraints and sequence dependent setup times. They dealt with the question whether it is possible to design an efficient list scheduling algorithm to minimize makespan for this problem. Tavakkoli-Moghaddam, Taheri, Bazzazi, Izadi, and Sassani (2009) presented a two-level mixed-integer programming model and a GA for bi-objective unrelated PMSP with release dates, precedence constraints and sequence dependent setup times to minimize the number of tardy jobs and sum of the completion times. Gacias, Artigues, and Lopez (2010) proposed an exact branch-and-bound procedure and a climbing discrepancy search heuristic for the identical PMSP with precedence constraints and sequence dependent setup times while minimizing sum of completion times and maximum lateness. Driessel and Monch (2011) addressed identical PMSP to minimize total weighted tardiness with release dates, precedence constraints and sequence dependent setup times. They suggested several variants of variable neighborhood search schemes for solving the considered problem. A hybrid intelligent solution system based on using GA and simulated annealing (SA) has been proposed by Çakar, Köker, and Sari (2012) to minimize mean tardiness in parallel robots scheduling problem with unequal release dates and precedence constraints.

On the other hand, jobs may often not be processed on any of the available machines but rather must be processed on a machine belonging to a specific subset of the machines (Pinedo, 1995). This constraint which is called under different names, such as machine eligibility restrictions, processing set restrictions and scheduling typed task systems is also widely encountered in real scheduling environments. Practical applications of machine eligibility restrictions are found in both manufacturing and service systems such as in steel making industry (Yang, 2000), in semiconductor manufacturing (Wang, Wang, & Chen, 2013), in automobile gear manufacturing process (Gokhale & Mathirajan, 2012), in the management of hospital operating rooms (Vairaktarakis & Cai, 2003).

There are some works done related to unrelated or identical parallel machine scheduling problem with machine eligibility restrictions and other operational constraints. Centeno and Armacost (1997) investigated the identical PMSP with release dates and machine eligibility restrictions to minimize the maximum lateness. They developed a heuristic algorithm that resulted from combining the least flexible job first rule (LFJ) and the least flexible machine first rule (LFM). Later Centeno and Armacost (2004) developed a heuristic algorithm that integrated LFJ, LFM and the longest processing time (LPT) for the above problem to minimize makespan. Sheen, Liao, and Lin (2008) developed a branch and bound approach which applying several immediate selection rules for solving the identical PMSP with machine availability and eligibility constraints while minimizing the maximum lateness. Gao (2010) presented a novel artificial immune system for solving bi-objective unrelated PMSP with machine eligibility restrictions. The objectives are minimizing the