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A hybrid multi-objective grey wolf optimizer for dynamic scheduling in a real-world welding industry

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A B S T R A C T

Welding is one of the most important technologies in manufacturing industries due to its extensive applications. Welding scheduling can affect the efficiency of the welding process greatly. Thus, welding scheduling problem is important in welding production. This paper studies a challenging problem of dynamic scheduling in a real-world welding industry. To satisfy needs of dynamic production, three types of dynamic events, namely, machine breakdown, job with poor quality and job release delay, are considered. Furthermore, controllable processing times (CPT), sequence-dependent setup times (SDST) and job-dependent transportation times (JDTT) are also considered. Firstly, we formulate a model for the multi-objective dynamic welding scheduling problem (MODWSP). The objectives are to minimize the makespan, machine load and instability simultaneously. Secondly, we develop a hybrid multi-objective grey wolf optimizer (HMOGWO) to solve this MODWSP. In the HMOGWO, a modified social hierarchy is designed to improve its exploitation and exploration abilities. To further enhance the exploration, genetic operator is embedded into the HMOGWO. Since one characteristic of this problem is that multiple machines can handle one operation at a time, the solution is encoded as a two-part representation including a permutation vector and a machine assignment matrix. To evaluate the effectiveness of the proposed HMOGWO, we compare it with other well-known multi-objective metaheuristics including NSGA-II, SPEA2, and multi-objective grey wolf optimizer. Experimental studies demonstrate that the proposed HMOGWO outperforms other algorithms in terms of convergence, spread and coverage. In addition, the case study shows that this method can solve the real-world welding scheduling problem well.

1. Introduction

Welding is one of the most crucial technologies of materials forming and processing in modern manufacturing enterprises, which has been extensively applied in various industries such as automobile manufacturing, petroleum chemical industry and shipbuilding (Lu et al., 2016). Welding process has occupied a significant proportion of manufacturing process (Mendes et al., 2016). Its efficiency impacts the whole production efficiency greatly. Therefore, a reasonable welding schedule scenario can help to improve production efficiency. Consequently, welding scheduling problem plays a major role in promoting an enterprise to be a manufacturing giant. However, there is little research on welding scheduling problem. Unlike general scheduling problems, the special characteristic of the welding scheduling problem lies in the number of machines to process each job. In traditional scheduling problems, each job is usually processed on at most one machine at a time. However, in a realistic welding situation, it is common to observe that multiple welding machines can process one job at the same time. Thus, the machine assignment on each operation should be considered in the welding scheduling problem, which significantly increases the difficulty of problem solving. In addition, welding scheduling problem is also NP-hard since the classical scheduling problem such as flowshop is already NP-hard (Garey et al., 1976). Most research on the scheduling field is focused on static scheduling problems in which all the information is assumed to be unchanged during the period (Lu et al., 2016). Nevertheless, the practical welding process is usually affected by unexpected real-time events that can lead to deterioration of the original schedule. Thus, study on dynamic scheduling problem can better reflect the requirements of the actual production environment. Real-time dynamic events in the scheduling field may be categorized into two groups (Cowling and Johansson, 2002; Stoop and Wiers, 1996; Suresh and Chaudhuri, 1993).

(a) Resource-related: machine breakdown, tool unavailability, delay in the arrival or shortage of materials, etc.
(b) Job-related: rush job, job cancellation, changes in job processing

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time, poor quality of job, etc.

Although preventive maintenance can reduce the disruption probability, it cannot eradicate uncertainties from the system (Katragjini et al., 2013). The current technologies for addressing the dynamic scheduling problem include completely reactive, pro-active and predictive-reactive scheduling (Ouelhadj and Petrovic, 2009). Among them, the predictive-reactive scheduling is the most commonly used rescheduling method in which an original schedule is adjusted in response to the dynamic environment. However, it may generate a totally different schedule from the previous one, which causes instability of the production system (Rangsaritratsamee et al., 2004). Consequently, dynamic scheduling problem should consider not only production efficiency (e.g., makespan) but also instability. Therefore, this issue is a multi-objective dynamic welding scheduling problem (MODWSP) and is very great of significance in real-world production systems.

There is no research addressing a realistic MODWSP in comparison with the majority of studies on static scheduling problems in other manufacturing processes. However, dynamic scheduling problems have attracted increasing attention due to its strong industrial background (Nie et al., 2013). Recent reviews of dynamic scheduling are provided by Ouelhadj and Petrovic (2009) and Priore et al. (2014). To solve these dynamic scheduling problems, some dynamic scheduling methods are developed. Yaochu and Branke (2005) provided a survey of evolutionary algorithms (EAs) in dynamic environments. Recently, Katragjini et al. (2013) considered a dynamic flowshop scheduling problem with the objective to minimize makespan and instability by using a weighted sum method. Li et al. (2015) proposed a single-objective teaching-learning-based metaheuristic to solve the flowshop under five uncertainties simultaneously. Tang et al. (2014) presented an improved differential evolutionary to solve the real-world dynamic scheduling in steelmaking-continuous casting production. However, the above methods for dealing with multi-objective scheduling problems are to combine them into a single-objective function by using a weighted sum approach. In most real-world scheduling problems, nevertheless, objectives are evaluated in different scales and thus it is difficult to determine weight values (Ciavotta et al., 2013). Therefore, it is better to handle multiple objectives with knowledge about Pareto dominance. Pareto-based multi-objective evolutionary algorithm (MOEA) is very suitable for solving multi-objective optimization problem since it can yield the non-dominated solutions in a single run (Gen and Lin, 2014; Shen and Yao, 2015). As mentioned above, the studied problem is a new scheduling issue, since it breaks a traditional concept that each job can be processed on at most one machine at a time in the conventional scheduling problem, whereas each job can be handled by multiple machines at a time in the MODWSP. The actual processing time of each operation is associated with number of the machine to process the corresponding operation. This characteristic makes the MODWSP unique comparing to other multi-objective dynamic scheduling problems. A new encoding scheme and search operators have to be designed to fit the characteristic of this new scheduling problem. Furthermore, most of original metaheuristics are developed to solve continuous problems and they cannot be directly applied to this scheduling problem. Therefore, it is imperative to study the welding scheduling problem in terms of both theory and application.

So far, various EAs have been adopted to solve a variety of optimization problems (El Sehiemy et al., 2013; Gao et al., 2015; Garg et al., 2014; Kazakov and Lempert, 2015; Lin et al., 2015; Loubière et al., 2016; Manjarres et al., 2013; Niu et al., 2013; Panda and Abraham, 2015; Precup et al., 2013; Zeng and Dong, 2016). Grey wolf optimizer (GWO) (Mirjalili et al., 2014) is a new swarm intelligence algorithm inspired from mimicking the leadership hierarchy and hunting mechanism of grey wolves. GWO is proven to be competitive or superior to other classical metaheuristics such as differential evolutionary and particle swarm optimization algorithm (Mirjalili et al., 2014). Furthermore, GWO is a very efficient metaheuristic algorithm due to its high convergence speed and simple mathematical model. The reason for the high convergence of GWO lies in the search mechanism. More precisely, the wolf population can be categorized into four groups (i.e., alpha, beta, delta and omega) based on their fitness. The search process in GWO is guided by the best three wolves at each generation. This search mechanism promotes the exploitation because all candidate wolves (solutions) are attracted toward the best three wolves, thereby converging faster to these good wolves. For this reason, the convergence performance of GWO can be improved. Additionally, GWO has been successfully applied to some application fields. For example, Saremi et al. (2015) proposed the use of evolutionary population dynamics in GWO. Noshadi et al. (2015) adopted GWO to solve PID-type fuzzy logic controller for a multi-input multi-output active magnetic bearing system. Precup et al. (2016a) applied GWO to the tuning of PI-Fuzzy controllers with a reduced process parametric sensitivity. Jayakumar et al. (2016) used the GWO to solve combined beat and power economic dispatch. Precup et al. (2016b) applied GWO to fuzzy control systems with reduced parametric sensitivity. Emary et al. (2016) developed a novel binary GWO to select the optimal feature subset for classification purposes. Based on the effectiveness of the GWO and nature of the multi-objective optimization problem (MOP), a new hybrid multi-objective grey wolf optimizer (HMOGWO) with genetic algorithm (GA) is proposed to solve this MODWSP. Although multi-objective grey wolf optimizer has been proposed (Mirjalili et al., 2016), it is used to solve continuous MOPs. The main reasons for developing HMOGWO for MODWSP are that the problem under this study is NP-hard, and GA has been demonstrated to be an effective approach for tackling the combinatorial optimization problem (Jalilvand-Nejad and Fattahi, 2015; Lin et al., 2013; Mou et al., 2014; Ruiz et al., 2006; Zhang et al., 2011). Furthermore, many MOEAs have been proposed to deal with practical engineering optimization problems. Deb et al. (2002) presented the classical NSGA-II, which adopts the fast non-dominated sorting and crowding distance strategies. Zitzler et al. (2001a) proposed the SPEA, which uses an external archive to manage non-dominated solutions and adopts a clustering scheme to maintain the size of the archive. However, no free lunch principle implies that one algorithm cannot obtain the better result than all the others on all the problems. In general, an appropriate combination of different search schemes may improve the performance of the algorithm, and even conquer the limitation of the single metaheuristic (Li et al., 2010; Ma et al., 2014; Tang and Wang, 2013). As mentioned earlier, the candidate wolves are attracted toward the potential optimal solutions by the best three solutions according to the fitness. But as a result of such an exploitative effect, the population of GWO is prone to stagnation in a local optimum. However, GA has a good exploration ability, and hybridizing of GWO and GA can balance exploration and exploitation of the proposed algorithm in this paper. The above reasons motivate us to design a hybrid multi-objective GWO with GA for this real-world dynamic scheduling problem.

To the best of authors' knowledge, a real-world MODWSP has been not yet reported in the previous research. The purpose of this paper is to develop a high-performance multi-objective predictive-reactive scheduling method for this MODWSP in order to narrow the gap between theoretical research and applicable practice. In this paper, we have accomplished the following five aspects: (1) a mathematical model for MODWSP is constructed. This model considers three objectives consisting of makespan, machine load and instability simultaneously. (2) A hybrid multi-objective optimization algorithm based on GWO and GA is developed to address this MODWSP. (3) An effective encoding scheme is presented according to characteristic of the considered problem. (4) The effectiveness of each improvement strategy of HMOGWO is validated by a considerable of experiments, and (5) the HMOGWO has been successfully applied to a real-world dynamic