Low Carbon Multi-Objective Shop Scheduling Based On Genetic and Variable Neighborhood Algorithm

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Abstract. Aiming at the low-carbon scheduling problem of flexible job shop, the carbon emission and key scheduling objectives of machining system are studied. Firstly, the carbon emissions directly generated by machines and indirectly generated by waste treatment are considered in the calculation of carbon emissions, and then a multi-objective optimization model is established with completion time, total machine load and carbon emissions as the objective function; secondly, the hybrid algorithm of genetic variable neighborhood is designed to solve the optimization model, and the completion time, total machine load. Finally, the production example is simulated in Matlab environment. The experimental results show that the multi-objective scheduling model is feasible and effective. According to the production situation of the workshop, the producer can allocate the weight of each objective, and reduce the carbon emissions in the production process on the premise of ensuring the balance of the completion time and equipment utilization.

Keywords: Flexible Workshop Scheduling, Carbon Emission, Multi-Objective Optimization, Genetic Algorithm, Neighborhood Structure

1. Introduction
With the rapid development of the global economy, the demand for energy is increasing, and a large number of greenhouse gases are produced in the process of using energy, which has caused the global temperature to rise continuously and brought serious environmental problems [1]. As an important driving force of global economic development, manufacturing industry consumes nearly 1/3 of global energy and produces a large amount of carbon dioxide [2]. At present, China is still in the key stage of industrialization development, most of the machinery manufacturing industry is relatively backward, but also adopts the production mode of high pollution and carbon dioxide emissions, resulting in carbon dioxide emissions can not be ignored. Therefore, how to reduce the emission of carbon dioxide and waste and develop low-carbon economy is one of the key issues to be solved.

Production scheduling is a typical combinatorial optimization problem, which is the core of production operation. Flexible job shop scheduling problem (FJSP) is the further research of workshop scheduling problem. It allows different processes of workpiece to be processed on different machines, which more in line with the current actual production workshop work, and is an important research
direction in scheduling field [3]. In the workshop production process, it directly affects the product processing sequence and the choice of processing machine [4], and then affects the carbon emission of workpiece in the production process. Therefore, if energy consumption is taken into account in the formulation of production plans and adjustment strategies to achieve energy conservation and emission reduction, then this is a good way to achieve green manufacturing [5]. Many scholars have carried out in-depth research on this issue. Gokan may et al [6] proposed a production scheduling strategy to improve the production and environmental performance of the job shop system, which can complete in required time and reduce energy consumption. Mouzon [7] proposed a heuristic algorithm to calculate the energy consumption of a machine tool and extend the working time of the workshop scheduling model.

Therefore, through the study of the above literature, this paper makes a further study on the low-carbon scheduling of flexible job shop. Therefore, on the basis of the above literature research, this paper makes a further study on the low-carbon scheduling problem of flexible workshop, comprehensively considers the carbon emissions generated by the energy consumed by the machine tool in the processing of workpieces and the carbon emissions generated in the treatment of waste liquid and waste materials, and establishes a mathematical optimization model with the minimum processing time, the minimum total machine load and the minimum total carbon emissions as the optimization objective under the condition of satisfying certain constraints, all the objective functions are in the optimal state.

2. Carbon Emission Accounting of Machining System
In the manufacturing process of products, carbon emission involves various aspects, including the preparation of raw materials, parts processing, workpiece transportation, etc., which will directly or indirectly produce carbon emissions [8]. In this article, the carbon dioxide total emissions generated by the machining system are mainly divided into two categories: one is carbon dioxide produced by energy consumption in the process of parts manufacturing, for example, the carbon dioxide emission generated by the electric energy consumed by the machine tool in processing parts; the other is the carbon emissions generated by the treatment or secondary recovery of the waste generated in the manufacturing process, for example, the carbon dioxide emission generated by the treatment of waste coolant before it is discharged into the sewage system.

2.1 Carbon Emissions from Processing
Machine tool is the carrier of parts processing, and the energy consumed by different machine tools is different [9]. Therefore, it is an effective way to reduce carbon dioxide emissions to study the resources consumed by machine tools in processing parts. The actual running state of the machine is a dynamic conversion process of starting, preheating, no-load, processing, no-load and unloading, and the energy consumption of the machine tool is different in different states [10]. During startup, the instantaneous power of the machine tool is large, but the duration is relatively short, and it needs to be preheated for a period of time before it can work. During machining, the energy consumed by the machine tool is mainly used to cut the workpiece and maintain the operation of the auxiliary system. When the rotation speed of the spindle is constant, the carbon emission generated by the machine in unit time remains unchanged. When the machine is unloaded, the energy consumed by the machine is mainly used to maintain the idling of the spindle, automatic tool change, tool withdrawal and other tool operations. Therefore, in this paper, three key stages of preparation, processing and no-load are considered in the carbon emission.

2.2 Carbon Emissions from Waste Treatment
The machine tool needs to change the coolant and lubricating oil on a regular basis. The replaced waste liquid cannot be discharged directly, which will cause secondary pollution. Therefore, the waste liquid can only be discharged after treatment. A large amount of waste will be produced when the machine tool processes the raw materials. Generally, the waste will be recycled for secondary
Energy is also consumed when waste liquid and waste are recycled, which indirectly results in carbon emission. Because there are many kinds of energy consumed and the calculation is complex, in order to facilitate the research and calculation, the energy consumption needs to be converted into a unified standard. As shown in table 1 and table 2, the energy consumed in the treatment of unit waste liquid and waste can be converted into standard coal coefficient, and the energy consumed in unit electric energy, lubricating oil, coolant, etc. can be converted into carbon emission factor [11].

**Table 1.** Conversion coefficient of unit waste energy consumption into standard coal

| Conversion coefficient of unit waste energy consumption into standard coal | Waste liquid (L) | Waste (kg) |
|--------------------------------------------------------------------------|-----------------|------------|
|                                                                          | 4.5             | 0.011      |

**Table 2.** Carbon emission factors of small and medium-sized enterprises

| Carbon emission factors | Electric energy | Lubricating oil | Coolant |
|-------------------------|-----------------|-----------------|---------|
| Unit                    | kg-CO$_2$/(kw·h) | kg-CO$_2$/(L)   | kg-CO$_2$/(kg) |
|                         | 0.54            | 0.469           | 5.143   |

3. Low Carbon Scheduling in Flexible Job Shop

3.1 Problem Description

The problem of FJSP in low-carbon environment can be described as: \( n \) workpieces are processed on \( m \) machines; each workpiece contains several processes, each process can be processed on one or more machines; different performance machine tools have different processing energy consumption and different carbon dioxide emissions in the processing process. Therefore, it is necessary to select the machining machine and sequence of each workpiece reasonably so as to optimize one or several indexes of the whole machining system.

This problem has the following assumptions:

1. Each process of the same workpiece cannot be processed by multiple machines at the same time;
2. The workpiece can not be interrupted when it is processed on the machine tool;
3. Zero time, every machine tool can be used;
4. Each machine can not process other workpieces while processing workpieces;
5. The processing technology of workpieces is determined, and the priority of all workpieces is the same;
6. Different performance machines produce different carbon emissions.

3.2 Symbol Definition

The definition of each parameter symbol in this paper is as follows:

- \( m \): number of machines; \( n \): number of workpieces; \( i \): workpiece;
- \( j \): working procedure; \( k \): processing machine; \( n_{ij} \): operation quantity of workpiece \( i \);
- \( t_c \): time for completion; \( t_{ke} \): starting and preheating time of machine \( k \);
- \( E_{ke} \): carbon emission per unit during machine start-up and warm-up; \( E_{ke} \): carbon emission per unit when the machine is idle; \( t_{ke} \): idle time of processing machine; \( C_{ijk} \): machining sequence of parts machining time on the machine; \( S_{ij} \): discharge amount of waste liquid upon completion of each process; \( t_{ijk} \): processing time of working procedure \( j \) of workpiece \( i \) on machine \( k \);
- \( E_{ij} \): unit carbon emission of process \( O_{ij} \) when it is processed on machine \( k \); \( t_{ijkp} \): preparation time of process \( O_{ij} \) on machine \( k \); \( t_{ijku} \): idle time of operation \( O_{ij} \) on machine \( k \);
- \( L_{ij} \): discharge amount of waste materials at the completion of each process;
\(a_1\): conversion coefficient of energy consumption per unit waste liquid to standard coal;  
\(a_2\): conversion coefficient of unit waste energy consumption into standard coal;  
\(\tau\): carbon emission factors of energy consumed in waste liquid treatment.

3.3 Establishment of Model Objectives

The completion time can intuitively reflect the production efficiency of the workshop. The total load of the machine can reduce the overall loss of the equipment and the production cost of the workshop [12]. Low carbon manufacturing is the only way for the sustainable development of the industry in the future. These indicators are the important goals pursued by the enterprise. Therefore, this paper takes the completion time \(C_{\text{max}}\), total machine load \(W_T\) and total carbon emissions \(E\) as the optimization objectives, and establishes a low-carbon scheduling model of flexible workshop. The specific mathematical model is as follows:

\[
f_1 = \text{Min} \ C_{\text{max}} = \min \{\max \ C_{ij}; i = 1,2,3,...,n\} \tag{1}
\]

\[
\text{s.t.} \begin{cases} C_{ijk} - C_{i(j-1)m + t_{ijk}} \\ C_{egk} - C_{igk} \geq t_{egk} \\ C_{ijk} \geq t_{ijk} \end{cases}
\]

\[
f_2 = \text{Min} \ W_T = \min \{\sum_i^n \sum_j^m \sum_k^m X_{ijk}(t_{ijkp} + t_{ijk} + t_{ijkd})\} \tag{2}
\]

\[
f_3 = \text{Min} \ E = \min \left\{ \sum_k^m E_{ks} t_{ks} + \sum_i^n \sum_j^m \sum_k^m X_{ijk} E_{ijk} t_{ijk} + \sum_k^m E_{k} t_{k} + \sum_i^n \sum_j^m h a_{1i} \right\} \tag{3}
\]

Wherein: formula (1) represents the minimum maximum completion time of workpiece \(i\); formula (2) represents the minimum total machine load, which includes the preparation time, processing time, and idle time of process \(O_{ij}\) on machine \(k\); \(X_{ijk}\) is the decision variable, when process \(j\) of workpiece \(i\) is processed on machine \(k\), \(X_{ijk} = 1\), otherwise \(X_{ijk} = 0\); formula (3) represents the minimum total carbon emission, which includes the start-up time of all machines carbon emissions from moving and preheating, processing workpieces, idle time and waste and liquid treatment.

For multi-objective optimization problems, it is often difficult for multiple objective functions to reach the optimum at the same time when they meet the constraints. Generally, each objective function conflicts with each other, that is, when one objective function reaches the optimum, other objective functions are often not optimal. Therefore, in this paper, the weighted summation method is used to allocate different weight coefficients [13] according to the importance of each objective, and then a new objective function is constructed by linear weighting. In this way, the multi-objective problem is transformed into a single objective optimization problem, and the solution process is simpler, so as to achieve the optimal scheduling goal. The specific operation steps are as follows:

\[
\text{Min } f = \min (w_1 C_{\text{max}} + w_2 W_T + w_3 E)
\]

Where, \(w_1\), \(w_2\), \(w_3\) respectively represent the weight coefficients of the completion time, the total load of the machine and the carbon emission.

3.4 Selection of Algorithm

FJSP problem is a complex combinatorial optimization problem. At present, genetic algorithm, grey wolf optimization algorithm and variable neighborhood search algorithm are mostly used to solve it [14]. Among them, genetic algorithm is widely used to solve flexible job shop scheduling because of its strong generality, excellent calculation and strong global search. The variable neighborhood search algorithm can make the current local optimal solution close to the optimal solution in repeated iterations through progressive screening of different neighborhoods, and has strong local search ability.
[15]. Therefore, this paper combines the genetic algorithm with the variable neighborhood algorithm, so that it not only has a strong neighborhood search ability, but also has a good global search ability, in order to improve the speed and quality of solving workshop scheduling.

4. Case Analysis
Verify the feasibility of low carbon scheduling model and algorithm through actual workshop production. Take the flexible job shop low-carbon scheduling model in which six simplified workpieces are processed on six devices in a manufacturing workshop as an example. The results after operation are shown in the following table 3:

| Programme | 1      | 2       | 3       | 4       | 5       |
|-----------|--------|---------|---------|---------|---------|
| C_{max} (min) | 66.8   | 69.2    | 84.5    | 70.6    | 74.5    |
| W_T (min)  | 268.6  | 269     | 277     | 270.6   | 272     |
| E (kg-CO2) | 500.214| 479.194 | 467.154 | 485.204 | 476.114 |

Table 3. Example results of 6 × 6

It can be seen from table 3, that scheme 2 is a better solution. Compared with scheme 1 where the decision variable is biased to the maximum completion time, when the maximum completion time is increased by 2.4, the carbon emission is reduced by 21.02. Compared with scheme 6 where the decision variable is biased to the total load of the machine, the machine load is only increased by 7. Compared with scheme 3 where the decision variable is biased to the total carbon emission, the maximum completion time is reduced by 15.2 In this case, the total carbon emission only increased by 12.04.

From these results, it can be seen that minimizing the maximum completion time, minimizing the carbon emissions and minimizing the total machine load are contradictory goals in the production process of low-carbon scheduling workshop. When the completion time is shortened, the total load of the machine will increase and more carbon emissions will be generated; conversely, when the carbon emissions are reduced, the maximum completion time will increase. Therefore, manufacturers can allocate the weight of each optimization objective according to the production situation of the workshop. When they pay attention to the on-time delivery and production performance, they can increase their weight and ignore the carbon emission; when they pay attention to the carbon emission, they can increase their weight and appropriately extend the completion time without affecting the delivery time; when there is no requirement for production, they can comprehensively consider the three advantages to make the production process more balanced.

5. Summary
The low-carbon scheduling problem is a modern manufacturing model which considers the economic benefits and environmental impact. By optimizing the processing process of the workpiece, the reasonable processing method is adopted to reduce the carbon emission of the machining system. Therefore, this paper studies the scheduling problem of low-carbon flexible job shop, establishes the optimal scheduling model aiming at the minimum completion time, the minimum total machine load and the minimum carbon emission, and verifies the optimal scheduling model proposed in this paper through the simulation of an example by the genetic variable neighborhood algorithm, which can reduce the carbon emission while ensuring the completion time and the total machine load are small volume.

As there are many levels of carbon emission in the production workshop, in the future research, on the one hand, the carbon emission generated in the process of loading and unloading of workpieces will be taken into account to further improve the scheduling model; on the other hand, some new
Intelligent algorithms will be tried to apply to the workshop scheduling problem to improve the speed and quality of solution.

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