Computers & Industrial Engineering 78 (2014) 135–147

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

A hybrid tabu search for batching and sequencing decisions in a single machine environment ☆

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ARTICLE INFO

Article history:
Received 29 August 2013
Received in revised form 28 August 2014
Accepted 7 October 2014
Available online 23 October 2014

Keywords:
Batching
Incompatible job families
Family dependent setup time
Hybrid tabu search
Heuristics

ABSTRACT

This paper proposes a hybrid tabu search (HTS) to minimise the total weighted tardiness (TWT) for the batching and sequencing of jobs originating from incompatible families in which sequence dependent family setup times exist on single machine. The developed HTS includes distinguished features such as the strict arc based tabu classification along with dynamic tabu tenures, hybrid neighbourhood structures and iterative phases which consist of job and batch sequencing phases. The authors developed a testing methodology to determine the quality of the HTS solution. A mixed integer linear programing (MILP) model was developed to evaluate the optimality of the solution of the HTS for a small-size instance that consists of 640 problems. In addition, three dispatching rule heuristic combinations (EDD–EDD, EDD–BATCS and ATC–BATCS) were developed to test the HTS for large-size instances that deals with 1440 problems. The HTS provided comparable results with the MILP for small-size instances and outperformed the developed dispatching heuristics.

1. Introduction

Scheduling research with batching elements is gaining more attention due to its practicality in real-life manufacturing settings. Batching is commonly applied in semiconductor burn-in operations, Environmental Stress Screening (ESS) chambers, and chemical, food, and mineral processing industries, to name a few. The ever-changing demands and difficult competition within the marketplace have prompted manufacturers to utilise their resources efficiently by reducing costs as much as possible while delivering products to the customers at the right time. This requires significant compromise for achieving various targets, such as optimal utilisation of machines, minimising work-in-process, satisfying customers' orders and reducing lead times. In real-life situations, production schedules aim exactly to meet customer orders since almost every customer cannot accept orders beyond a specific due date. As a result, tardiness criterion has a significant importance in scheduling practices. One of the complications that face schedulers in the manufacturing industry is the presence of setup time and in many situations, the setup time is ignored in order to have a less complex scheduling problem.

This paper recognises the importance of both the due date and setup times in the scheduling problem. For this reason, this paper deals with scheduling problem that aims to minimise the total weighted tardiness on a single machine. We introduce a mixed integer linear programming (MILP) model for batching and sequencing of jobs originated from incompatible families with the objective of minimising total weighted tardiness. In addition, we propose a hybrid tabu search (HTS) for the same scheduling and sequencing of large-size problems. Finally, the performance of the developed models is evaluated.

The paper is organised as follows. In Section 2, previous works which are related to our problem are reviewed. The problem definition and MILP model is presented in Section 3. The hybrid tabu search is presented in Section 4. This is followed by design of experiments and computational results in Sections 5 and 6. Finally, conclusion is presented in Section 7.

2. Literature review

A survey on US manufacturing practices by Wisner and Siferd (1995) revealed that the most important performance criterion in scheduling area is meeting customers' due dates; however, only 58% of the industrial planners successfully managed to satisfy this criterion. A recent survey by Vallada, Ruben, and Minella (2008) on minimising total tardiness for flowshop problems, observed that

☆ This manuscript was processed by Area Editor T.C. Edwin Cheng.

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http://dx.doi.org/10.1016/j.cie.2014.10.010
0360-8352/

performance measures based on meeting due dates are more relevant than those based on completion time, given its importance to real-life consideration. Based on the survey done among the practitioners in the industry, Panwalkar, Dudek, and Smith (1972) revealed that approximately seventy percent of industries schedule at least one operation that needed sequence-dependent setup times. On the other hand, almost fifteen percent of the industries testified that the entire operations applied sequence-dependent setup times. Analysis by Conner (2009) indicated that half of the studied 250 industrial projects consisted of sequence-dependent setup times. In situations where these setups were applied well, almost 92% of the customer's due dates were manageable. However, most research on single machine scheduling either ignores setup times or makes an assumption of sequence independent setups (Potts & Van Wassenhove, 1987, 1991).

In establishing the complexity of the single machine problems with the TWT criterion, Lawler (1977) and Lenstra, Rinnooy Kan, and Brucker (1977), have played a very important role in the literature by proving the problem is NP-hard in a strong sense. It should be noted that the problem is NP-hard even in the ordinary sense, without considering setups and weights for jobs (Du & Leung, 1990). Cheng, Ng, Yuan, and Liu (2005) stated that although the single machine problems with the TWT criterion occur often in real-life industrial practices, however, very limited research considers arbitrary due dates, and weights have been reported in the scheduling literature. This can be attributed to the arbitrary due date models which are analytically difficult to solve, and some researchers design special due date models to cope with the complexity.

Family scheduling problems which are integrated with batching elements have greater advantages in reducing the number of setups and subsequently results in the enhancement of the utilisation of machines (Shen & Buscher, 2012). Moreover, batching of incompatible job families is a common problem encountered in classical and semiconductor manufacturing, and various chemical and heat treatment processes. Although Potts and Kovalyov (2000) provided a comprehensive review of batching problems, cases with incompatible job families were not discussed in that review. However, Perez, Fowler, and Carlyle (2005) documented the scheduling research done by previous researchers for batch processing which occurs in the semiconductor industry related to the scope of their study. They modelled a diffusion operation as a single batch machine for sequencing jobs originated from incompatible families and aims to minimise TWT. In addition, they concluded that the problem of batching of incompatible families is of importance to both industry practitioners and academicians.

The solutions for a single machine scheduling problem include exact methods, dispatching rules heuristics and metaheuristics. Colak Altunc and Keha (2009) stated that MILP models are known to represent many real-life scheduling problems. However, despite the recent advancement of computer technology and commercial solvers, optimality is still an unsolved issue in many scheduling problems where solution within a reasonable polynomial time is unachievable. They propose a reduced time-indexed formulation and interval-indexed formulation for a single machine TWT problem by using a set of feasible solutions first attained by some other heuristics and attempt to improve the feasible solutions. Kirlik and Oguz (2012) formulated an MILP model for the single machine TWT problem which considers sequence dependent setup times. However, no attempt was made to solve the MILP problem to optimality because finding a solution to the mathematical model was not practical.

On the other hand, dispatching rules such as the EDD and the ATC has been popular while providing reasonably good results for problems related to tardiness (Pinedo, 1995). In application of the rule to batching problems, the ATC rule always outperforms the EDD as a dispatching rule to form batches (Perez, 1999 and Devpura, Fowler, Carlyle, & Perez, 2000). Perez et al. (2005) have implemented both rules for making the decisions of batching and subsequently sequencing of the batches and labelled the combined heuristics: EDD–EDD and ATC–ATC. Mason, Fowler, and Carlyle (2002) proposed a modification of the ATCS index that was developed by Lee, Bhaskaran, and Pinedo (1997) to accommodate the batch processing tool groups which they call BATCS. Further investigations were carried out by Mason, Fowler, Carlyle, and Montgomery (2005) to test the BATC. They compared its performance with seven other dispatching rules and reported that the BATCS produces the best overall scheduling plans in terms of the TWT. However, they reported that the BATCS requires large computational times. It is important to note that Mason et al. (2005) stated that their BATCS reported in 2002 is an effective dispatching heuristic for single machine scheduling problems. The slack term of the BATCS index was later altered by Pfund, Fowler, Gadkari, and Chen (2008) and called the new rule as BATCSmod. Besides this, they have extended the original ATCS to ATCSR by explicitly considering exponential term for the ready times in the index for the identical parallel machine with sequence dependent setup time consideration. By proposing a grid search method to generate the scaling parameters values, the ATCSR has outperformed many types of construction heuristics such as EDD, WSPT, ATCS, BATCS, BATCSmod and the X-RMmod.

One of the most profound metaheuristic in the scheduling literature is the Tabu Search (TS) which is a well-known heuristic for providing remarkable solutions to difficult combinatorial problems such as the travelling salesman problem. Vaessens, Aarts, and Lenstra (1994) showed that the TS heuristic is the most effective method among the local search techniques in scheduling problems. In their literature review, Allahverdi, Ng, Cheng, and Kovalyov Mikhail (2008) conclude that in almost half of the research papers that deal with metaheuristics for scheduling problems, TS heuristics were used to provide a solution to the scheduling problems considered. The pioneer researchers in the development of the TS were Glover and Laguna (1989), Laguna, Barnes, and Glover (1989) and Widmer and Hertz (1989). TS is a metaheuristic that employs a local search method to search the neighbourhood space away from local optimality (Glover & Laguna, 1997). Bozejko, Grabowski, and Wodecki (2006) presented a fast TS algorithm with specific neighbourhood which uses block of jobs and a compound move approach for the single machine TWT problem. The introduction of compound moves that involves in executing some moves concurrently helped to decrease the computational effort for the neighbourhood search and accelerated the convergence of the algorithm. Moreover, by implementing some elimination criteria, the neighbourhood size had been reduced which further helped to lower the computational effort. Based on the computational experiments conducted on benchmark problem sets, the TS produced enhanced results compared to other prominent algorithms available in the literature.

A robust TS was developed by Bilge, Kurtulan, and Kirac (2007) for the single machine TWT problem and they stated that initial solutions played a main role in deciding the effectiveness of the final TS solutions. Further they elaborated that if a good initial solution is not provided, the solution quality of TS worsens. In addition, they have shown that varying the tabu tenure provides better results instead of simply engaging a fixed tabu tenure value for the whole period of the TS computation. Most recent, Shen and Buscher (2012) addressed the serial batch scheduling problem embedded in a job shop environment to minimise makespan. They developed a TS which incorporates batching into a scheduling phase. The outcomes of their TS were compared to the TS developed by Nowicki and Smutnicki (1996). They concluded that an algorithm which does not consider batching or setup time cannot