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# Modeling and Simulation of Water Bottle Packaging Production Line

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**Abstract:** The bottling production line has a complicated process, and uses a combination of modeling, simulation, and optimization to analyze the load of each production station and rationally arrange production system resources. Use plant simulation to simulate the physical production line, analyze the production equipment to introduce multi-level experiments in the capacity optimization process of the temporary storage area, and analyze the signal-to-noise ratio of the data to determine the weight ratio of each temporary storage area affecting production efficiency. The actual workshop finds a low-cost and high-efficiency ratio scheme. The constraint theory (TOC) was used to find the bottleneck of the production line, and the improvement plan of the station was proposed and the program verification was feasible in the physical workshop, and the production process was optimized.

## 1. Introduction

With the rapid development of China's economy and increasing market demand, the automatic bottle packaging production line is gradually integrating into people's daily life. The quality and efficiency of bottle packaging are closely related to the efficiency of the enterprise. In the context of the low-carbon economy era, in order to enhance comprehensive competitiveness, enterprises are increasingly demanding green, energy-saving, safe, and independent innovation designs.The production process of the bottled packaging production line is complicated, and there are many processes such as sleeve labeling, laser coding, heat shrinking, and stacking and packaging. However, the processing equipment of each process is different, the theoretical processing time of each process is different from the actual processing time, the reliability of each equipment is different, and it is easy to cause blockage in mass production, resulting in uneven production load of each station, which is serious. Lead to the entire production line.If the preparation is too small, it will cause the line stoppage caused by the shortage of materials, which will ultimately affect the production efficiency of the enterprise [1].Cannot make full use of the production capacity of the equipment, and the stability of the market demand is very high [2].Eliminate production bottlenecks [3]. Configuring the staging area [4]. Reasonable optimization of the process [5], Is the main way to improve the efficiency of the production line. In order to integrate different types of equipment into a highly efficient and fully automated production line, this paper uses Siemens plant simulation software to simulate the production line, design multi-level and multi-factor analysis to analyze the factors affecting the production line efficiency, and apply the constraint theory to find the bottleneck, and optimize the above problems

## 2. Automatic bottle production line production process

### 2.1 Introduction to the process of bottle packaging

The bottle packaging production line includes the following processes:

The sleeve labeling process: the program control sleeve labeling machine is adopted. The main function of the labeling machine is to carry out the labeling of the vessel. According to the bottle's requirement for the size of the label, the label is sent to the center pillar and waits for the labeling to cut off the label that has been sent to the center pillar. The sleeve labeling machine is under artificial control. Set parameters such as production speed, label length, labeling, labeling, bottle delay, etc., and manually turn on the device.

Laser coding process: Laser coding machine is a high-tech product integrating laser technology, precision machinery, electronic technology, etc. Generally, the optical laser and high-speed scanning galvanometer are used, and the marking control software is used for common commodities in daily life. The whole machine of the coding machine is small, the interface is intuitive, and it is convenient for users to process.

Heat shrinkable sleeve labeling process: The RL1200 shrink packaging machine is used to wrap the shrink film around the product or the package, and after heating, the heat shrinkable film shrinks and wraps the product or the package. The maximum temperature of the heat shrinking furnace: 160-260℃ can be adjusted arbitrarily. The power is 22KW, including two fans with a power of 1.1KW, using a three-phase five-wire 380V50HZ power supply.

Packaging container finishing process: using the packaging system of model BZL150Z, the power is 0.75KW. When the water bottle reaches the finishing system, the sensor device is triggered. Each 12 bottles trigger a pushing device to send the stacked bottles to the fully automatic heat. Shrink film sealing and cutting machine.

Heat shrinkable film air cutting process: RFL1200 automatic shrink film sealing and cutting machine is used for sealing and cutting before heat shrink packaging machine to adapt to different width products. The maximum output per minute is 8-12 bags, and the compressed air consumption is 0.6-0.8Mpa per minute.

### 2.2 Process flow

The process flow of different packaging production lines is different. The processing flow of the laboratory water bottle packaging production line is introduced below. The preparation of the filling water bottle is completed as shown in Fig. 1, the labeling is carried out according to the size of the bottled water, and the production date of the water bottle is carried out. And the batch coding, shrinking and labeling through the heat shrinking furnace, packing the mineral water bottles according to the customer's requirements, packing the heat shrinkable film of the bottled water bottle, and putting the whole package into the heat shrinking furnace for heat shrink packaging.

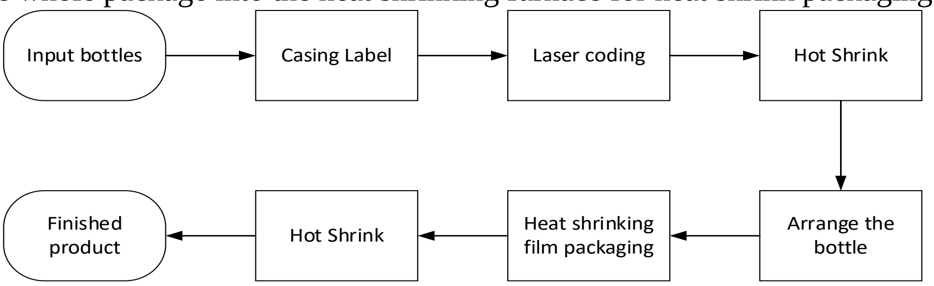


Figure 1. Bottle packaging process.

## 3. Water bottle packaging production line simulation

The entire packaging production line is a complex system, and the model of the system is difficult to describe with mathematical formulas. At the same time, with the development of digital manufacturing technology, the production line simulation technology is widely used in production line optimization [6].It is based on simulation technology and models various stations and production processes on the production line [7].Create a complete manufacturing process in a virtual environment and optimize production configuration [8].So we can use simulation to effectively solve this problem, making the analysis line intuitive and efficient. However, the processing time of each station in the process of water bottle packaging is fluctuating, and the reliability of machinery and equipment is widespread. Therefore, using the simulation platform plant simulation to map the various equipment stations in the physical workshop in the simulation platform, make the physical production line correspond to the virtual production line, and input its theoretical parameters into the virtual model to obtain the simulation model.

### 3.1 Plant simulation

Plant simulation is a widely used software in the field of shop floor simulation. It is developed by Siemens to enable users to simulate and optimize production logistics systems and processes. It can analyze the performance indicators of various stations in the production line in the simulation environment, such as analyzing the system output rate. Personnel equipment load, production bottleneck, etc [9].

### 3.2 Establishment of simulation model

Based on the physical production line of the water bottle packaging process, the plant simulation software is used to map the actual equipment station of the physical workshop. The specific process is as follows. The production line is a one-way pipeline, and the production line model shown in Fig. 2 is established according to the processing flow chart and the actual layout of the production line. The model contains the production process from the completion of the filling of the water bottle into the production line to the completion of the package and into the storage area, reflecting the operation of the packaging line. After the model is built, the various stations and the transfer system theoretical parameters are input into the simulation model. The production line is named Line 1, and then the same simulation model is constructed. According to the measured average processing parameters such as processing time or speed, and historical production. The data is obtained from the reliability of the equipment, and each station is coded. The production line is named Line2. It is convenient to calculate the production efficiency of the production line later. Since Line2 is a parameter obtained from historical processing data, it is instructive to use this model for simulation optimization.

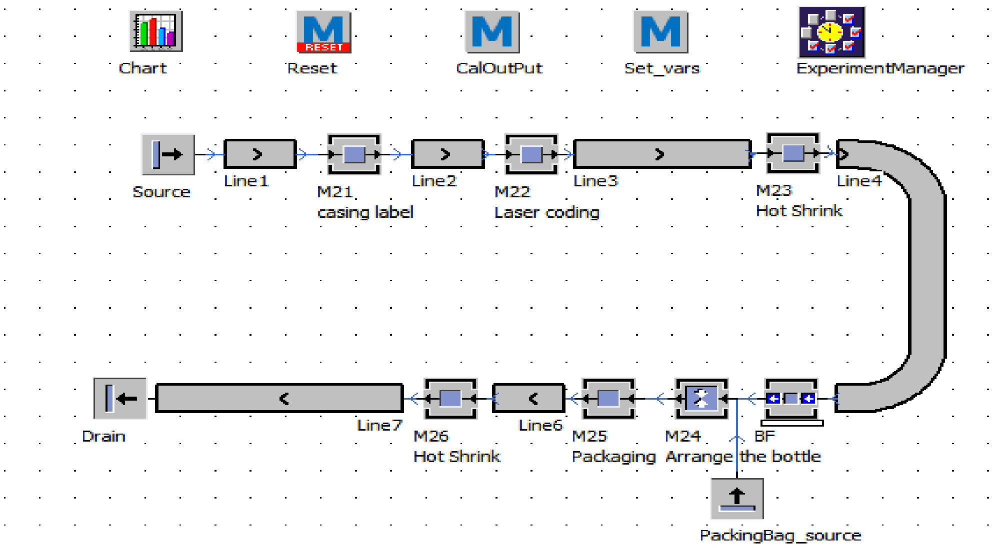


Figure 2. Simulation model of bottle packaging production line.

## 4. Multi-factor multi-level simulation experiment

### 4.1 Staging area setting

Due to the objective problems such as fluctuations in production time and equipment reliability, each station of the production line needs to be equipped with an appropriate proportion of temporary storage area. To solve the problem of cost waste caused by inaccurate capacity in the temporary storage area, multi-factor and multi-level simulation experiments are designed. You can find the appropriate ratio of the capacity of the temporary storage area. Since M21 is the first station for supplying raw materials, there is enough capacity in the temporary storage area before the M24 station, so the temporary storage area is no longer set. The front ends of the remaining four stations are respectively set to four temporary storage areas numbered BF1-BF4.

### 4.2 $7^2 \times 6^2$Factor design

According to the actual production line, the multi-factor and multi-level experiments can be designed for the maximum temporary storage area capacity space. The actual maximum capacity BF1 and BF2 capacity is 31, and the maximum capacity of BF3 and BF4 can be set to 21. To improve the simulation efficiency, the capacity of the BF1 and BF2 temporary storage area is set from 1 to 31 in increments of 5; the capacity of the BF3 and BF4 temporary storage area is set from 1 to 21, and the increment is 4 as shown in Table 1, for a total of 1764. Sub-simulation experiment. Each simulation time is 8h. After the simulation test, the HTML format report can be obtained, and 1764 sets of experimental results can be obtained. According to the experimental data, it can be clearly found that the productivity maximum value and the minimum value have a large difference. From the table data, the maximum ratio 31/31/17/17 is not the highest production efficiency.

Table 1. Factor ratios for multilevel experiments.

| Input value | BF1 | BF2 | BF3 | BF4 |
|---|---|---|---|---|
| Lower level | 1 | 1 | 1 | 1 |
| Upper level | 31 | 31 | 21 | 21 |
| Increment | 5 | 5 | 4 | 4 |

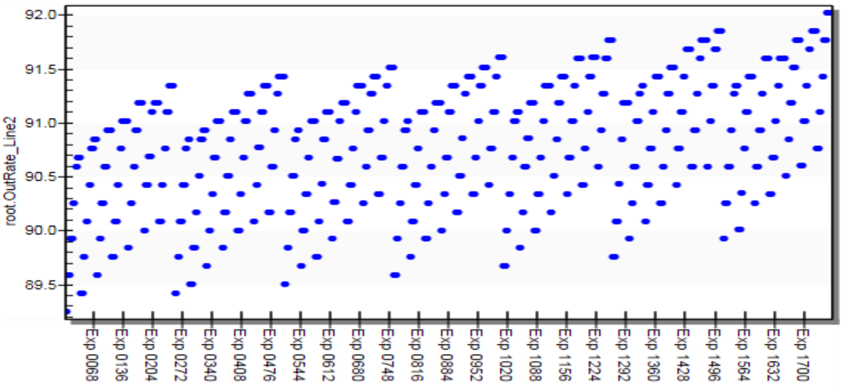


Figure 3. Multi-level factor experiment results.

### 4.3 Experimental data analysis

The simulation results were analyzed and evaluated using the analysis method of Minitab software. The experimentally obtained 1763 sets of data are imported into the table for signal-to-noise ratio analysis in the software to obtain the main effect map, as shown in FIG4.

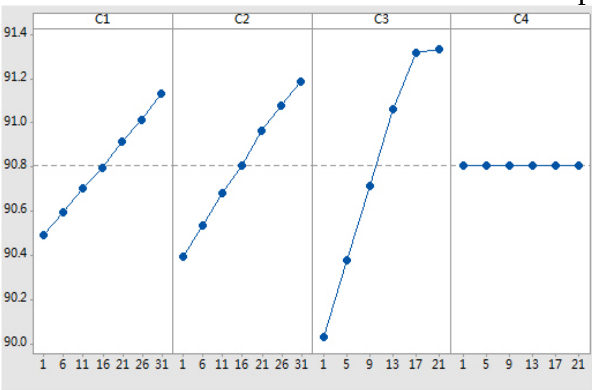


Figure 4. Buffer capacity size main effect diagram.

C1-C4 corresponds to BF1-BF4 respectively. It can be seen from the figure that the capacity of BF1-BF3 is the main factor affecting the efficiency of the production line. The capacity of BF3 has the greatest impact on the efficiency of the production line. The influence of BF1 and BF2 on the efficiency of the production line is basically the same. BF4 has almost no effect on the efficiency of the production line. According to the influence of the capacity of each temporary storage area on the output rate of the main effect diagram, six sets of higher productivity ratios are selected from the simulation experiment data, as shown in Table 3. Since BF3 and BF4 occupy more space, the BF3 should be selected first. The lowest ratio of BF4 capacity is taken as the optimal ratio. Secondly, considering the capacity of BF1 and BF2, we choose BF1-BF3 capacity to be 21/31/13. Since BF4 capacity has little effect on the production line efficiency, we decided not to set BF4. storage cache.

We will select the temporary storage area ratio and set the production line for 24h simulation to get the production efficiency increased to 87.67%, and the production efficiency is obviously improved.

Table 2. Multilevel experimental results of factor ratio and results.

| | BF1 | BF2 | BF3 | BF4 | Out Rate Line |
|---|---|---|---|---|---|
| EXP1219 | 21 | 26 | 21 | 1 | 91.61 |
| EXP1243 | 21 | 31 | 13 | 1 | 91.60 |
| EXP1429 | 26 | 21 | 17 | 1 | 91.69 |
| EXP1507 | 26 | 31 | 21 | 1 | 91.85 |
| EXP1747 | 31 | 31 | 13 | 1 | 91.77 |
| EXP1753 | 31 | 31 | 17 | 1 | 92.02 |

## 5. Bottleneck analysis

To achieve higher production efficiency in the production line, we can carry out bottleneck analysis on the production line. The Theory of Constraints (TOC) states that the production efficiency of a system is determined by one or several constraints (bottlenecks) in the system. TOC rationally adjusts bottleneck equipment to increase system production efficiency and improve system bottleneck resources in a targeted manner [10]. The bottleneck resources commonly found in production systems are usually a work center or a production facility, which has the highest usage rate and the production load exceeds the production capacity. Therefore, through the simulation data of the production equipment, the processing equipment with high usage rate and continuous increase of the production system can be obtained. However, there are uncertain factors in production, which are likely to cause changes in production bottlenecks. The key to TOC is to continuously break through system constraints, rationally adjust bottleneck equipment to increase system production efficiency, and improve system bottleneck resources in a targeted manner. The literature analyzes the causes of bottleneck transfer and proposes corresponding prevention and response plans. Therefore, to ensure the correct identification of bottleneck resources within the specified processing time, it is necessary to analyze the workload rate of each production equipment in the corresponding time. When the system continues to simulate for 24 hours, its working condition is shown in Figure 5. According to the resource information statistics chart, the M22 heat shrinkable sleeve task has the highest load rate. According to the basic idea of TOC, it can be judged that M22 is the bottleneck device of the production system.

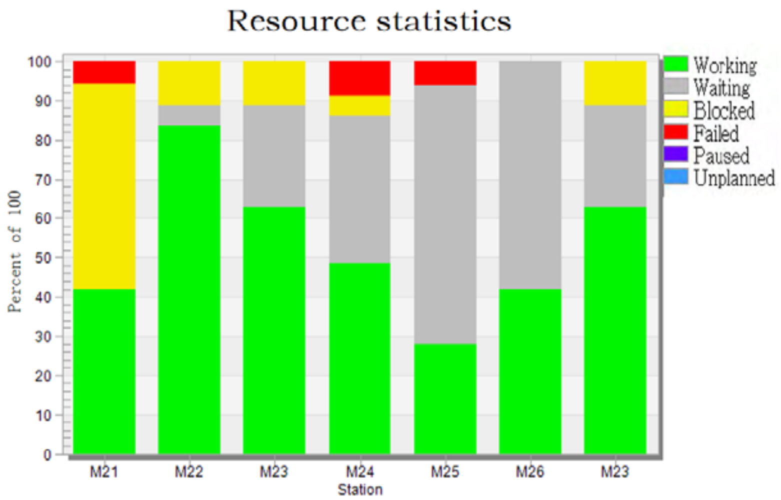


Figure 5. Production equipment simulation status.

For a bottleneck equipment production system, a certain processing process can be used to reduce the processing time of the bottleneck process. Taking the theory of constraint as the guiding ideology, the bottleneck resource is identified, and a detailed solution based on the theory of constraint theory is given to realize resource sharing and complementary advantages. In summary, according to the problems of the production system, set the relevant parameters of the equipment in the model, carry out the simulation experiment, and propose the optimization scheme of the production line. The processing time of the heat shrink sleeve labeling process is determined by the conveyor speed of the heat shrink sleeve labeling station. To reduce the processing time of the heat shrinkable sleeve working position, we can adjust the conveyor speed appropriately, in order not to affect the processing quality, and increase the temperature of the heat shrinking furnace, and through repeated simulation experiments, repeated optimization, so that the production efficiency is higher. Upgrade, and test in the physical production line, the test results are shown in Table 3, the production efficiency before the optimization is significantly improved.

Table 3. Measured processing time and finished product quantity.

| **Before optimization** | | **After optimization** | |
|---|---|---|---|
| Time | Value | Time | Value |
| 1:00:00.0000 | 102 | 1:00:00.0000 | 105 |
| 2:00:00.0000 | 252 | 2:00:00.0000 | 265 |
| 3:00:00.0000 | 366 | 3:00:00.0000 | 386 |
| 4:00:00.0000 | 516 | 4:00:00.0000 | 544 |
| 5:00:00.0000 | 608 | 5:00:00.0000 | 670 |
| 6:00:00.0000 | 758 | 6:00:00.0000 | 829 |
| 7:00:00.0000 | 870 | 7:00:00.0000 | 960 |
| 8:00:00.0000 | 968 | 8:00:00.0000 | 1084 |

## 6. Conclusion

The parameters of the physical production line and the historical production data are analyzed and modeled. The performance index of each station of the production line is simulated and analyzed by the plant simulation software platform. The results of the multi-level simulation experiment of the temporary storage area are selected and filtered by the signal-to-noise ratio analysis. The TOC theory is used to optimize the bottleneck process. The simulation results show that the production line modeling and simulation can analyze the production efficiency and equipment load of the production line, judge the production bottleneck, and provide efficient and rapid solutions for enterprise production management. To load the digital development trend and realize real-time simulation optimization decision, further research is needed.

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