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A multi-objective approach to welding shop scheduling for makespan, noise pollution and energy consumption

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A B S T R A C T

Sustainable scheduling problems have attracted great attention from researchers and enterprises. Sustainable scheduling should simultaneously consider economic, environmental and social impacts. However, to date, most studies on sustainable scheduling problems have emphasized the balance between the economy (e.g., makespan) and the environment (e.g., energy consumption or carbon emissions). Noise pollution is an important social issue and harmful to human health, however, it was ignored in most previous studies. Thus, this study investigates a welding shop scheduling problem (WSSP) that considers noise pollution alongside more common energy consumption and productivity issues. The studied WSSP is unique because multiple welders could simultaneously carry out the same task. First, we present a new mathematical model of the multi-objective WSSP. A novel hybrid multi-objective grey wolf algorithm (HMOGWO) is then designed. A new local search strategy based on the problem's properties is proposed to improve exploitation capability of the HMOGWO. In addition, a new energy saving strategy is presented to extend the operational life span of welders and promote energy efficiency. Finally, to demonstrate the effectiveness of the HMOGWO and the new energy saving strategy, we compare our proposal with other multi-objective optimization algorithms through comparison experiments. The results indicate that the proposed HMOGWO and energy saving strategy are superior to the competitors on this problem. Additionally, this method is successfully applied to a real-world case.

1. Introduction

With increasing public concern for environmental protection, sustainable manufacturing has received great attention from academia and industry. It is crucial to consider economic, social, and environmental impacts during sustainable manufacturing (He et al., 2017; Luo et al., 2013; Yan, X. et al., 2017). However, manufacturing is among the highest energy-consuming sectors, and contributes significantly to noise pollution and carbon emissions. For example, the manufacturing sector consumed approximately 50% of the total electrical energy and produced over 26% of the total carbon dioxide emissions in China (Fang et al., 2011; Liu et al., 2015). Moreover, noise pollution from manufacturing sectors is one of the most serious social issues. Noise pollution not only causes health disorders such as dizziness, headaches, and hearing loss, but also causes emotional disorders of workers, such as sadness and irritability (Garcia-Nieto et al., 2012).

Scheduling is an important part of manufacturing systems. A reasonable schedule can contribute to sustainable manufacturing (Lu et al., 2017). Therefore, sustainable scheduling problems have received increasing attention from researchers in recent decades. However, in most previous studies, sustainability criteria were limited to energy consumption or carbon emissions. For instance, in one of the earliest studies on sustainable scheduling problems made by Mouzon et al. (2007), a turn on/off strategy to control a machine was proposed to reduce the total energy consumption criterion. Gahm et al. (2016) recently reviewed energy-efficient scheduling problems, and Lu et al. (2017a) recently proposed a hybrid multi-objective backtrack search algorithm to address a particular flowshop scheduling problem to minimize the energy consumption and makespan. Lei et al. (2017) considered a flexible job shop scheduling problem to minimize the workload balance and total energy consumption, and developed a novel shuffled frog-leaping algorithm to solve this problem. Che et al. (2017) studied an

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energy-efficient unrelated parallel machine scheduling problem to minimize electricity cost, and proposed a two-stage heuristic algorithm to solve large-scale problems. Liu et al. (2017) studied a fuzzy flowshop scheduling problem targeting production efficiency and energy consumption, and proposed an improved genetic algorithm to solve this problem. These studies did not consider noise pollution, and only two studies have covered this topic to date. Yin et al. (2017a, b) formulated two novel mathematical models for job shop scheduling and flexible job shop scheduling problems that considered productivity, carbon emissions, and noise pollution, and used a weighted-sum approach to solve this multi-objective optimization problem. Due to the apparent limitations of the weighted-sum approach, which often cannot identify satisfactory non-dominated solutions, it is necessary to search for a high-performance algorithm to manage sustainable scheduling problems.

This paper reports a study regarding a welding shop scheduling problem (WSSP) experienced by a practical production shop in China. Welding production requires to consume huge energy, which inevitably causes the serious environment problem such as global warming and toxic gas emissions. Furthermore, in the welding process, it also generates a social problem such as noise pollution and high-risk operation, which can severely harm employees' health and safety. The objectives of this WSSP are to simultaneously minimize the makespan, noise pollution, and the total energy consumption. Welding technology has been applied in many industrial fields, such as automotive, shipbuilding, microelectronics, aeronautics, and astronautics, therefore, sustainable production issues have wide ramifications and it is vital that WSSPs in the welding industry are addressed. This WSSP is experienced by a practical production shop in which production usually involves five stages (Lu et al., 2017b): (1) Splices of small pieces. (2) Web grouping. (3) Internal seam welding. (4) Encapsulation. (5) Fillet welding. Fig. 1 presents a production process flow of a welding plant.

The WSSP could be viewed as a particular permutation flowshop scheduling problem (PFSP) with controllable processing times. In traditional scheduling problems, one operation was often processed by a single welder (or machine) at a time. However, a major characteristic of the WSSP is that multiple welders can simultaneously process the same operation, which increases the complexity of solving the problem. PFSP is non-deterministic polynomial-time hardness (NP-hard) (Garey et al., 1976). Consequently, the WSSP is also NP-hard, therefore, large-scale WSSP instances could not be solved within a reasonable amount of time through exact methods. Fortunately, metaheuristics provide suitable approaches to solve such combinatorial optimization problems (Yang et al., 2015). Among them, grey wolf optimizer (GWO) (Lu et al., 2018; Mirjalili et al., 2014) has received widespread attention owing to its good performance and simple mechanism. For example, Lu et al. (2017b; 2016) adopted a multi-objective GWO to solve a WSSP associated with productivity. Although the GWO can effectively solve such problems, the green objectives such as noise pollution and energy consumption are not considered in these studies.

Thus, previous research has not addressed noise in the context of the WSSP, therefore, the purpose of this study is to obtain a set of trade-off solutions that consider makespan, noise pollution, and energy consumption, thus, this study addresses the following three issues:

(1) Some novel aspects of modeling the problem were researched. First, this study investigated a WSSP that included noise pollution, which is rarely considered. Previous studies involving noise pollution focused solely on the job shop and its flexible environment (Yin et al., 2017a; b). Second, the model was required to consider the technological constraint of multiple welders simultaneously conducting one operation in the WSSP. Third, an energy saving strategy was designed to guarantee a reduction in the energy use and service span of welders. Consequently, we formulate a new multi-objective mathematical model for this WSSP.
(2) The novel aspects of the algorithm's design were as follows. First, a novel hybrid multi-objective grey wolf discrete optimization algorithm was proposed for the WSSP. The improved elements of this algorithm included an encoding and decoding scheme, population initialization, and an update operation. Second, a new local search strategy based on identifying the problem's properties was proposed to enhance the quality of the solutions.
(3) Several characteristics were displayed during the experimental analysis. First, the effectiveness and feasibility of the proposed improvement strategies were validated through experiments. Second, we demonstrated how each improvement strategy affected the performance of the proposed algorithm. Third, we successfully tested the proposed method in a real-world case and improved the practical production system.

The remainder of this paper is organized as follows. In Section 2, a mathematical model for the test case is developed. In Section 3, the proposed multi-objective optimization approach is presented. In Sections 4 and 5, the numerical experiment and case study are presented, and in Section 6, conclusions and future directions are discussed.

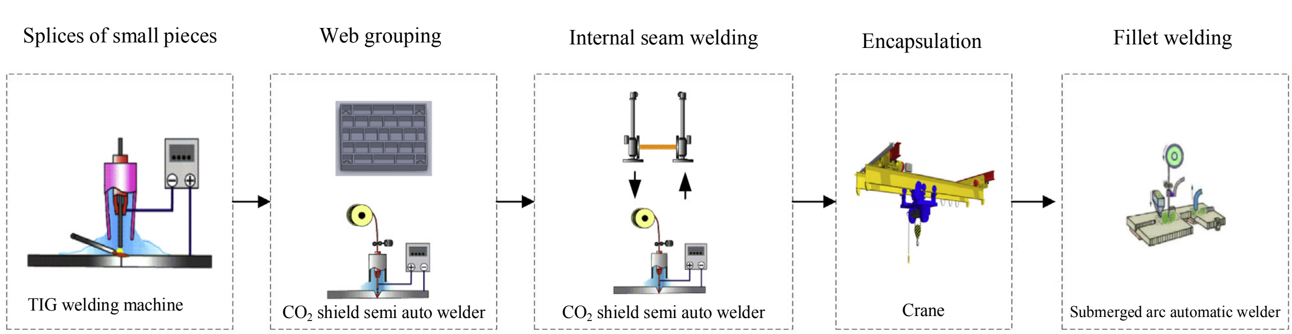

Fig. 1. A flow chart for a welding shop scheduling plant.