Engineering Applications of Artificial Intelligence 23 (2010) 765–771

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

A meta-heuristic approach to solve a JIT scheduling problem in hybrid flow shop

Safa Khalouli *, Fatima Ghedjati, Abdelaziz Hamzaoui

CReSTIC-URCA, UFR Sciences Exactes et Naturelles Moulin de la Housse, BP 1039, 51687 Reims cedex 2, France

ARTICLE INFO

Article history:
Received 15 May 2009
Received in revised form
5 November 2009
Accepted 16 January 2010
Available online 9 February 2010

Keywords:
Hybrid flow shop
Earliness
Tardiness
Scheduling
Ant colony optimization
Meta-heuristic

ABSTRACT

In this paper we address a hybrid flow shop scheduling problem considering the minimization of the sum of the total earliness and tardiness penalties. This problem is proven to be NP-hard, and consequently the development of heuristic and meta-heuristic approaches to solve it is well justified. So, we propose an ant colony optimization method to deal with this problem. Our proposed method has several features, including some heuristics that specifically take into account both earliness and tardiness penalties to compute the heuristic information values. The performance of our algorithm is tested by numerical experiments on a large number of randomly generated problems. A comparison with solutions performance obtained by some constructive heuristics is presented. The results show that the proposed approach performs well for this problem.

1. Introduction

The hybrid flow shop (HFS), also called multiprocessor or flow shop with parallel machines, consists of a set of two or more processing stages (or centers) with at least one stage having two or more parallel machines. The hybrid characteristic of a flow shop is ubiquitously found in various industries. The duplication of the number of machines in some stages can introduce additional flexibility, increase the overall capacities, and avoid bottlenecks if some operations are too long. So, scheduling in HFS has a great importance from both theoretical and practical points of view. Most scheduling problems are very difficult to solve (Blazewicz et al., 1996; Graham et al., 1979). That is why; the majority of the problems addressed in scheduling are only evaluated by a single criterion (such as makespan, total tardiness, workloads of machines, etc.) (T'kindt and Billaut, 2005). However, in the literature, many researches in scheduling show that the majority of industrial problems involve generally simultaneous incommensurable criteria, which they can sometimes be contradictory (Zitzler and Thiele, 1999). So, in this paper, we address a bi-criteria HFS scheduling problem which is the earliness–tardiness (ET) penalties (Hoogeveen, 2005). The ET problem encompasses a category of problem with the objective to complete each job as close to its due date possible. It represents a nonregular optimization criterion based on due dates (Gupta et al., 2002). The considered objective represents just in time (JIT) production concept (Portmann and Mouloua, 2007). In fact, in a JIT environment, minimizing earliness would reduce inventory costs and/or deterioration of product while minimizing tardiness would reduce a late cost or the loss of customers. In this scenario both early and tardy completion of jobs is disadvantageous to manufacturers and customers.

This bi-criteria scheduling problem is NP-hard since the simpler mono-criterion HFS problem, made up of two stages and having at least two machines available in one of the stages, with makespan criterion is already NP-hard (Gupta, 1988). In addition, earliness/tardiness criteria, with distinct due dates, usually induce NP-hard problems (Hendel and Sourd, 2007). Then, it is unlikely to find an optimal solution without the use of an essentially enumerative algorithm and the computational time increases exponentially with problem size (Babayan and He, 2004). Therefore, the development of heuristics and meta-heuristics that can give good (or eventually optimal) solutions is well justified. So, this study considered the application of an ant colony optimization (ACO) meta-heuristic to HFS scheduling problem with minimization of the ET penalties. Indeed, ACO has been successfully used in solving several single criterion scheduling problems (see for example Alaykýran et al., 2007; Khalouli et al., 2008a). Likewise, some studies have recognized that the ACO approaches are suitable to solve multi-criteria scheduling problems such as in Gravel et al. (2002), Khalouli et al. (2008b), and Yagmahan and Yenisey (2008).

* Corresponding author. Tel.: +33 3 25 42 71 78; fax: +33 3 25 42 01 98.
E-mail addresses: safa.khalouli@univ-reims.fr, safa_khallouli@yahoo.fr (S. Khalouli), fatima.ghedjati@univ-reims.fr (F. Ghedjati), abdelaziz.hamzaoui@univ-reims.fr (A. Hamzaoui).

0952-1976/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engappai.2010.01.008

The remainder of this paper is organized as follows. First, literature review section provides an overview related to the ET problems and the application of ACO method on scheduling. Section 3 is dedicated to the description of the HFS problem. Section 4 presents some constructive heuristics based on some priority rules for solving the considered problem. In Section 5, we describe the approach to solve the HFS problem with ET penalties. In order to show the efficiency of the suggested methodology, computational results are provided in Section 6. Finally, Section 7 concludes the paper.

2. Literature review

Next, literature on solution methods developed for the earliness/tardiness scheduling problems and ant colony optimization applications on scheduling are summarized.

2.1. Earliness/tardiness scheduling problems

For solving scheduling problems, various intelligent heuristics and meta-heuristics have become popular such as simulated annealing (SA), tabu search (TS), multi-agent system (MAS), genetic algorithm (GA) and ACO. Most of the works that tackle ET problem deal with single machine (Merkle and Middendorf, 2005; M'Hallah, 2007; Valente and Alves, 2007). Likewise, many results exist for parallel machines earliness/tardiness scheduling problem, especially when all jobs have the same due date (Balakrishnan et al., 1999; Ventura and Kim, 2003). However, relatively little researches have considered the ET costs in the objective function on flow shop or job shop environments. So, Rajendran and Alicke (2007) developed some dispatching rules to solve the flow shop ET problem with bottleneck machines. In Valencia and Rabadi (2003), the authors proposed a MAS approach to solve the job shop ET problem with common due date. In Huang and Yang (2007) an ACO algorithm is presented for the job shop ET problem. To deal with the flexible job shop ET problem, a MAS scheduling method is proposed in Wu and Weng (2005). To our knowledge, there is a limited literature focused on the ET criteria for solving the HFS scheduling problem. In Janiak et al. (2007) three meta-heuristic approaches based on SA, TS and a hybrid SA/TS have been used to solve the HFS problem which minimizes the cost criterion consisting of the total weighted earliness, the total weighted tardiness and the total weighted waiting time. Some existing heuristic solution approaches for the classical permutation flow shop problem have been generalized for the HFS problem with controllable jobs and assignable due dates with the sum of earliness and tardiness penalties, the weighted completion time of jobs and the costs of due date assignments (Gupta et al., 2002). A particular HFS problem with minimization of the ET performance measure is proposed by Finke et al. (2007) which is known as flow shop with machine tiers (FMT). In this problem, the solution is restricted to permutation schedules as the machine assignment for every job are deterministic and known in advance. To deal with the FMT-ET problem, the authors proposed a TS procedure.

2.2. Ant colony optimization applications

The ACO approaches imitate the behavior of real ants when searching for food. Some observations have shown that: although an ant has limited capacities, it can with the collaboration of the other ants find the shortest path from a food source to their nest without visual cue. To perform complex tasks, a colony of ants uses a chemical substance called "pheromone", which they secrete as they move along. The pheromone provides ants with the ability to communicate with each other. Being very sensitive to this substance, an ant chooses in a randomly way the path comprising a strong concentration of this substance. Thus, when several ants cross the same space, an emergence of the shortest path is obtained. The ACO algorithms use system formed by several artificial ants. These latter not only simulate the behavior of real ants described above, but also (i) apply additional problem-specific heuristic information, (ii) can manage the deposited quantity of pheromone according to the quality of the solution; moreover it is possible to have various types of pheromone, and (iii) has a memory which is used to store the search history. Each ant uses the collective experience to find a solution to the problem. The first ACO algorithm is called ant system (AS) (Colorni et al., 1992). It has been used to solve the traveling salesman problem (TSP). Then, AS was improved and extended. The improved versions include the ant colony system (ACS) (Dorigo and Gambardella, 1997), the Max–Min ant system (MMAS) (Stützle and Hoos, 1997), etc. The ACO algorithms have been also successfully used for solving a range of combinatorial optimization problems: the vehicle routing problem, the quadratic assignment problem, etc. Likewise, they have been applied to miscellaneous scheduling problems such as, single machine (Den Besten et al., 2000; Gagné et al., 2002), parallel machines (Sankar et al., 2005; Srinivasa Raghavan and Venkataramana, 2009), flow shop (Gajpal et al., 2006; Stützle, 1998; Ying and Liao, 2004; Ying and Lin, 2007), job shop (Colorni and Dorigo, 1994; Zhang et al., 2006), open shop (Blum, 2005), the general shop scheduling or group shop scheduling (including the job shop and the open shop) (Blum and Sampels, 2002, 2004), the hybrid flow shop(Alaykýran et al., 2007; Khalouli et al., 2008a, 2008b), and the hybrid job shop (Nait Tahar et al., 2005).

3. Problem formulation

The manufacturing environment of the HFS is considered as an extension of the classical flow shop. In fact, it presents a multistage production process with the property that a set of n jobs needs to be processed at all the stages in the same order, starting at stage 1 until finishing in stage S. Each stage i consists of a given number m_i ($m_i \geq 1$) of identical parallel machines available from time zero, and denoted $M_i = (M_{i1}, M_{i2}, \ldots, M_{im_i})$. So each job j needs several operations (O_{1j}, O_{2j}, …, O_{Sj}), where O_{ij} has to be processed by one machine out of a set of given machines at the i th stage during an uninterrupted p_{ij} time units (the preemption is not allowed) and can start only after the completion of the $(i-1)$ previous operations. The starting time and the completion time of an operation are denoted t_{ij} and C_{ij}, respectively. In this paper we assume that:

- setting up times of machines and move times between operations are negligible;
- machines are independent from each other;
- jobs are independent from each other;
- at a given time, a machine can only execute one operation.

Solving HFS scheduling problem consists of assigning operations to machines on each stage (routing problem) and sequencing the operations assigned to the same machine. The objective is to organize the execution of the n jobs on the machines in order to minimize an objective function. Defining C_j as the completion time and d_j as the due date of job j, we propose to develop schedules for the HFS problem that complete each customer order (which can be represented by a job j) at or near its due date dj. In this scenario, both the early and tardy completion of jobs would