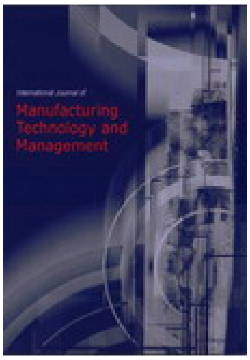

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An optimisation control method of manufacturing whole process based on real-time information drive

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Abstract: In order to overcome the problems of low production efficiency and large deviation in production process tracking, this paper proposes a real-time information driven optimisation control method for the whole production process. Firstly, scan the manufacturing process through the physical unit of the whole manufacturing process. Secondly, the real-time information drive is used to design the information acquisition unit of the production line. Then, the real-time information flow drive of the production line is formed. Finally, the adaptive production and manufacturing parameters are calculated, and then combined with the firefly algorithm to complete the optimal control of the whole production and manufacturing process. The experimental results show that the enterprise output of this method is higher, and the tracking absolute value deviation does not exceed 0.01, indicating that the whole process optimisation control effect of this method is better.

Keywords: information flow drive; real-time acquisition; production parameters; the whole process; firefly algorithm; optimal control.

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1 Introduction

In the modern manufacturing environment, improve product quality, reduce production costs and improve delivery speed has become a manufacturing the concentrated reflection of the enterprise market competitiveness, and it also depending on the manufacturing enterprise whether can in time according to the process progress, to sequence the entire manufacturing process to carry on the reasonable optimisation and control (Wang et al., 2020). With the expansion of business scope and production scale of manufacturing enterprises, the application degree of digital technology is getting higher and higher. In the process of production, a large number of data are produced, which are characterised by multiple sources and complex forms (Chai et al., 2022). This includes a large amount of unvalue-added data, which greatly increases the opacity of the manufacturing process. In order to effectively obtain the information of manufacturing process and improve the transparency of production management, it is urgent to design a reliable optimisation control method for the whole process of manufacturing (Kovacova et al., 2020).

Therefore, a manufacturing network process optimisation and decision-making method based on cloud computing is designed in Shan et al. (2019). This method firstly in cloud computing environment for cloud structure design, and to the needs of customers by means of scenario analysis, presented with box set, then the total cost of production, product delivery time as the optimisation goal, using the robust optimisation method to construct manufacturing process optimisation model, and through the duality theory to simplify the algorithm. This method can improve the production efficiency, but the production process tracking deviation is large. In Wang et al. (2020), an optimisation method for assignment process of mixed-flow production line is designed. In this method, the planned task nodes and equipment capacity are taken as constraints, and the minimum completion time is taken as optimisation objective. On the basis of individual optimisation by genetic algorithm, simulated annealing algorithm is used to obtain the near-optimal production job assignment scheme through several iterations. This method can reduce the production process tracking deviation, but the production efficiency is low. In Song et al. (2019), a production process simulation and optimisation method based on digital factory is designed. This method takes advantage of digital factory simulation way, in the Flexslm environment simulation was carried out on the production line design, after each location information data, according to the simulation analysis results of the simulation data, by adjusting the speed of conveyor belt, increase location methods such as optimising process, this method can shorten the production time, but the production process tracking deviation.

To solve the above problems, this paper proposes a real-time information-driven optimisation control method for the whole process of production and manufacturing. The specific research ideas are as follows:

First, the whole process of production and manufacturing is scanned and monitored. Design the physical unit of the whole process of production and manufacturing, give the physical unit structure diagram of the whole process of production and manufacturing, build the physical unit of the whole process of production and manufacturing to realise the scanning and monitoring of the whole process;

Secondly, production line information collection. Based on the real-time information drive, the production line information collection unit was designed, and the status information of the die table at each trigger point was summarised to form the real-time information flow drive of the production line and complete the collection of the production line information.

Then, the whole process of manufacturing is optimised and controlled. Based on the calculation of adaptive manufacturing parameters, the least time cost and the least processing cost were taken as the optimisation objective to design the objective function, and then combined with firefly algorithm to complete the optimisation control of the whole process of manufacturing.

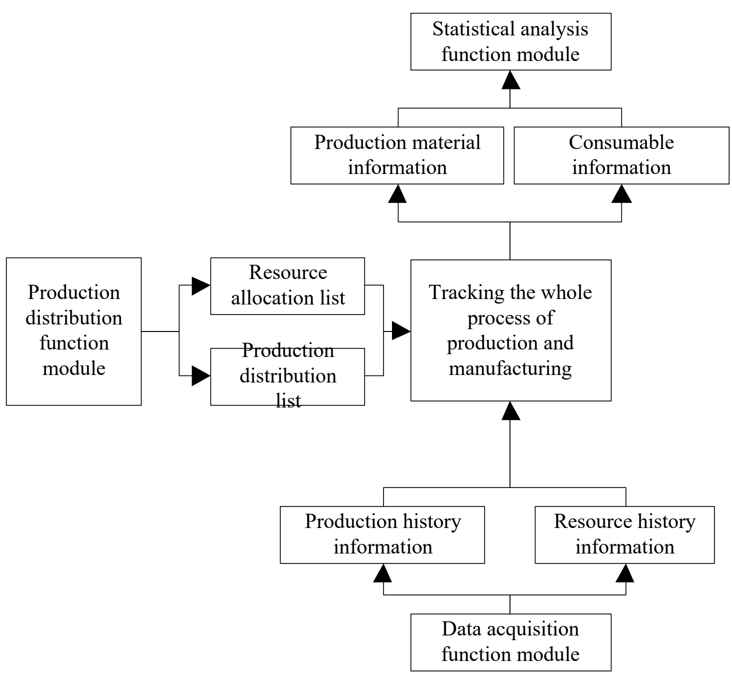
Finally, the optimisation control effect of the whole process of manufacturing is verified by the two indexes of production efficiency and production process tracking deviation.

2 Information processing of the whole process of production and manufacturing driven by real-time information

2.1 Scanning and monitoring of the whole process of manufacturing

The construction of the physical unit of the whole process of production and manufacturing is the basis of the optimisation control of the whole process of production and manufacturing, which can realise the scanning and monitoring of the whole process (Weichert et al., 2019). Therefore, this study designed physical units of the whole process of production and manufacturing by designing functional modules of production allocation, statistical analysis and data acquisition, and updated and tracked the dynamic information of production and manufacturing in real-time, as shown in Figure 1.

Figure 1 Physical unit structure diagram of the whole process of production and manufacturing



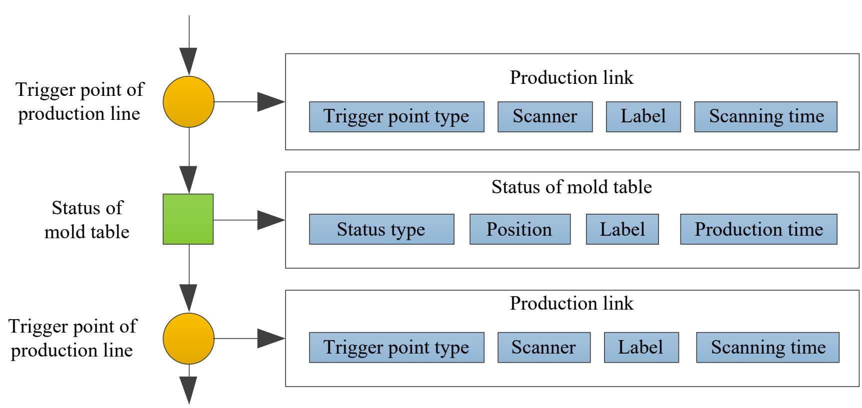
In Figure 1, the design production allocation function module can provide the enterprise with the production and manufacturing material information. The data collection function module is used to collect the production and manufacturing material data, and the statistical analysis function module is used to analyse the generated and manufactured materials and manufacturing data. For abnormal data problems in the production process, the production scheduling module is used to realise the transfer of relevant data. In the scheduling module, the management personnel raise relevant questions, thus forming a process progress checklist. The staff schedules the data according to the checklist, and realises the information exchange of the whole production process through these modules.

2.2 *Design production line information collection based on real-time information drive*

Real-time information driving is to collect massive data in real-time by means of mobile Internet or other relevant software, organise the data to form information, then integrate and refine the relevant information, and form an automatic decision function through training and fitting on the basis of the data. The scanning and monitoring of the whole process of production and manufacturing can be realised by using the physical unit of the whole process of production and manufacturing constructed in Section 2.1. In order to further realise the conversion from the real-time scanning data of the whole process of manufacturing to the position data of the mould table, this study designed the production line information collection unit based on the real-time information driving. After setting several trigger points on the production line, the real-time production information of trigger points was collected to judge the current state information of the production line, and then the manufacturing process of the production line was recorded.

Production line information collection unit consists of 'production line trigger point', 'production link' and 'die state', as shown in Figure 2.

Figure 2 Structure diagram of production line information acquisition unit driven by real-time information (see online version for colours)



The monitored production line die table will pass through each trigger point in turn, and the transition process between trigger points can be regarded as a certain state of the die table. The real-time information flow of the production line can be formed by summarising the status information of each trigger point to upload the mould platform. Driven by this information flow, the collection of production line information, including the position information and status information of the mould platform, can be completed. Among them:

1 Production line trigger point

RFID scanner is installed at each trigger point, which is successively installed at the entrance and exit of each station in the production line. After a change in the mode state, the scanner is triggered to initiate the next production step. Each trigger point corresponds to the scanner, and each scanner has an independent number (Cui et al., 2019; Krisztián et al., 2022).

2 Production link

The starting information of each production link is a kind of instantaneous information generated by trigger points, which can be used to record the production line information transmitted by each trigger point. Production information is the only factor that drives the change of die position. Production process information includes four types of attribute data, which are trigger point type, scanner number, label number and scanning time respectively.

3 Die state

The status information of the die table reflects the current running status of the die table in the production line. Each type of module state information includes four types of attribute data, including module position type, position number, label number and duration of the same state. Where, the position number corresponds to the scanner at its trigger point.

3 Optimisation control of whole process of manufacturing based on real-time information drive

The optimal control method of the whole manufacturing process is an abstract engineering problem. In order to convert it into a mathematical function to solve the problem, this paper proposes a real-time information driven method to design the objective function, add the manufacturing penalty function, and solve the manufacturing penalty function through the firefly algorithm. The obtained solution is the best manufacturing control scheme to realise the optimal control of the whole manufacturing process.

3.1 Adaptive manufacturing parameter calculation

In order to ensure the continuity of different processes in production, adaptive manufacturing parameters are calculated in this study.

In the process of production, the production equipment operation in different settings are simulated values, and differences between different equipment components of raw material quality, the working environment may also exist in different time periods in a variety of factors of production behaviour and production speed causing interference, these factors in different extent affect production line drive constant value. This leads to inconsistent production speed on the production line (Ottman et al., 2019; Nazoykin and Blagoveshchensky, 2019; Liu et al., 2019). Therefore, when calculating the adaptive manufacturing parameters, the control work of the production line should be set as open -loop control according to the demand of production and processing, and the load of the production equipment should be controlled comprehensively under the premise of ensuring the stability of the overall speed. According to the principle of three-phase regulation of load value, the electromagnetic rotation speed in the production line is designed. The setting of this parameter can be expressed by the following calculation formula:

$$\omega = \frac{60f}{n} \tag{1}$$

where ω represents the rotating electromagnetic speed of the production line operating equipment, f represents the operating frequency of AC power supply, and n represents the polar logarithm of the motor rotor of the operating equipment.

Considering that in the subsequent optimisation control process, the rotor of the rotor of the production equipment is difficult to achieve the same control with all the processes on site. Therefore, it is necessary to calculate the speed difference in the control, and carry out adaptive control of the production speed according to the value of the difference. The calculation process of the difference is as follows:

$$\Delta\omega = \frac{\omega - \tilde{w}}{\omega} \tag{2}$$

In the formula, $\Delta\omega$ represents the rotating speed difference and $\tilde{w}$ represents the effective rotating speed of the rotor of working equipment.

In the calculation process, it is taken into account that the speed difference value of the production line operating equipment always varies in the range of 0~1 (Sahoo et al., 2021). Therefore, at the moment when the processing line starts, the value of $\tilde{w}$ can be set to 0 and the value of $\Delta\omega$ can be set to 1. When the production parameters meet the above requirements, the speed difference value is the maximum value. When the production line produces no-load operation, the value of $\tilde{w}$ is infinitely close to ω and the corresponding $\Delta\omega$ value is low. In this case, $\Delta\omega$ is generally less than 0.01. When the equipment in the production line works under the rated load condition, the rated speed difference of the production line operation equipment can be ω_0, according to the actual production demand, ω_0 value is generally in the range of 0.01~0.07. In combination with equation (1) and equation (2), the adaptive manufacturing parameters are calculated. The process is as follows:

$$\tilde{w} = (1 - \Delta\omega) \times \frac{60f}{n} \tag{3}$$

When the operation equipment in the production line is empty, the output power of the equipment will increase synchronously with the increase of the load value of the equipment. In this case, the balance of the operation of the equipment can only be improved by reducing the speed (Jeong et al., 2020; Wang, 2021). Therefore, it is necessary to continuously carry out adaptive debugging of equipment in the production line, so as to ensure the stability of production line speed.

3.2 Design optimisation objective function

Different manufacturing enterprises have different requirements and standards for production line scheduling, but most enterprises will take the objective function as the most reliable basis for production line scheduling (Wang, 2020). From a practical point of view, the optimisation control of the full flow of production and manufacturing is essentially a combinatorial optimisation problem. Under multiple constraints, the optimal collaborative control scheme is found to make the production line processing time is the shortest, the processing cost is the lowest, and then the production income is the highest. Therefore, based on the calculation of adaptive manufacturing parameters, the least time cost and the least processing cost are regarded as the optimisation objective design objective function.

1 Minimum time cost

It is assumed that f_1 represents the objective function of the minimum time cost of production and manufacturing of the full flow, which can be expressed by the formula:

$$f_1 = \min\left(\frac{\max t_i}{t_j}\right) \tag{4}$$

where i represents the product category, j represents the number of processes, t_i represents the time required to produce a product, and t_j represents the time spent in the whole control process.

2 Minimum processing cost

It is assumed that f_2 represents the objective function of the minimum processing cost for the full flow of production and manufacturing, which can be expressed by the formula:

$$C = \min\left(C_1 + C_2\right) \tag{5}$$

where C represents the minimum processing cost of the whole flow of production and manufacturing, C_1 represents the product processing cost, and C_2 represents the penalty cost of advance or delay. The calculation process is as follows:

$$C_1 = \alpha n + \beta q + \gamma r \tag{6}$$

$$C_2 = \sum_{i=1}^{n} w_i \times \left|p_i - d_i\right| \tag{7}$$

where α represents the unit processing cost of the i^{th} product, n represents the number of products to be produced, β represents the unit cost required to replace the device, and q represents the number of replaced devices, γ represents the movement cost of production line devices, r represents the number of movement of production line devices, w_i represents the penalty coefficient of advance or delay of the i^{th} product, p_i represents the completed quantity of i^{th} product, d_i represents the planned processing quantity of i^{th} product.

In order to further improve the control precision of the whole process of production and manufacturing, a penalty function is added in the control process, and equation (5) can be converted into:

$$C = \min\left(C_1 + C_2 + C_\partial\right) \tag{8}$$

$$C_\partial = \partial \times \varepsilon \tag{9}$$

$$\varepsilon = \begin{cases} 1, & \text{Unique production equipment} \\ 0, & \text{other} \end{cases} \tag{10}$$

where C_∂ represents the penalty function, ∂ represents the penalty coefficient, and ε represents the auxiliary parameter of the penalty function, which can be 1 or 0.

3.3 Optimisation and control design of the whole process of manufacturing

On the basis of taking the least time cost and the least processing cost as the optimisation objective function, the following three constraint conditions are set for the optimisation control process:

- Constraint condition 1: the first manufacturing process takes time t_A:

$$t_A \geq t_1 \times l_1 + t_2 \tag{11}$$

where t_1 represents the time of transporting the products to the first processing die table, l_1 represents the distance of logistics loading area, and t_2 represents the waiting time in loading area.

- Constraint condition 2: Processing time of products to be produced t_B:

$$t_B \geq t_3 \tag{12}$$

where t_3 represents the processing time of the i^{th} product to be produced in the j^{th} procedure.

- Constraint 3: The last manufacturing process takes time t_C:

$$t_C \geq t_4 \times l_2 + t_5 \tag{13}$$

where t_4 represents the time required to transport products to the unloading area of the logistics centre, and t_5 represents the waiting time after all procedures are completed.

Under the constraints of the above conditions, firefly algorithm is used to complete the optimisation control of the whole process of manufacturing. Firefly algorithm is a kind of bionic algorithm which takes firefly as the imitation object and solves the optimisation problem by imitating firefly luminous phenomenon. It is of great significance to solve the problem of optimal control. Relevant scholars made the following assumptions in firefly algorithm:

a Each firefly can achieve mutual attraction;

b In firefly algorithm, attraction is positively correlated with brightness of light. As they fly, brighter fireflies attract less bright fireflies to them because they are brighter.

c The brightness value of fireflies should be set reasonably according to the problems to be solved. The brightness value of each firefly at a particular location is fixed, and this variable is subject to the problem being solved.

In the standard firefly algorithm, the solution of the optimisation control of the whole process of production and manufacturing can be regarded as a group of fireflies in flight, and the location of the fireflies with higher brightness can be regarded as the optimal solution. Due to the effect of mutual attraction, all fireflies will keep approaching the fireflies with the optimal position.

Suppose that a and b respectively represent two fireflies, h_{ab} represents the absolute brightness between the two fireflies, g represents the flight distance, and the change process of h_{ab} with g is as follows:

$$h_{ab}(g) = h_b \times \delta \times g \tag{14}$$

where h_b represents the light intensity of firefly b under the condition of $g = 0$, and δ represents the constraint condition of attraction, which generally satisfies $0.01 \leq \delta \leq 100$. The attraction between two fireflies is described as follows:

$$\theta_{ab}(g) = \theta_0 \times \delta \times g_{PQ} \tag{15}$$

where θ_0 represents the attraction of fireflies at the maximum fluorescence point, and the Cartesian distance between two fireflies at positions P and Q is expressed by g_{PQ}. Then the Cartesian distance can be expressed as:

$$g_{PQ} = |P - Q| \tag{16}$$

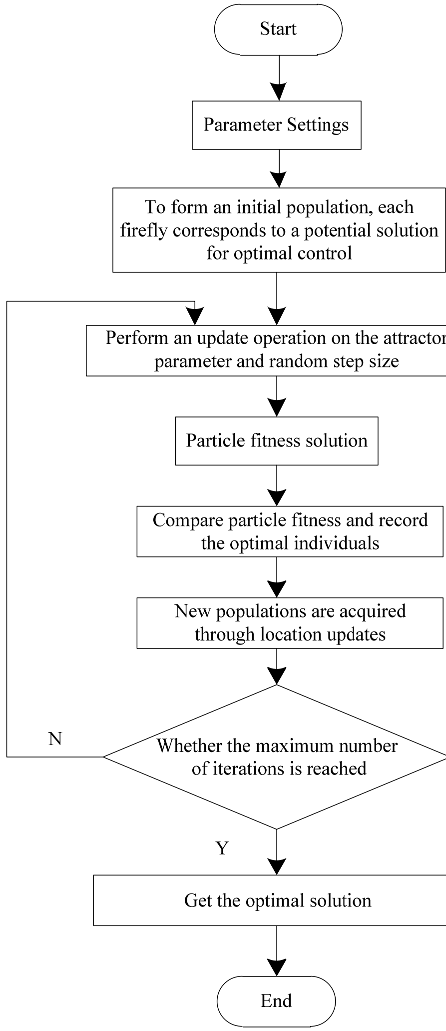
In the process of optimisation and control of the whole process of production and manufacturing, the attraction motion of firefly b with stronger brightness to firefly a can be expressed by the formula:

$$P(t+1) = P(t) + \frac{\theta_{ab}(g)}{\mu} \tag{17}$$

where $P(t)$ represents the influence of firefly's current position, and μ represents the difference between upper and lower limits of the optimisation control objective function of the whole process of production and manufacturing in the search space.

By improving the attractive term and random term of the basic firefly algorithm, a relatively superior initial search environment can be provided for the optimisation control of the whole process of production and manufacturing, so as to effectively play the advantage of firefly algorithm in solving the optimal control solution of the whole process of production and manufacturing. The specific optimisation control process of the whole process of production and manufacturing is shown in Figure 3.

Figure 3 Production and manufacturing process optimisation control flow chart

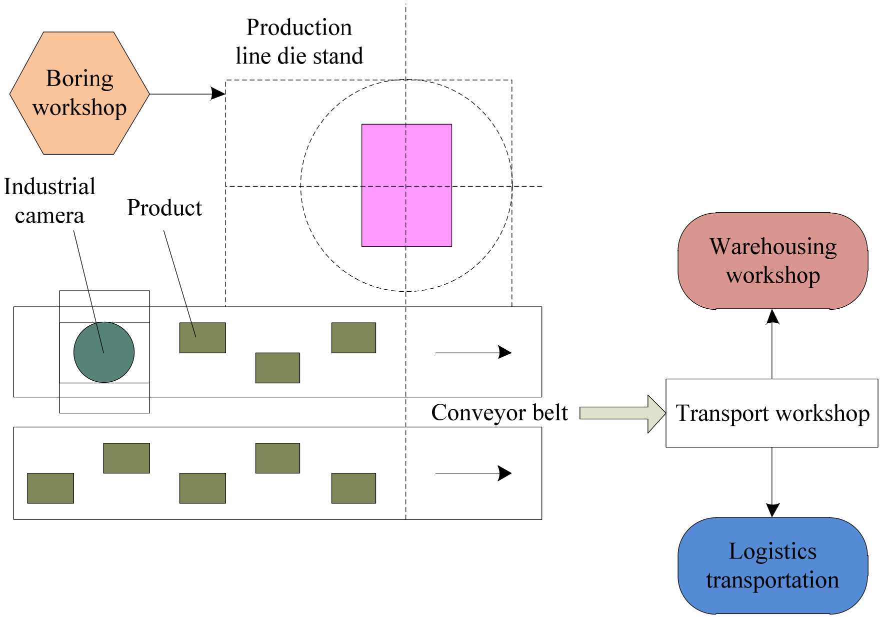


4 Experiment and result analysis

4.1 Experimental design

In order to verify the practical application performance of the above designed optimisation control method for the whole process of manufacturing based on real-time information, the following test process is designed. The participating unit selected in the experiment is enterprise A in a city industrial park. The enterprise for large-scale steel production and processing enterprises. The experimental platform is the basis of the optimisation control performance test of the whole process of manufacturing. The experimental platform is set up in the production workshop of the enterprise, as shown in Figure 4.

Figure 4 Schematic diagram of experimental platform (see online version for colours)



MATLAB software was used to simulate the optimisation control process of the experimental platform and verify the effectiveness of method of this paper. In order to avoid too single experimental results, method of Shan et al. (2019) and method of Wang et al. (2020) were used as comparison methods to complete performance verification together with method of this paper.

4.2 Index design

a Enterprise steel production m_p. The output of moulded steel produced per hour after optimised control can directly reflect the effectiveness of control methods for different manufacturing processes. The specific calculation formula is as follows:

$$m_p = \frac{m_{pd}}{\Delta t} \tag{18}$$

In the above formula, m_{pd} represents the total steel production of the enterprise, Δt represents the time of producing m_{pd} tons of steel. The higher the output, the higher the production efficiency, the better the effect of optimal control.

b Absolute deviation d_p of whole process tracking. The specific calculation formula is as follows:

$$d_p = \frac{h_p}{j_o} \tag{19}$$

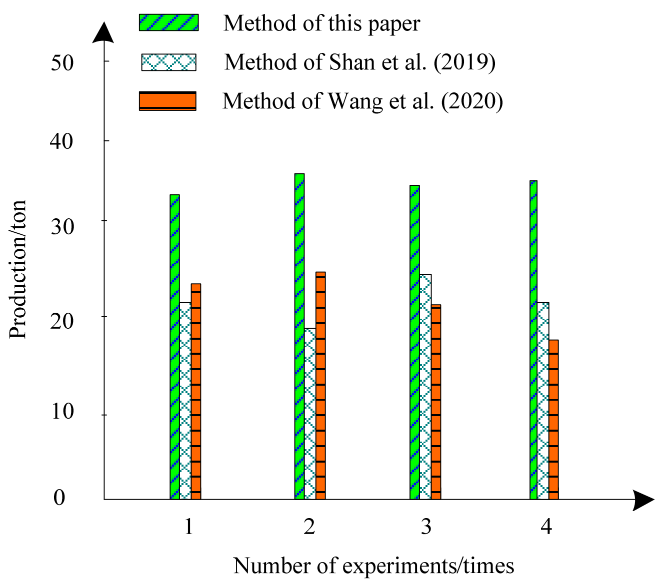
In the above formula, h_p represents the measured value of tracking the whole process of production and manufacturing, and j_o represents the actual position of tracking the whole process of production and manufacturing. The deviation of absolute value of tracking of the whole process of production and manufacturing, the smaller its value is, the better the tracking effect of the information of the process of production line is, and the better the control of the production and manufacturing process is.

4.3 Result analysis

4.3.1 Steel production of the enterprise

First, the hourly output of moulded steel produced by enterprise A was tested after optimising control by different methods. The results are shown in Figure 5.

Figure 5 Steel production of enterprise A after applying different methods (see online version for colours)

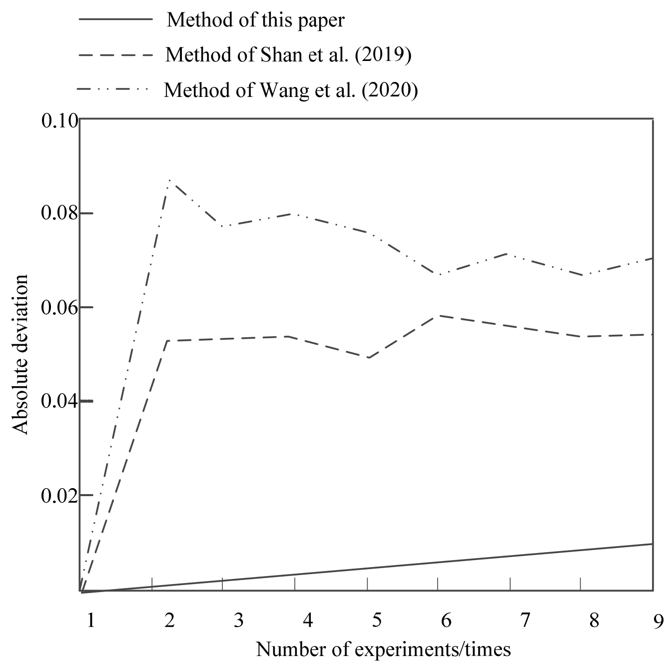


According to the results shown in Figure 5, the steel output per hour of method of this paper is always more than 30 tons after optimising and controlling the whole manufacturing process of enterprise A, which is significantly higher than the two comparison methods. At the same time, in the four experiments, the variation trend of steel output of enterprise A is relatively stable after the application of method of this paper, but the steel output is not stable after the application of the two comparison methods. The above results show that method of this paper has more advantages in improving the production efficiency of enterprise A and can achieve better control. This is because this method can summarise the mould status information at each trigger point, form the real-time information flow drive of the production line, complete the collection of the production line information, take the minimum time cost and the minimum processing cost as the optimisation objective design objective function, and then combine the firefly algorithm to complete the optimisation control of the whole production process, so as to effectively improve the steel production of the enterprise.

4.3.2 Absolute deviation is tracked throughout the manufacturing process

Then verify the tracking absolute deviation of the whole process of production and manufacturing with different methods, as shown in Figure 6.

Figure 6 Comparison results of absolute value deviation tracking in the whole process of production and manufacturing



According to the results shown in Figure 6, the maximum deviation of absolute value of method of Shan et al. (2019) for tracking results of the whole process of production and manufacturing is 0.06. After using method of Wang et al. (2020), the maximum deviation of absolute value of tracking results of the whole process of production and manufacturing is 0.083. However, after the application of method of this paper, the absolute value deviation of the tracking of the whole process of production and manufacturing is not more than 0.01, indicating that method of this paper has a better tracking effect on the information of the production line process and is more conducive to the regulation of the production and manufacturing process. This is because this paper uses real-time information to drive the design of the production line information collection unit, summarises the mould status information at each trigger point, and uses the firefly algorithm to complete the optimisation control of the whole production process, effectively reducing the absolute value deviation of the whole process tracking. In the long run, this method is more suitable for the optimisation control of the whole production process.

5 Conclusions

In order to realise the control effect of the whole process of manufacturing, this study designed a new optimisation control method based on real-time information driving. Firstly, the physical unit of the whole process of production and manufacturing and the information collection unit of the production line are designed. The information collection of the production line is completed by summarising the status information of the die table at each trigger point through real-time information driving. Then, the adaptive manufacturing parameters were calculated, and the least time cost and the least processing cost were taken as the optimisation objective function, and the firefly algorithm was used to complete the optimisation control of the whole manufacturing process. The experimental results show that:

1 After using method of this paper to optimise and control the whole manufacturing process of A company, the steel output per hour is always more than 30 tons, indicating that method of this paper has more advantages in improving the production efficiency of A company and can achieve better control.

2 After the application of method of this paper, the absolute value deviation of the tracking of the whole process of production and manufacturing is not more than 0.01, indicating that method of this paper has a better tracking effect on the information of the production line process and is more conducive to the regulation of the production and manufacturing process.

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