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A comparison of two stage-based hybrid algorithms for a batch scheduling problem in hybrid flow shop with learning effect

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A B S T R A C T

This paper addresses the hybrid flow shop batch scheduling problem with sequence- and machine-dependent family setup times where the objective is to *simultaneously* minimize the weighted sum of the total weighted completion time and total weighted tardiness, being mindful of the producer and customers, respectively. In order to reflect the industry requirements, machine availability times, job release times, machine capability and eligibility for processing jobs, stage skipping, and learning effect are considered. Unlike group scheduling, batch scheduling disregards the group technology assumptions by splitting pre-determined groups of jobs into inconsistent batches to perform timely processing of jobs with higher priority and utilize the maximum available capacity of the machines. One of the contributions of this research is to realize the benefits of integrating the batching decision into the group scheduling approach. Another contribution is to develop robust meta-heuristics based on hybridization of local search and population-based structures along with the stage-based interdependency strategy to solve the research problem. An initial solution finding mechanism and a comprehensive data generation mechanism are developed. The efficiency and effectiveness of the meta-heuristic algorithms are verified by lower bounds obtained by two mixed-integer linear programming models. The benefits of considering the batching decision with respect to desired lower bounds on batch sizes will hopefully encourage practitioners to apply the batch scheduling approach instead of the group scheduling approach.

1. Introduction

Group technology, designed to improve manufacturing and design productivity, is a philosophy that capitalizes on product similarities based on their processing requirements. Cellular manufacturing (CM) is one of the applications of group technology with the purpose of processing families of parts. Each manufacturing cell is a cluster of dissimilar machines or processes dedicated to the manufacture of families of parts. Hybrid flow shop (HFS), an extended and advanced version of flow shop structures, can be utilized by each cell to increase the flexibility of the production line as well as to decrease the cycle time of production. The efficiency of the HFS has made it popular for its application in modern electronics industries, including semiconductor wafer fabrication and printed circuit board manufacturing (Neammanee and Reodecha, 2009; Choi et al., 2011).

In the HFS environment of each manufacturing cell, the choice of an effective scheduling approach can have a strong impact on the cell performance, especially when a large variety of parts are produced as multiple part families, setup times between families are significant, and/or the cell is operating at or near its capacity. This being the case, two traditional and novel scheduling approaches can be implemented for sequencing part families as well as parts within each family, i.e., group scheduling and batch scheduling, respectively. The traditional group scheduling approach processes each family as a single batch, complying with the Group Technology Assumptions (GTAs), while the novel batch scheduling approach can split each family of jobs into smaller batches by violating the GTAs. Although there are different types of batch scheduling problems with respect to cross families (Nekoiemehr et al., 2015), parallel batching (Amin-Naseri and Beheshti-Nia, 2009), multi-project scheduling (Voß and Witt, 2007), and any other type of batch scheduling with batch processing machines, the batch scheduling problem addressed in this research is completely different and applied to improve the efficiency of the traditional group scheduling approach. The benefits of batching in group scheduling will hopefully encourage practitioners to apply the batch scheduling approach.

The rest of the paper is organized as follows. The problem is clearly stated in Section 2. The related works along with the application, motivations, and contributions of the research problem are explained in

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Section 3. The methodology used to address the research problem is proposed in Section 4 including two mixed-integer linear programming models as well as two basic and hybrid meta-heuristic algorithms. Common implementation strategies related to all hybrid algorithms are explained in Section 4.3 through Section 4.5. Section 5 comprehensively describes the experimental setup and data generation mechanism. Thereafter, the performance of the proposed meta-heuristic algorithms is evaluated in Section 6 with the help of the optimal solutions and lower bounds, at three different levels. In addition, several statistical experiments are conducted to compare the different search algorithms. Finally, in Section 7, a concise conclusion about the research and potential for future research is presented.

2. Problem statement

The problem addressed in this research is to schedule N different jobs clustered into g pre-determined groups as inconsistent batches with respect to desired lower bounds on batch sizes, where each group contains n_i jobs (i.e., $\sum_{i=1}^{g} n_i = N$). An HFS is a unidirectional flow shop, where at least one of the stages includes unrelated-parallel machines (not necessarily all identical) and jobs are processed only on one machine in each stage, although it is possible for a job to skip one or more stages. Also, the machines assigned to a stage with long runtimes (bottleneck stage) are run simultaneously with different eligibilities and capabilities in processing. The runtime of jobs is influenced by a position-based learning effect because of learning attained by workers while performing similar jobs in a batch, i.e., dynamic run time. The learning effect represents the workers' abilities to learn how to perform a job faster as time progresses and, consequently, the run time of the job is decreased. A sequence- and machine-dependent setup time is required between each of two consecutively scheduled batches on each machine. Some jobs and machines might not be available at the beginning of the planning horizon. There should be a balance between setup time and cumulative run time of each batch processed on a machine, which is determined by a manufacturing company's policy in terms of the minimum number of jobs assigned to a batch, i.e., desired lower bounds on batch sizes. Finally, the objective function composed of two criteria is to *simultaneously* minimize the weighted sum of the total weighted completion time and total weighted tardiness of jobs. The first favors the producer's interest by minimizing work-in-process (WIP) inventory, inventory holding cost, and energy consumption as well as maximizing machine utilization, while the second favors the customers' interest by maximizing customers' service level and delivery speed.

Each group might have several different batch compositions corresponding to different stages. A batch composition corresponding to a particular stage determines the number of batches assigned to a group as well as the number and the type of jobs assigned to each batch of that group with regard to desired lower bounds on batch sizes. Since all jobs of each group can be processed as different batch compositions corresponding to all stages in batch scheduling, it is referred to as inconsistent batches. Although there is at least one machine to process consecutively all jobs of each group as a single batch in each stage, a batch cannot be processed on a machine if there is at least one job in the batch which cannot be processed on that machine and/or the number of jobs assigned to the batch is less than the desired lower bound on that machine.

3. Background

Based on a recent comprehensive review on group scheduling problems reported by Neufeld et al. (2016), the flow shop group scheduling problem as well as its related scheduling environments including flexible and hybrid flow shops have received much attention in the practice and academic- oriented literature (Kazemi et al., 2017; Lei and Zheng, 2017; Rossit et al., 2017; Komaki et al., 2016; Mahdavi et al., 2011). Based on similarity in the objective function, problem assumptions, and the solution methods between the research problem addressed here and previous works on group scheduling, Table 1 lists some publications on group scheduling in terms of different shop environments, while Table 2 lists publications on batch scheduling.

The batch scheduling problem addressed in this research is shown in Table 2. This research addresses the gap in the previous work by Shahvari and Logendran (2016) to generate and compare a hybrid of local search and population-based algorithms, show an industrial application of current work in detail, along with the other realistic industry requirements such as learning effect. Apart from this, this research shows the benefits of integrating the batching decision in the traditional group scheduling approach proposed by Bozorgirad and Logendran (2013, 2015).

3.1. Application, motivation, and contribution

The semiconductor industry is the aggregate collection of collaborative companies in the design and fabrication of semiconductor devices. The LCD, TFT-LCD, LED, LED-backlit LCD, and OLED are typical products of semiconductor light source manufacturing systems, the middle stage in the electronics value chain, which receive semiconductors as their main input to produce a panel, and the panels themselves are the main input for many other electronic industries such as television sets, mobile phones, etc. This research covers most of the challenges in the semiconductor light source manufacturing systems. The ever-changing design of semiconductor light sources, together with their huge seasonal demand, and generally for related panels, make the introduction of flexibility within job shops in HFS production systems critical for practitioners. Thus, the planning and scheduling role in the middle stage of the electronics value chain have crucial impact on timely delivery of the input for the next stage of the electronics value chain.

Semiconductor light sources of the same type (for example LED-backlit LCD) are categorized into different groups in terms of shape, size, technological manufacturing, production planning, etc. Apart from this, each semiconductor light source manufacturing system includes a lot of individual operations, which can be divided into several main sub-processes such as fabrication process, cell process, and module process. Each sub-process performed in a cell of CM includes most complicated machines, which are typically controlled by operators and placed in a serial sequence, so that parallel machines with different capabilities and eligibilities are simultaneously run in bottleneck stages. A few inter-cell movements are usually inevitable because complete disaggregation of cells is not always possible and it might be costly. In terms of position-based learning effect, workers learn to process similar semiconductor light sources within a batch faster. The semiconductor light sources might be released into the related cells at dynamic times, and machines are also assumed to be made available in the cells at dynamic times. Also, some semiconductor light sources and, consequently, some semiconductor light source batches can skip one or more operational stages because they may not need an operation to be performed in these stages. Since consecutive semiconductor light source batches belong to different groups on a machine, a sequence- and machine-dependent setup time is considered for switching processes between batches.

Therefore, the motivations of this research are as follows:

- to investigate the scheduling problem in such a manufacturing cell with the help of a mathematical model as well as providing a set of efficient meta-heuristic algorithms, specifically for industry-size problems,
- to process semiconductor light sources of the same group as multiple batches with respect to customers' priorities and batch development restrictions since the orders for semiconductor light sources of the same group might be released to the manufacturing system by different customers with different delivery times,
- to uncover the benefits of integrating the batching decision in the traditional group scheduling approach, i.e., the novel batch scheduling approach,