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Research paper

An effective multi-objective discrete grey wolf optimizer for a real-world scheduling problem in welding production

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ABSTRACT

This paper aims to provide a solution method for a real-world scheduling case from a welding process, which is one of the important processes in modern industry. The unique characteristic of the welding scheduling problem (WSP) is that multiple machines can process one operation at a time. Thus, WSP is a new scheduling problem. We first formulate a new multi-objective mixed integer programming model for this WSP based on a comprehensive investigation. This model involves some realistic constraints, controllable processing times (CPT), sequence dependent setup times (SDST) and job dependent transportation times (JDTT). Then we propose a multi-objective discrete grey wolf optimizer (MODGWO) considering not only production efficiency but also machine load on this real-world scheduling case. The solution is encoded as a two-part representation including a permutation vector and a machine assignment matrix. A reduction machine load strategy is used to adjust the number of machines aiming to minimize the machine load. To evaluate the effectiveness of the proposed MODGWO, we compare it with other well-known multi-objective evolutionary algorithms including NSGA-II and SPEA2 on a set of instances. Experimental results demonstrate that the proposed MODGWO is superior to the compared algorithms in terms of convergence, spread and coverage on most instances. Finally, MODGWO is successfully applied to this real-world WSP. This implies that the proposed model is feasible and the proposed algorithm can solve this real-world scheduling problem very well.

1. Introduction

Welding is one of the most crucial technologies of materials forming and processing in modern manufacturing sectors [1], which has been widely applied in a variety of industrial fields such as petroleum chemical industry, mechanical industry, space flight and aviation, and microelectronic engineering. Welding process accounts for a noticeable portion of the total manufacturing process [1]. In general, a reasonable welding schedule scenario can effectively improve production efficiency. Thus, welding scheduling problem (WSP) plays an important role in promoting an enterprise to be a manufacturing giant. However, studies on the WSP are relatively scarce in comparison with other real-world scheduling problems such as steelmaking scheduling issues [2–9]. The main reasons for few researches on the real-world WSP may be the following aspects.

(1) The main difference between WSP and the traditional scheduling problem is the number of machines required to process the operation of one job. In most scheduling problems, one job is usually handled by one and only one machine at a time. However, in a realistic welding situation, it is common to observe that multiple welding machines can process a job at the same time. This characteristic should be considered when modeling and solving WSP. Thus, it increases the difficulty of modeling.

(2) WSP can be regarded as a special permutation flow shop scheduling problem (PFSP). Thus, WSP is also NP-hard due to NP-hard nature of the PFSP [10]. Nevertheless, WSP is more sophisticated in the practical production since it involves some realistic constraints, sequence dependent setup times (SDST), job dependent transportation times (JDTT), and controllability of processing times at certain stages. However, most existing models are simplified versions ignoring some realistic assumptions, which cannot completely satisfy requirements of the real-word welding workshop.

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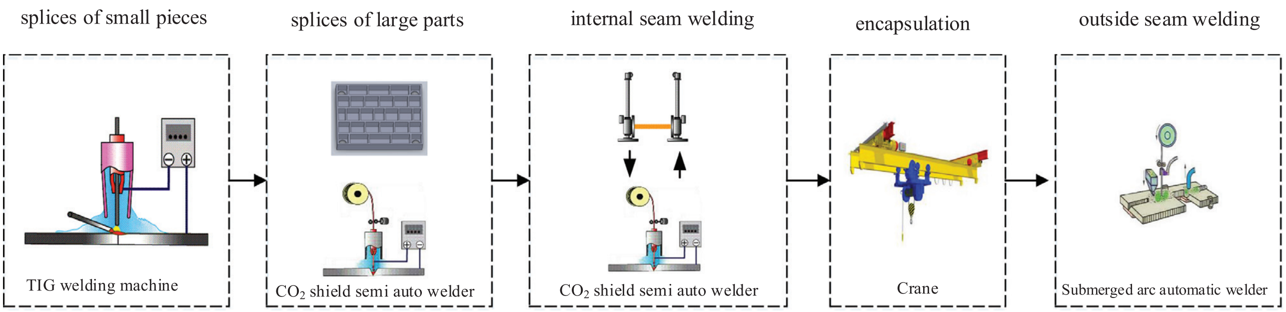

Fig. 1. The process flow chart for a welding plant.

The above reasons increase the complexity of this study. Clearly, there still exists a significant gap between theoretical research and practical application [8]. Therefore, WSP is an important research topic in terms of both theory and application.

This paper investigates a multi-objective WSP from a realistic welding workshop in China, which has guiding significance on the modern welding industry. In this realistic workshop, the welding process mainly includes five stages (see Fig. 1): (1) Splices of small pieces, in which many small pieces such as rib plate and cover plate are melted into several parts by the TIG welding machine, and then these parts are conveyed to the next stage. (2) Splices of large parts, in which several parts are melted into a complete part by the CO_2 shield semi auto welder. (3) Internal seam welding, in which continuously weld on the web, plate and so on. Turn over the part after the welding operation of one side of the web is completed, and perform the same operation on the other side of the web by the CO_2 shield semi auto welder. (4) Encapsulation, in which box beam is transferred down by the crane and fixed in a predetermined position. (5) Outside seam welding, in which the both sides of the box beam are welded by the submerged arc automatic welder. Furthermore, the real-world WSP is a multi-objective optimization problem (MOP) in nature. Purely single-objective scheduling problem cannot fully reflect the requirements of the real-world production system. Thus, this real-world WSP takes into account two main criteria, namely, makespan and machine load or interference. One simple strategy for addressing multiple objectives is to combine them into a scalar function by giving fixed weights to each objective function, and then an optimization algorithm is adopted to solve this scalar objective problem. Nevertheless, in most MOPs, objectives have different scales and thus it is difficult to determine weight values [11]. Therefore, it is better to handle multiple objectives with knowledge about Pareto dominance. Pareto-based multi-objective evolutionary algorithm (MOEA) is suitable for solving multi-objective scheduling problems since it can yield the non-dominated solutions in a single run [12]. For example, Han et al. [13] presented an improved NSGA-II and applied it to tackle the lot-streaming flow shop scheduling problem with four criteria. Ciavotta et al. [11] developed a new MOEA and provided a comprehensive study on multi-objective permutation flow shop with sequence dependent setup times. Wang et al. [14] developed a multi-objective genetic algorithm based on the immune and entropy concept for flexible job shop scheduling problem. Amin-Tahmasbi and Tavakkoli-Moghaddam [15] proposed a multi-objective immune system to address a bi-objective flow shop scheduling problem with SDST. Zheng and Wang [16] developed a Pareto-based estimation of distribution algorithm to solve a production scheduling problem. Rifai et al. [17] proposed a novel multi-objective adaptive large neighborhood search algorithm to address a distributed permutation flow shop scheduling problem. A recent review on the multi-objective permutation flow shop scheduling problem is provided by Yenisey and Yagmahan [18]. Based on the merits of Pareto-based methods, they not only obtain non-dominated solutions in a single run but also reveal a tradeoff relation between several criteria. Therefore, we adopt a Pareto-based MOEA to address this considered problem.

Recently, many metaheuristics have been developed such as virus colony search [19], whale optimization algorithm [20], ant lion optimizer [21], grey wolf optimizer [22] and backtracking search algorithm [23]. Among them, grey wolf optimizer (GWO) [22] is a new swarm intelligence algorithm inspired from mimicking the leadership hierarchy and hunting mechanism of grey wolves. GWO is proven to be superior or competitive to other classical metaheuristics such as differential evolutionary, genetic algorithm and particle swarm optimization algorithm. GWO has been successfully applied to many engineering fields, such as parameter estimation in surface waves [24], optimization of controller's gains [25], the optimal power flow problem [26], hyperspectral image classification [27] and designing photonic crystal waveguides [28]. Based on the effectiveness of GWO and the nature of the multi-objective (MOP), a new multi-objective discrete grey wolf optimizer (MODGWO) is proposed to solve this multi-objective WSP. The main reasons for applying MODGWO in WSP are that the problem under study is NP-hard and GWO has been demonstrated to be an effective approach for tackling the flow shop problem [29]. In addition, GWO is easy to implement due to its a few parameters and simple mechanism. These motivations drive us to design a new multi-objective algorithm based on GWO for this scheduling problem. To the best of the authors' knowledge, no paper has been reported that addresses a real-world WSP using MODGWO. Although a multi-objective GWO (MOGWO) has been proposed [30], MOGWO is designed to deal with continuous MOPs rather than combinatorial optimization MOPs. In this paper, we have accomplished at least three things in order to narrow the gap between theoretical research and practical application. First, a new multi-objective mathematical model for this WSP is formulated. Second, an efficient MODGWO is developed to obtain a trade-off curve between the makespan and the penalty of machine load (or machine interference). Third, the proposed MODGWO is used to solve a real-world welding scheduling case, which achieves good results.

The remainder of this paper is organized as follows. The mathematical model for this scheduling problem is formulated in Section 2. Section 3 describes a new multi-objective optimization approach for this WSP. Sections 4 and 5 present experimental results and a case study, and Section 6 provides the conclusions and future work.

2. Problem statement and mathematical modeling

In this section, we first give a problem statement and then present a detailed multi-objective mathematical model for the WSP which derives from a realistic welding workshop.