Research on Logistics Simulation and Optimization of Die Forging Production Line Based on Flexsim

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Abstract. Long forging production cycle and low equipment utilization are the important problems currently facing domestic die forging ring production lines. To solve this problem, a simulation optimization method for die forging production line based on Flexsim was proposed. Firstly, the ECRS theory method was used to analyze the bottleneck process of the production line. Then, a logistics simulation model of die forging production line based on Flexsim, the parallel and cyclic processing steps were set reasonable parameters and simulated. Next, through logic analysis, methods such as adding processing equipment, improving equipment efficiency and balancing equipment handling tasks were used to optimize and improve the production line. Finally, compared and analyzed the original and optimized model. The simulation results show that the optimized production line equipment task allocation tends to be rationalized, the equipment utilization rate is increased by 4.34%, and the product cycle time is reduced by 27.65%, and optimized planning and design are achieved.

Keywords: Production logistics; Parallel processing; Cyclic processing; Flexsim, Modeling; Simulation optimization.

1. Introduction

With the rapid development of China's manufacturing industry, the research on production logistics systems has attracted more and more attention from scholars. Applying computer simulation technology, simulating dynamic production processes, and digging out bottlenecks in the system have extremely important practical significance for optimizing production logistics systems, shortening production cycles, and improving production efficiency [1].

Flexsim, as a logistics simulation software that can dynamically simulate the actual operation of the production line, has been widely used in practical engineering problems [2]. Chang et al. [3] Adopt the value flow graph analysis method, use Flexsim software to simulate the assembly production logistics, and verify the feasibility of the optimization plan. Li et al. [4] The Flexsim software is used to simulate the logistics of the press-fitting production line, and the production efficiency of the tire press-fitting is improved through the production line balancing method. Kluska et al. [5] Based on Flexsim hybrid modeling method and agent simulation method, it provides a design method of production logistics.
system. Zhu et al. [6] The use of Flexsim to model and simulate the operation of the cold chain logistics distribution center to achieve efficient distribution of cold chain logistics. Shortening the production cycle and improving production efficiency are important components of the optimization of the production logistics system. This article mainly analyzes the forging process of a company's die forging production line, with the goal of minimizing the completion time of all workpieces and improving equipment utilization. Use the industrial engineering theory ECRS analysis method for preliminary analysis, and then use Flexsim to establish the forging production line model. The simulation analysis obtains the blocking rate, idle rate, work ratio, and waiting ratio of each process. Through the processing and analysis of simulation data, the Optimize and improve the unreasonable places, so as to improve the equipment utilization rate of the forging line, and then improve the production efficiency.

2. Analysis of the Status of Die Forging Production Line

2.1. Production Process
This article focuses on the forging process of a company's die forging production line. According to the capacity of the material rack, heating furnace and cooling station, the production method of processing 60 workpieces at a time is determined by the least common multiple. In accordance with the principle of energy saving and the particularity of the ring die forging production line, a batch of workpieces can be processed without interruption, and the production operation mode adopts three shifts. The forging line has a total of 23 procedures and 20 stations. The entire production process includes parallel procedures of the same model of equipment and cyclic processing of general equipment. The standard processing flow chart of the forging production line is shown in Figure 1, and the processing time and other parameters are shown in Table 1.

![Figure 1. Standard processing technology flow.](image-url)
Table 1. Processing time and other parameters.

| Station                  | Processing time (s) | Carry time (s) | Capacity | Station                  | Processing time (s) | Carry time (s) | Capacity |
|-------------------------|---------------------|----------------|----------|-------------------------|---------------------|----------------|----------|
| rack shelf stack        | 0                   | 6              | 60       | dimension measurement2  | 20                  | 50             | 1        |
| code reading 1          | 2                   | 36             | 1        | heating furnace3        | 5400, 3600          | 36             | 2        |
| heating furnace 1, 2    | 10800               | 32             | 6        | Ring rolling machine    | 300, 120            | 36             | 1        |
| Three-station press     | 300                 | 20             | 1        | dimension measurement3  | 20                  | 50             | 1        |
| press                   | 2                   | 50             | 1        | code reading4           | 2                   | 300            | 1        |
| code reading2           | 2                   | 300            | 1        | Pre-rolled cooling      | 28800               | 300            | 60       |
| ring billet cooling     | 2880                | 300            | 60       | Ring rolling machine    | 120                 | 15             | 1        |
| repair area             | 3600                | 300            | 60       | code reading5           | 2                   | 15             | 1        |
| ring billet transfer    | 0                   | 0              | 60       | Finish cooling          | 28800               | 15             | 60       |
| code reading3           | 62, 2               | 70             | 1        | Laser coding            | 30                  | 0              | 1        |

2.2. Process Optimization Analysis

In the engineering practice, according to the actual operating process, the industrial engineering theory and method ECRS analysis principles are used, that is: eliminate, combine, rearrange and simple, detailed and comprehensive analysis of the entire production line [7]. The theoretical analysis and scheme of ECRS are shown in Table 2.

Table 2. ECRS theoretical analysis and plan.

| Optimization Strategy | Content                                                      | Measures                        |
|-----------------------|--------------------------------------------------------------|---------------------------------|
| Eliminate             | Unnecessary processes and transportation can be cancelled    | Repeat process                  |
| Combine               | Necessary equipment and personnel that cannot be cancelled   | Combine multiple devices         |
| Rearrange             | Cancellations and mergers fail to meet optimization requirements | Adjustment process              |
| Simple                | When none of the above methods can be used                    | Using advanced equipment and simple methods |

Through the optimization analysis of the process of the production line, find the matching point of the coordinated work of equipment, operators and robots. Combined with the 5W1H work analysis method, you can find the improvement direction of the production process and build a new work process [8]. Theoretical method analysis shows that the current problems exist in the production line: (1) According to the characteristics of the heating furnace processing multiple workpieces at a time, after the completion of heating, it will cause congestion of downstream production line equipment, and there is an unreasonable resource allocation. (2) The robots M2 and M3 are unreasonable in the amount of handling tasks. M3 has many times of transportation, long routes, and overloaded. (3) The processing capacity of general equipment in the pre-rolling and final rolling stages is limited, which causes certain work pieces to be blocked.

2.3. Production Line Balance Rate

Production line balance means that the load difference between processes or stations is the smallest, and the flow is smooth, reducing the waiting or detention caused by operating time [9]. It can speed up product flow, reduce production cycles, improve operating efficiency, optimize operating processes, and reduce costs.
Due to the increasing degree of automation of production lines, the calculation of the balance rate of the production line, on the basis of traditional calculations, also needs to consider the existence of multi-person operations or individual stations in the same station, the process may have automated equipment, unmanned operations and other problems.

\[ \text{LOB} = \frac{\text{Sum of time of each process}}{\text{Bottleneck time of average working time of human or main equipment in each process} \times \text{Sum of people or equipment}} \times 100\% \]

3. Model Establishment and Adjustment Parameters

This article is based on the actual layout of the forging production line. According to the preliminary logistics layout plan, the actual production line of the factory is reduced by the same proportion, and the processor is arranged at the actual position of each equipment. This ensures that the model established can accurately describe the actual system [10]. According to the processing requirements of die forging, the model establishment requires 1 generator, 2 temporary storage areas, 21 processors, 6 operators, 3 robots, 2 forklifts. The Flexsim simulation model of the forging production line is shown in Figure 2.

The key to the simulation is the establishment of the model and the control of the parameters. This research combines the actual production needs of the forgings to match the actual production data for the established model. The parameter settings include equipment processing time, equipment capacity, priority processing, and workpiece identification, and other ancillary conditions. The actual operation of the forging production line is more complicated and can be divided into three processing stages: blank making stage, pre-rolling stage, and final rolling stage. This parameter setting only describes the main processes. According to the characteristics of the small batch production of the forging production line, the generator needs to stop when it needs to produce 60 workpieces, so the model termination and opening conditions are set constraints in its creation trigger. The temporary storage area can be used as a rack to set the corresponding capacity to meet the single production demand. In the heating furnaces 1, 2 parallel processes, a scheduling strategy is added-flexible allocation, using the priority of idle equipment and priority processing, which can balance the task allocation and production rhythm between multiple devices of the same model. The heating furnaces 3, 4, and 5 also adopt a flexible distribution logistics scheduling strategy.

![Figure 2. Flexsim simulation model of forging production line.](image)

According to the die-forging process, there are many chances of defective products, which need to be repaired, so set the percentage of defective rate on the code reading platform. Heating furnaces 3, 4, 5, conveyor belt 2, code reading 3, etc are general equipment. In actual production, for workpieces processed by general equipment in the pre-rolling stage and final rolling stage, the equipment needs to recognize whether the workpiece has been processed once by the shape of the workpiece and give the corresponding time to process. The parameter setting of this model mainly deals with the label of the workpiece, the equipment identifies the type of the workpiece for processing by identifying the label of the workpiece, ensuring that the processing status of the workpiece is consistent with the actual processing process. In addition, set priorities for the equipment to process differently labeled workpieces, and prioritize processing of the previous batch of workpieces on general-purpose equipment. In order to avoid the chaos of the flow of the workpiece, the expansion machine and the size inspection 3 are...
constrained and managed. The robot's transfer time in each process is different, so a global table is used in the model to manage the robot's transfer time in each process. At the same time, the network node is used to set the planned logistics trajectory of the robot.

4. Cause Analysis and Improvement

4.1. System Simulation Analysis

Bottleneck procedures and equipment and personnel arrangements in the manufacturing process are the two major factors affecting production. Therefore, analysis of equipment processing time, blocking time, and idle time is needed to dig the potential productivity of the production line, eliminate bottlenecks and improve equipment utilization rate [11].

The system model is completed, with the goal of minimizing the completion time of all workpieces, reducing idle rates, and increasing equipment utilization. Analyze the motion state of the production line, obtain the statistical results of the running time of each entity of the system after multiple simulations, and use MSOffice Excel to output the simulation data to obtain the total processing time of 52:24:51. In order to analyze the model in a more targeted and intuitive way, the main equipment utilization rate derived from Flexsim is shown in Figure 3. The processing time of heating furnaces 1, 2, 3, 4, and 5 respectively accounted for 29.28%, 29.4%, 57.4%, 49.27%, and 43.36% of the total processing time. The processing time of the three-station press, ring rolling machine, and bulging machine were respectively accounted for 9.54%, 13.36%, 3.82% of the total processing time, and the ring billet cooling, pre-rolling cooling, and final rolling cooling processing times accounted for 39.96%, 57.57%, and 54.19% of the total processing time. It is analyzed from Figure 4 that during the entire production process, the equipment runs relatively smoothly, but the overall equipment utilization is not high, and there are also high and low equipment utilization in the internal mismatch; Congestion occurred when reading code 1, heating furnace, cooling, repair area, reading code 3, conveyor 2, dimension measurement 2, indicating bottleneck procedures between upstream and downstream equipment, and there is room for further optimization.

![Figure 3. Utilization of major equipment.](image)

The inner circle of Figure 4 (a) represents the proportion of the robot's tasks during processing, and the outer circle represents the utilization rate of the entire processing process. From this analysis, it can be concluded that the proportion of robot task distribution is unbalanced and M1 serves three processes. M2 serves one process, M3 serves seven, and M1 and M3 have long running routes, which has a certain
impact on the handling of heating furnace workpieces. The task balance can be redistributed to achieve operational balance. From the layout of the production line and Figure 4 (b), it can be obtained that the utilization rate of the operators is not high. Due to the relatively centralized configuration, the operators in two processes can be combined to improve the utilization rate.

![Figure 4. Utilization rate of main execution equipment.](image)

4.2. Optimization

According to the existing problems of the forging production line, according to the optimization goal, combined with the actual operation of the production line, an optimization plan is made [12]. Through improvement and optimization, the number of heating furnaces and robots that meet production requirements can be determined, and various manufacturing links can be improved, thereby reducing the overall imbalance of the production line. Based on the preliminary analysis of the above simulation results, two aspects can be analyzed to obtain an optimized solution.

From the perspective of reducing the processing time: (1) improve the yield, reduce the repair rate of the workpiece, improve the production efficiency of the forging line, and reduce the repair time. (2) Reduce the heating time by improving the temperature conversion efficiency of the heating furnace. (3) Speed up the heat dissipation of the workpiece and reduce the standing cooling time.

Solution one: adjust the heat transfer efficiency of the heating furnace to 80% of the original; speed up the heat dissipation of the workpiece and improve the heat dissipation rate of the original 80%. After running the optimization model, the processing time was 41:02:48, and the production cycle of the workpiece was shortened by 21.69%.

From the perspective of increasing the utilization rate of equipment: (1) Adopt pull production method, pull the input of raw materials in the rack to avoid material accumulation [13]. (2) Increase the feedback mechanism, to reduce the input of rack workpieces in the event of a blockage in the downstream stage, to balance the amount of work in process on the production line [14]. (3) Based on the principle of economical operation route, set motion trajectories for robots, remover, and crane to optimize the transportation distance [15]. (4) Due to the large number of tasks, M2 and M3 task weights are redistributed, to reduce the process backlog caused by M3. (5) There are many tasks in the pre-rolling and final rolling stages. An additional heating device is added to speed up the workpiece processing speed. (6) By merging operators from multiple processes, the operator utilization rate is increased and labor costs are reduced.

Solution two: add a heating furnace to the general process, balance the robot task assignment, and combine operators in adjacent processes. After running the optimization model, the main equipment operation results are shown in Figure 5. The entire production processing time is 47:32:13, and the production cycle of the workpiece is shortened by 9.3%. Heating furnace 1, 2 equipment utilization increased by 3.12%, 2.9%, three-station press, ring rolling machine, bulging machine processing time equipment utilization increased by 0.96%, 1.34%, 0.38%, ring billet cooling equipment Utilization increased by 4.14%.
In order to meet the production needs, shorten the processing time, and improve the utilization rate of equipment and personnel. In summary, the two optimization schemes are determined to adjust the heat transfer efficiency of the heating furnace, speed up the heat dissipation of the workpiece, add a heating furnace to the general process, balance the robot task assignment, and merge the operators of adjacent processes.

Running the optimization model, the total processing time was 37:55:03, and the production cycle of the workpiece was reduced by 27.65%. It can be seen from Figure 6 that after the optimization of the main equipment such as the heating furnace, the three-station press, the ring rolling machine, and the expansion machine, the utilization rate has improved significantly, and the idle rate and the blocking rate have also decreased. By adjusting the heat transfer efficiency of the heating furnace and accelerating the heat dissipation of the workpiece, the overall processing time can be greatly shortened, and the processing efficiency of the workpiece is improved; the general equipment is blocked at the pre-rolling and final rolling stages, which is a bottleneck process of the system. Adding a heating furnace improves the overall utilization rate of the heating furnace. Due to the preliminary simulation results, the operator has more idle time and does not make good use of the operator, resulting in a waste of human resources. By combining operators in adjacent processes, improved operator utilization and reduced labor costs. After optimizing the execution equipment, as shown in Figure 7, the task re-assignment of M2 and M3 robots makes the division of robots more clear, but the overall utilization of the production line is less improved. After the operator's resource integration, the personnel utilization rate has greatly improved, and the personnel arrangement has become more rational.

4.3. Comparison of Production Line Optimization Results
The improved optimization plan can find a balance point in improving the smoothness of the production line, improving production efficiency, and reducing logistics costs.
From Table 1, the sum of the time of each process can be obtained, and the working time of the heating furnace of the bottleneck process, so as to obtain the balance ratio of the production line before optimization is 13%; from the final optimization plan, the total process time and the working time of the bottleneck process are obtained, so the optimized production line balance rate is 15%.

From the balance of the production line before and after optimization, it can be seen that the balance ratio of the improved and optimized forging production line has been improved, from 13% to 15%. Due to the longer heating time of the heating furnace during the forging production process, the balance of the production line has been initially improved. And other processes are more balanced, and equipment utilization has improved significantly.

The comparison and analysis of the optimization of the entire station of the production line. As can be seen from Figures 8 and 9, the overall processing rate of the station has increased to varying degrees. The improvement of the heat conversion efficiency of the heating furnace has greatly improved the utilization rate of the equipment. The processing rate of other major equipment has increased by an average of 4.34%, the idle rate of the equipment has decreased, and the production and processing have become more balanced.

5. Conclusion

Based on the actual running status of the die forging production line, combined with the processing characteristics of die forging forming, this paper uses Flexsim software to establish a simulation model of the forging production line, simulates and analyzes the system, digs out the bottleneck process, and uses logic analysis and industrial engineering theoretical analysis to obtain the optimization plan. Through the analysis of the production data of the optimization model, the optimization of the heat transfer efficiency of the heating furnace and the general process equipment, the optimized production line not only improves the equipment utilization rate of each production link, shortens the product cycle, and reduces the idle rate of each process. This optimization model has important research significance for the reasonable allocation of equipment tasks of forging production lines, improving equipment utilization, and reducing production logistics costs, and has certain reference value for future research on other production line optimization problems.

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