Engineering Applications of Artificial Intelligence 63 (2017) 98–107

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

The two stage assembly flow-shop scheduling problem with batching and delivery

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ARTICLE INFO

Article history:
Received 8 May 2016
Received in revised form
10 March 2017
Accepted 9 May 2017

Keywords:
Two-stage assembly flow shop
Batched delivery system
Mathematical model
Imperialist competitive algorithm
Hybrid algorithm

ABSTRACT

This paper investigates the two-stage assembly flow shop scheduling problem with a batched delivery system where there are m independent machines at the first stage doing the components of a job and multiple identical assembly machines at the second stage, each of which can assemble the components and complete the job. The objective is to schedule the jobs, to form them into batches so as to minimize the sum of tardiness plus delivery costs. To the best of our knowledge, the assembly flow shop scheduling problem with this objective function has not been addressed so far. A mathematical model for this problem is presented. However, due to the fact that this model happens to be a mixed integer nonlinear programming model and cannot guarantee to reach the solution at reasonable time we developed the imperialist competitive algorithm (ICA) and a hybrid algorithm (HICA) by incorporating the dominance relations. Computational results show that HICA performs better than ICA with respect to the value of the objective function, However the runtime of the ICA is less than HICA.

1. Introduction

Nowadays, with moving industries toward just-in-time manufacturing and emersion of global markets, manufacturing companies are more and more being dragged into a competition in which cutting cost and reducing production span are vital traits of dominant firms. Hence the integrated scheduling of production and distribution is too important for manufacturing companies, However the benefits and challenges of coordinated decision making within supply chain scheduling including batching and delivery have not been studied widely especially on multi-machine scheduling problems.

The two-stage assembly flow shop problem (TAFP) has many applications in industry. Potts et al. (1995) illustrated an application of TAFP in personal computer manufacturing and Navaei et al. (2013) presented a real life example and described an application in bedroom furniture manufacturing. Moreover, the problem has application in some other areas such as in database distribution (Allahverdi and Al-Anzi, 2006) and label sticker manufacturing system (Lin and Liao, 2003).

The first study in assembly-type flow shop scheduling problem was accomplished independently by Lee et al. (1993) and Potts et al. (1995) with respect to makespan minimization. Lee et al. (1993) considered the TAFP with two machine at the first stage processing components of jobs and one assembly machine at the second stage that assembles the two parts into a product. Potts et al. (1995) generalized the problem to the situation where there are m machines at the first stage and like Lee et al. (1993) proved that the investigated problem is NP-hard in order to minimize makespan. Hariri and Potts (1997) considered the same problem and provided several dominance relations and used them to develop a branch and bound algorithm. With the computational experience, they demonstrated the superiority of their branch and bound algorithm over that of Lee et al. (1993). Another branch and bound algorithm for TAFP was proposed by Tozkapan et al. (2003) in order to minimize the total weighted flowtime.

Sung and Kim (2008) extended the problem of Lee et al. (1993) to the case of existing two identical and independent parallel assembly machines at second stage with respect to minimize sum of completion times. They proposed the lower bound based on the SPT rule and used it to develop a branch and bound algorithm for the problem. Sung and Juhn (2009) considered the TAFP in the case of outsourcing one of the two components at the first stage subject to job-dependent lead time. For the mentioned problem, they provided three heuristics and a branch and bound algorithm by implementing dominance properties. Fattahi et al. (2014) considered the assembly-hybrid flow shop with two fabrication stages and an assembly stage. Fabrication stages consist of parallel machines which process the components of a product and then components are assembled into the product on the assembly stage. They proved that the mentioned problem with the objective function of makespan is strongly NP-hard, so in order to solve it, a hierarchical branch and bound algorithm was presented.

Heuristics and metaheuristics have also been widely used as the

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http://dx.doi.org/10.1016/j.engappai.2017.05.004
0952-1976/

solving procedure in TAFP literature. For the first time, Allahverdi and Al-Anzi (2006) aimed to minimize maximum lateness in TAFP and developed three heuristics: particle swarm optimization (PSO), Tabu search, and earliest due date (EDD). Minimizing bicriteria of makespan and mean completion time is an Another objective function considered by Allahverdi and Al-Anzi (2008). They proposed three heuristics for the mentioned problem: simulated annealing (SA), ant colony optimization (ACO), and self-adaptive differential evolution (SDE) which SA was shown to be the best. Torabzadeh and Zandieh (2010) took the same objective function and introduced the cloud theory-based simulated annealing algorithm (CSA) which was indicated to perform better than the SA proposed by Allahverdi and Al-Anzi (2008) formerly. Mirsanei et al. (2010) developed a novel simulated annealing (NSA) for minimizing makespan in two-stage hybrid flow shop where each stage consists of multiple identical parallel machines. Solano-Charris et al. (2009) studied the same problem and chose the objective of minimizing both makespan and total completion time and proposed an ant colony optimization method. Navaei et al. (2014) for the first time, chose the objective function of minimizing sum of holding and delay costs in the assembly flow-shop with non-identical assembly machines and sequence dependent setup times. They developed four hybrid meta-heuristics based simulated annealing (SA) and the imperialist competitive algorithm (ICA). Allahverdi and Aydilek (2015) aimed to minimize total tardiness in TAFP and presented eleven algorithms and extensive computational experiments.

Scheduling problem with the extension of batching and delivery are important when the jobs are to be delivered to different customers or transferred to other machines or factories in batches leading to decrease in the total delivery cost. This class of problems occurs within the framework of supply chain management. In these situations, products could be delivered immediately after the end of their processing time to prevent tardiness which may lead to customer dissatisfaction. On the other hand, for cutting delivery costs, it may be advantageous to dispatch some products in a batch although this can increase the job tardiness.

Batching and delivery in supply chain scheduling has been addressed on single machine problems mostly. Herrmann and Lee (1993) considered the single machine scheduling problem with common restrictive due date and took the objective of minimizing sum of earliness and tardiness penalties and delivery costs of the tardy jobs. Chen (1996) studied the same problem where the common due date is a decision variable. Cheng et al. (1996) investigated a problem that arises when the objective is to minimize the sum of a function of the number of batches and job earliness penalties. A relation between this problem and parallel machine scheduling is established, which in turn makes it possible to reach complexity results and algorithms. Yin et al. (2012) extend the problem studied by Chen (1996) to the cases where holding cost is included in the objective function and an additional rate-modifying activity is allowed. Yin et al. (2013) also extend the problem of Chen (1996) by considering controllable processing times, which vary as a convex function of the amounts of a continuously divisible common resource allocated to individual jobs.

Hall and Potts (2003) have provided dynamic programming solutions for a range of scheduling problems that arise in an arbore scent supply chain. They aimed to minimize the overall scheduling and delivery cost by using several classical scheduling objectives. Mazdeh et al. (2007) considered one of the problem introduced by Hall and Potts (2003) that was batching and sequencing on a single machine under the batch availability assumption, in order to minimize the sum of flow times plus delivery costs. They developed a branch-and-bound solution scheme for the mentioned problem. Hamidinia et al. (2012) took the objective of minimizing total tardiness, earliness, holding and delivery costs on a single machine. They used different solving methods including mathematical modeling and genetic algorithm to obtain the solutions. Ahmadizar and Farhadi (2015) extended the problem of Hamidinia et al. (2012) by considering job release dates and due windows. Mazdeh et al. (2013) investigated single-machine batch scheduling problem with the objective of minimizing maximum tardiness and delivery costs which was proven to be NP-hard by Pundoor and Chen (2005). They provided a mixed integer nonlinear programming model and a branch and bound solution method. Rostami et al. (2015) studied the same problem with job release time but proposed a linear programming model capable of achieving the global optimum solution. Moreover they developed a branch and bound algorithm based on the LP relaxation of the MIP model.

There are also a few research addressing batching and delivery on multi-machine scheduling problems. Wang and Cheng (2000) studied Parallel machine scheduling with batching and delivery to minimize sum of the total flow time and delivery cost and indicated the problem is NP-hard in ordinary sense and proposed a dynamic programming algorithm to solve it. Soukhal et al. (2005) discussed two-machine flow shop where the jobs are dispatched to the customers by truck. They prove that this problem is strongly NP-hard in order to minimize the makespan when the capacity of a truck is limited to two or three parts with an unlimited buffer at the output of each machine. Finally Mazdeh and Rostami (2014) provided a mixed integer linear programming model and a branch and bound algorithm for two-machine flow-shop scheduling problem to minimize maximum tardiness and delivery costs.

As we mentioned before, multi-machine scheduling problems including batching and delivery systems are not studied widely in literature. Hence this paper investigates the two stage assembly scheduling problem within a batch delivery system with respect to minimize total tardiness plus delivery costs. To the best of our knowledge, this topic has not been studied so far.

2. Problem statement

There are N different jobs which belong to H customers. The total number of jobs belonging to customer j is shown by n_j so we have $\sum_{j=1}^{H} n_j = N$. Any job includes M individual components. Moreover, there are M independent machines in the first stage of production process such that each one performs various parts of a job independently. When the operation of all components ends, the job is assigned to one of Q assembly machines depending on which one of free. After assembly operation, it is required to decide on batching and sending of jobs. Any job could be sent immediately after completion time or wait for completion time of other jobs of that costumer; thus, the maximum number of batches for any customer equals to the number of his jobs. The batches are sent after completion; thus, the sending time of each batch is considered equal to the completion time of the last job of that batch. The delivery cost of any batch is independent of the size of batch. The objective is to minimize total tardiness plus delivery cost of jobs. Since two sentences of objective function are not of the same type, it is assumed that the jobs' total tardiness could be converted to cost by consideration of (∂) as the tardiness unit cost. Thus, the objective function will be in form of Eq. (1). In the real world examples related to this area, when tardiness occurs in delivery of orders to the customer, the tardiness unit penalty is imposed on producer which is here considered as (∂).

Waiting for completion of other orders of a customer and putting the orders in one batch could lead to increased tardiness of some orders and on the other hand decrease of delivery costs. In fact, this study seeks to trade-off between the tardiness and delivery costs in supply chain.

Bank et al. (2012) showed that two-machine flow shop problem with the objective function of total tardiness without consideration of deterioration is NP-Hard. Since two-stage flow shop is the extension of