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A dispatching rule-based genetic algorithm for multi-objective job shop scheduling using fuzzy satisfaction levels

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ABSTRACT

In this study, a dispatching rule based genetic algorithm with fuzzy satisfaction levels (FRGA) is proposed to solve the multi-objective manufacturing scheduling problem. The objective is to develop a decision making platform which appropriately handles conflicts among different performance measures in a manufacturing system. The proposed method focuses on a job shop scheduling problem with the objective of minimizing makespan, average flow time, maximal tardiness and total tardiness. Chromosome embeds the dispatching rules over the time period to help machine pick up the job from its queue. A two-level fuzzy approach evaluates each chromosome and indicates the overall satisfaction level. Various experiments are carried out to study the impact of FRGA parameters. FRGA manages to find optimal or near-optimal overall satisfaction level. Later, various tolerance levels of fuzzy linear membership functions and fuzzy operators are investigated. FRGA can quickly capture schedule(s) that highly satisfy decision makers based on decision makers' preferences.

1. Introduction

Scheduling is one of the critical problems that need to be addressed in order to improve efficiency and responsiveness of a service/manufacturing system (Pinedo, 2012). Essentially, scheduling determines how to allocate limited resources to a set of jobs over a period of time. This paper focuses on the job shop scheduling problem. Minimizing makespan in multi-machine scheduling problems has already received many researchers' attention for decades. In practice, decision makers also consider many other performance measures such as average flow time, maximum tardiness, and total tardiness. It is impossible to find a global optimal solution in a job shop due to its complexity when there are multiple conflicting multiple objectives. Rather than pursuing a perfect solution, this paper focuses on obtaining the schedule(s) with the highest fuzzy satisfaction levels. Linear fuzzy membership function is used to capture the decision maker's preferences in terms of each performance measure. Fuzzy operator eventually combines the results of individual performance measures and comprehensively presents the final results.

Job shop scheduling problem has been proven to be a NP-hard combinatorial problem which contains trillions of possible schedules as the problem size grows (Jain & Meeran, 1997). For the last four decades, many researchers studied the problem to come up with better solution methodologies. Those techniques range from the simple dispatching rules to mathematical programming, heuristics, and meta-heuristics. Dispatching rules are mostly intuitive in nature and can be easily implemented on the shop floor. Unfortunately, their solution quality is low due to the lack of flexibility (Sels, Gheysen, & Vanhoucke, 2012). Mathematical models guarantee the optimality but at high computational cost. Heuristics and meta-heuristics such as simulated annealing, tabu search, ant colony and genetic algorithms cannot guarantee the optimality, however their computation requirements are relatively low and do not grow exponentially as the problem size increases.

This paper proposes a dispatching rule-based genetic algorithm with fuzzy satisfaction levels to solve the multi-objective job shop scheduling problem. Dispatching rules for each machine at different time periods are encoded in the chromosome. Later, a discrete event simulation model is built to obtain the values of makespan, average flow time, maximum tardiness, and total tardiness. Finally, the fuzzy approach is used to evaluate the overall fuzzy satisfaction level based on the values of performance measures. The objective of the genetic algorithm is to identify the best combinations of dispatching rules which lead to schedule(s) with the highest overall satisfaction level.

The remainder of the paper is organized as follows. Section 2 reviews literature related to the solution methodologies in scheduling job shop as well as multi-objective decision making

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Table 1
Partial Pareto optimal solutions for ft06 JSSP.

Pareto solutions	Makespan	Average flow time	Maximum tardiness	Total tardiness
1	55[a]	50.83	15	29
2	64	44.17[a]	6	11
3	60	48.5	3[a]	9
4	69	48.3	3[a]	7[a]

[a] Indicates the optimal value with regard to the single performance measure.

problems. The problem is formulated and issues are discussed in Section 3. The proposed methodology is discussed in detail in Section 4. Section 5 proposes a fuzzy linear programming model. In Section 6, the performance of the proposed approach and the impact of various fuzzy parameters are investigated.

2. Literature review

Scheduling in job shops has received significant attention in the industrial engineering society. Under the job shop scheduling (JSSP) umbrella, there are various practical problems studied with different constraints and characteristics (Hasan, Sarker, & Essam, 2011; Roshanaei, Azab, & ElMaraghy, 2013; Vinod & Sridharan, 2009). This review mainly focuses on various solution methodologies as well as the issues and solutions in the multi-objective production scheduling field.

2.1. Review of solution methodologies for classical JSSP

Mathematical model formulation for the classical JSSP can be found in scheduling books (see Pinedo, 2012). Gromicho et al. applied dynamic programming based on Bellman equation which originally reduced the computational complexity of travelling salesman problem (Gromicho, Hoorna, Saldanha-da-Gamac, & Timmer, 2013). In Gromicho's paper, benchmark results clearly indicate that this exact algorithm is exponentially efficient than the exhaust search, and works successfully for some mid-complex testing cases. Kasemset et al. proposed an innovative bi-level programming approach where the first level attempts to optimize the utilization of bottleneck machines (Kasemset & Kachitvichyanukul, 2010). The second level decisions determine the job sequences with the objective of minimizing gaps between each performance and its optimal value. However, the model simplifies the problem by assuming that the bottleneck machines are known in advance, and needs to be further experimented with larger size problems.

According to Jain's comprehensive review of JSSP solution methodologies, many meta-heuristics approaches derived from artificial intelligence field are applied to solve various JSSP problems (Jain & Meeran, 1997). In addition to the traditional meta-heuristics, Muhamad et al. conducted a review on recent applications of artificial immune system in production scheduling problems (Muhamad & Deris, 2013). Nowadays, as the computing power increases, researchers focus on various hybrid approaches which combine two or more techniques. For example, Blum et al. combined local search with ant colony algorithm to enhance the quality while constructing the solutions. As a result, this hybrid approach significantly improved search ability of the traditional ant colony algorithm (Blum & Samples, 2004). The hybrid genetic algorithm has been widely applied to solve production scheduling problems and proved to be highly efficient in searching for the optimal sequence. In Qing-dao-er-ji's study, the computational efficiency of genetic algorithm is improved by introducing a heuristic based crossover operator, critical path based mutation operator and a local search (Qing-dao-er-ji & Wang, 2012). Chiou et al. proposed a hybrid genetic algorithm, where GA is used to identify job sequence, and dispatching rules are further used to allocate jobs to machines (Chiou, Chen, & Wu, 2013). Tay et al. combined genetic programming with dispatching rules in solving flexible JSSP. The authors developed a genetic programming tree to help build the comprehensive dispatching rules. The five composite rules are tested with various performance measures such as makespan, average tardiness, average flow time and percentage of tardy jobs. The composite rules consistently outperform other rules, and can be easily implemented (Tay & Ho, 2008). Süer et al. assumed dispatching rules change over the time period during scheduling as well as on different machines. Thus, in their study, genetic algorithm is used to identify the best combination of rules (Süer & Huang, 2007). Kapanoglu et al. suggested If-Then rules to pair dispatching rules with the intervals of queue lengths (Kapanoglu & Alikalfa, 2011). They concluded that their approach outperformed several dispatching rules.

2.2. Review of multi-objective decision making in production scheduling

Several papers have been published in the literature that attempts to improve the solution quality with regard to makespan. Decision makers also want to know how long each product stays in the shop; if the due dates can be met; how late the product will be delivered. Many studies highlight other performance measures such as total absolute differences of completion times (TADC) for each job, the average flow time, proportion of tardy jobs, mean tardiness, and maximum tardiness, flow time of job families and so on (Ganesan & Sivakumar, 2006; Sels et al., 2012; Yu, Kim, & Lee, 2011). Vilcot et al. considered makespan, flow time and tardiness measures for a flexible JSSP in printing and boarding industry (Vilcot & Billaut, 2011). T'kindt et al. summarized numerous industrial cases where the scheduling process involves multiple criteria (T'kindt et al., 2006, chap. 4). The authors believe the main objectives of a scheduling process include: 'minimize work-in-progress in the shop', make on time delivery, and 'optimize the shop resources'.

For most of the multi-criteria decision making process, it is infeasible to find an optimal solution which simultaneously optimizes each objective (Ehrgott, 2005). T'kindt et al. also pointed out that the scheduling problems have conflicting objectives (T'kindt, Scott, & Billaut, 2006). Take the ft06 problem for example with due times 39, 71, 51, 53, 38, and 45 for jobs 1, 2, 3, 4, 5 and 6, respectively (due time is set by slack factor 1.5 proposed by Sels et al. (2012)). Some of the Pareto optimal solutions are shown in Table 1. It is clearly observed that there is no single 'perfect' solution with regard to all flow-related and tardiness-related performance measures.

How to handle the trade-offs among various objectives has always been challenging in the multi-objective scheduling process. Solution techniques range from weighted method, ranking, non-dominant to ε-constrained, goal attainment, TOPSIS (technique for order preference by similarity to an ideal solution), and fuzzy decision making (Szidarovszky, Gershon, & Lucien, 1986; Yao, Jiang, Li, Zhang, & Geng, 2011). Yenisey et al. presented a comprehensive review of solution methodologies for multi-objective flow shop