

# Simulation and EVSM-based Lean Line Improvement

Rongkang Su

Industrial Engineering & Management, Southwest Petroleum University, Chengdu, China

**Abstract:** In today's dual-carbon economy, an increasing number of manufacturing companies are seeking ways to incorporate economic and environmental benefits into their improvement strategies. This has led to the concept of integrating green principles into lean improvement. Value Stream Mapping is a key analytical tool in lean manufacturing. This paper introduces Environmental Value Stream Mapping, which builds on this tool to address the lack of environmental factors in traditional value stream mapping analysis. Additionally, the environmental value stream mapping method is combined with simulation technology to enhance the objectivity of the future value stream mapping process. Using the production process of wear-resistant guide rods in a machinery factory as an example, this study applies the environmental value stream mapping method to identify problems in the production process from the perspectives of time and equipment energy consumption indexes. The study then improves the production line's value-added rate of time from 2.21% to 7.53% and the value-added rate of energy consumption from 43.92% to 58.39% through the implementation of industrial engineering improvement methods and Flexsim simulation technology. The goal of improving the efficiency of the production line while reducing energy consumption and protecting the environment was achieved.

**Keywords:** Environmental Value Stream Mapping; Lean Production; Production Line Improvement; Flexsim Simulation.

## 1. Introduction

In the context of the new normal economy, the impact of the production process on the environment has become a focus for enterprises and academics. Green and low-carbon production is the trend for enterprise operations. Lean manufacturing aims to produce low-cost, high-quality products that can meet customers' diverse needs quickly. Value Stream Mapping (VSM) is a key analytical tool in lean manufacturing and has significant applications in factory implementation[1]. Enterprises can use the diagram to determine the value-added and non-value-added time of their products, eliminate unproductive processes, and reduce waste of time, personnel, and materials [2]. This can improve their economic efficiency and competitiveness. However, traditional value stream mapping in the analysis process focuses only on improving production efficiency, shortening the production cycle and emphasizing time improvement, and does not fully consider the impact of environmental factors on manufacturing.

Literature research shows that foreign scholars have extended traditional value stream mapping to environmental value stream mapping (EVSM), which has been successfully applied. Garza-Reyes, et al. investigated the spiral rolling process in the mining consumables business unit of a company [3]. They found that the proposed PDCA-based EVSM methodology can effectively improve green operations. Egon Muller, et al. provided an EVSM methodology to analyze and optimize time and energy consumption in transport and logistics [4]. EVSM can identify problems, eliminate waste and systematically analyze the impact of the production process on the environment. However, research on value stream mapping in China still primarily focuses on traditional analysis. For example, Wenna Huang combined value flow mapping and lean manufacturing to improve the drive shaft production line [5]. Li Gu, et al. used value stream mapping to analyze and improve the production line in combination with ECRS principles, effectively reducing waste and improving overall efficiency

[6]. Although VSM can be applied to various situations, it is primarily based on the single dimension of time value-added rate. The lack of an objective foundation complicates the process of mapping future environmental value streams. In this way, future value stream mapping will be more objective and improvement plans will be more rational.

## 2. EVSM Application Process

Although companies may offer a variety of products, the implementation process for EVSM is similar to that for VSM. (1) Selection of product family. (2) Determine different production and environmental indicators according to the production characteristics of the product, and whether they are reasonable or not will directly affect the results of improvement. (3) Analyzing the production process and mapping out the current environmental value stream. (4) Identify the key problems and combine them with modelling techniques to make improvements. (5) Prepare future environmental value stream maps. (6) Evaluation and analysis after improvement. Lean production improvement is a systematic project that cannot be achieved overnight. Since a company's production environment is dynamic, integrating continuous improvement into the company's lean implementation is critical to avoid repetitive lean improvements. The following figure illustrates the specific EVSM application steps.

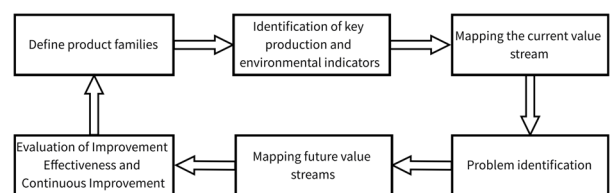


Fig 1. EVSM Application Steps

### 3. Analysis of the Current Production Situation based on EVSM

#### 3.1. Background of the Case

Enterprise A is a domestic manufacturer of electromechanical parts. The production mode is still mass production, resulting in a long production cycle for products with high precision requirements and many production processes. The production process has a significant impact on the environment due to high energy consumption, especially in heat treatment. Therefore, in order to achieve the goal of synergistically improving economic and environmental benefits, it is urgent to identify non-value-added processes and wasteful energy consumption points internally.

#### 3.2. Identify the Study Population and Map the Current EVSM

Wear-resistant guide rods are the main products of this enterprise, with a large demand and an average daily demand

of 20 pieces. The factory works 6d per week, 8h per day, but the production capacity of the product is still unable to meet the demand for orders, so choose the product as the object of study, analyze its production process. At the same time, the production process of wear-resistant guide rods in some of the equipment power, high power consumption, therefore, the choice of electrical energy as an environmental indicator for research.

Based on the data collected in the field, a value stream map of the current environment is drawn, as shown in Figure 2. The map consists of two main parts: (1) the upper part depicts the production process of wear-resistant guide rods, with the energy line and time line recording value-added and non-value-added data respectively. (2) The lower half of the graph shows the machining process of the wear resistant guide bars, along with the time and energy consumption lines. The adjacent data boxes contain key index data for each process, such as cycle time, power, machining time (which indicates the time spent consuming electrical energy on machines and equipment), shift, pass rate, and other relevant information.

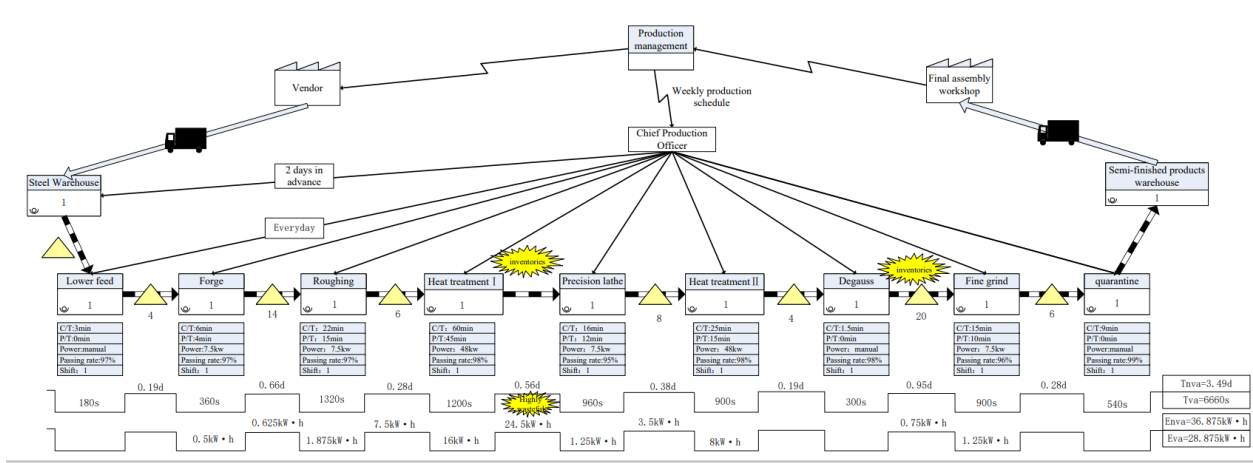


Fig 2. Current environmental value stream map

#### 3.3. Problem Identification

##### 3.3.1. Energy Consumption Value-added Rate

From the data provided by the energy consumption line in Fig. 2, the value-added rate of energy consumption in the production process of wear-resistant guide rods is calculated by using eq. (1).

$$\eta_{Eva} = \frac{E_{va}}{E_{nva} + E_{va}} \quad (1)$$

Where:  $\eta_{Eva}$  represents the energy value-added rate;  $E_{va}$  and  $E_{nva}$  are value-added and non-value-added energy, respectively.

The value-added rate of energy consumption of wear-resistant guide rods is 43.92% through calculation, and the "5W1H" in industrial engineering is used to find out the key factors affecting the value-added rate of energy consumption. After analysis, there are two main reasons: (1) the largest energy loss in the processing of wear-resistant guide rods is the finishing process, as shown in Figure 3-2, there is a non-value-added energy loss of 24.5 kw·h in this process, and the non-value-added energy consumption of this process accounts for 66.44%. The main reason is that: heat treatment process is mass production, and precision turning process is not enough inventory in the early stage, resulting in

equipment idle for a long time, resulting in products waiting for the completion of heat treatment I stage of the product before the waste, in the actual use of the value-added process but the time is shorter, the effective use of the rate is not high, resulting in the phenomenon of energy wastage exists. (2) There is 3.5 kw·h of non-value-added energy before heat treatment process II. The reason for this phenomenon is due to the energy loss of the automation device itself. Although this loss cannot be completely eliminated, the energy loss can be reduced by adjusting the production batch.

##### 3.3.2. Time-value-added Rate

Firstly, calculate the time value-added rate of the production process of wear-resistant guide rods in company A based on the data provided by the time line in the diagram and the following eq.

(1) Time-to-value ( $T_{va}$ ): the time in production that creates value for the product.

$$T_{va} = \sum_{i=1}^k CT_i \quad (2)$$

(2) Non-value-added time ( $T_{nva}$ ): time in production that does not produce value, such as time spent moving, waiting, staging, etc.

$$T_{nva} = \sum_{i=1}^k \overline{CT}_i \quad (3)$$

(3) Time Value Added ( $\eta_{Tva}$ ): the percentage of value added time versus production cycle time.

$$\eta_{nva} = \frac{T_{va}}{T_{va} + T_{nva}} \quad (4)$$

The time value added ratio of the wear resistant guide rod production line is calculated to be 2.21%. From the data, it can be seen that the non-value-added time of this production process is very high, resulting in a low value-added rate. It shows that there is too much time waste in this production line, and it is necessary to optimise and improve the production process as a whole, find out the causes of time waste, and formulate a corresponding improvement plan, so as to reduce the non-value-added time and improve the time utilisation rate. Combined with the relevant theories of lean production, the following problems are summarised.

#### (1) Poor production line balance

Production line balance requires a balanced allocation of each production demand in production to ensure that the working time of each station is balanced. This mainly involves the reasonable arrangement of workstations on the assembly line and the control of the workload of each workstation to ensure that the working time of each workstation is consistent with the production schedule. The balance state of the production line is judged by three indicators: the production line balance rate (P), the production line imbalance loss rate (d) and the production smoothing index (SI).

The line balancing rate P is an evaluation of whether the distribution of work is balanced in a complete production line or a part of a production line, and is a visual indication of the efficiency of the object of description. It is calculated as follows.

$$P = \frac{\sum_{i=1}^N T_i}{T_{max} \times N} \quad (5)$$

Where the numerator denotes the sum of the working time of all the processes of the production line under study,  $T_{max}$  denotes the working time of the bottleneck process of the production line, and N denotes the number of processes included in the production line.

$$d = 1 - P \quad (6)$$

Production smoothing index SI is an important indicator of the discontinuity of working time in each production process of a production line, which is measured by calculating the interrelationship of the working time of different processes of the production line. The formula is as follows:

$$SI = \sqrt{\frac{\sum_{i=1}^m (TT - T_i)^2}{N}} \quad (7)$$

Where SI represents the smoothing index of the production line;  $T_i$  represents the actual production beat time of the  $i^{th}$  process; TT represents the production beat demanded by the customer; N represents the number of processes included in the production line; the larger the value of SI represents the larger difference in the operating time between the processes of the production line, and the lower the corresponding production efficiency; on the contrary, the smaller the value of SI represents the closer the operating time between the processes of the production line, and the higher the corresponding production efficiency. On the other hand, the smaller SI value means the more similar the working time between the processes of the production line, the higher the corresponding production efficiency. Thus, according to the data, we can find out the production line balance rate P of the wear-resistant guide rod production line is 29.17%, the production line imbalance loss rate d is 70.83%, and the production smoothing index SI is 17.02.

#### (2) Failure to produce on schedule

Theoretically, the production beat of the plant should be 1191.27 s. However, from Fig. 2 and the data of the above three indexes, it can be seen that the processing time of each process varies, and it can be seen that the production line has the problem of unbalanced operating time and large degree of dispersion, in which the heat treatment II processes are batch processing, and the gap between the processing time and the beat is large, which results in the accumulation of the work-in-process, and causes the waste of too much production. Therefore, the failure to produce according to the beat is also an important factor affecting the time value-added rate. Excessive quantity of work-in-process in the production line.

## 4. Production Improvement based on IE and Simulation Technology

### 4.1. Improvements Targeting Energy Value-added Rates

#### 4.1.1. Establishment of Work-in-process Inventory Superstore for Fine-turning Processes

Through the problem analysis, it is found that the non-value-added energy consumption of the fine-turning process is higher mainly due to two reasons: firstly, the idle operation of the fine-turning equipment while waiting causes energy waste. The second is that heat treatment I process adopts batch production, which leads to long processing cycle and easy interruption of production. To solve this problem, we change the processing mode of wear-resistant guide rods on the equipment before heat treatment I process to single-piece flow production, change the moving order of work-in-progress from sequential moving to parallel moving mode, and set up fast production channel to reduce the inventory of work-in-progress through continuous flow. At the same time, the establishment of inventory supermarket, set up a certain number of wear-resistant guide bar in-process to improve the production continuity, to avoid batch production leads to the subsequent process of waiting, in-process backlog and other waste phenomena. Known heat treatment I process for each batch of 6 pieces, processing time of 60min, while the wear-resistant guide rod in the air hammer and other equipment using a single piece of parallel mode of production, the time were 3min, 6min, 22min, the time of 31min. according to the parallel mode of processing time calculation formula:

$$T = \sum T - (n - 1)T_{max} \quad (8)$$

Calculation found that: when  $n = 2$ , wear-resistant guide rod processing time is 53min, less than 60min; when  $n = 3$ , wear-resistant guide rod processing time is 75min, more than 60min. so the wear-resistant guide rod in the product supermarket capacity is set to 2 pieces.

#### 4.1.2. Heat Treatment II Process Improvement

Through the field inspection, it is found that the heat treatment II process is automated batch processing, and the energy loss of this process mainly comes from the inherent loss in the processing of the equipment. Moreover, due to the inconsistency of the processing quantity of each process, the production continuity is low, the number of materials loaded in each batch of heat treatment II process is small, the equipment starts and stops more often, the energy waste is larger, and the energy utilisation is not high. Therefore, in order to improve the production continuity, the number of

feedings per batch is increased from 4 to 8 pieces. After the improvement, it can be calculated that the energy waste can be reduced by 1.30 kW·h.

## 4.2. Improvements to time-value-added Rates

### 4.2.1. Internal Process Improvement

ECRS stands for Eliminate, Consolidate, Reschedule, and Simplify, and the ECRS principles are consistent with the concept of Lean Manufacturing, which applies to the reduction or elimination of waste in all steps associated with the manufacturing process. The ultimate goal is to simplify all steps in the manufacturing process and create a more efficient production system overall.

The production line imbalance loss time is equal to the sum of the time difference between the bottleneck station and the rest of the stations. the imbalance loss time of the wear-resistant guide bar production line in company X is 2611.89s, which is about 2.2 times of the production beat. The reason for this waste is the unbalanced distribution of workload among the stations. The process cycle time of demagnetisation at station 7 is only 90s, while the operation time of the bottleneck station is about 40 times as long as it. In addition, the operating time difference between 7 of the remaining 8 stations and the bottleneck station is more than 100s, which seriously affects the balance of the production line.

Then, by analysing the process flow, it is found that the processing time of degaussing process is only 90s, which is a big gap with the processing time of the two processes before and after, and there is a waste of waiting. According to the "ECRS" principle and the site inspection, it was found that the degaussing process and the fine grinding process can be combined, which not only reduces the waiting time, but also improves the production continuity.

## 4.3. Verification and Analysis of Improvement Effect Based on Flexsim Simulation

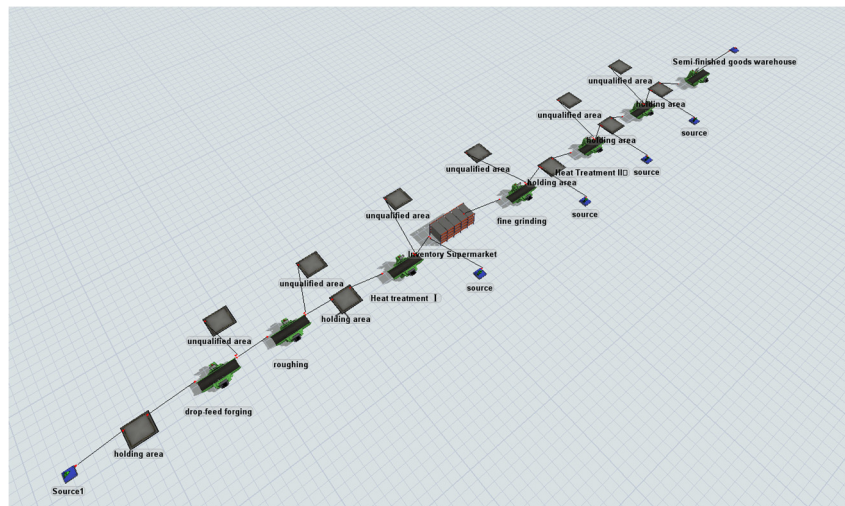
### 4.3.1. Building Simulation Models

According to the improvement plan, Flexsim simulation software was used to simulate the wear-resistant guide bar production line and record the working conditions of each station. Before establishing the simulation model, the solid objects used in the model are first defined, as shown in Table.

**Table 1.** Entity corresponds to each system element

Modelling element	System element	Note
Interim entity	Wear-resistant guide rods in production	Wear-resistant guide rods being machined
Processing unit	Production line stations	----
Generator 1	Wear-resistant guide rod raw material library	Storage of raw materials not yet in production
Generators 2-5	Wear-resistant guide rods in stock	----
Holding area	Unqualified area	Wear-resistant guide rods that fail during processing
Shelf for goods	Inventory Supermarket	----

In the simulation model of wear-resistant guide rod production line of Company X, there are 5 generators, 7 processors, 11 staging areas and, 1 shelf and 1 absorber. Drag the entities from the entity library to the software window, connect the entities according to the process logic and build the simulation model, as shown in Figure 3.



**Fig 3.** Simulation model of improved production line

### 4.3.2. Simulation Parameter Setting

#### (1) Generator parameter setting

The trigger time of the generator is determined by the fixed-beat process of the wear-resistant guide rod production line. From the improvement scheme, it is known that the time of the fixed-beat process is 540 s. Temporary entities are sent according to the arrival time interval, considering that the time is set to 540 s with a mean of 540 s and a normal distribution function of 10 for variance.

#### (2) Processor parameter setting

In the production process simulation, it is assumed that the

production line staff does not move in distance. The processor is used to simulate each station of the production line in reality, and the default name of the processor is changed to the name of the process in the actual production line. The processing time of the processor is the standard time of the process. For example, "Processor 1" is changed to "Unloading and forging", and the processing time is set to the standard time of 360s for unloading and forging.

#### (3) Parameter setting in the staging area

The staging area should avoid the phenomenon of serious accumulation when setting parameters. Therefore, this paper

sets the maximum capacity of the staging area capacity of the staging area is set to 10 units.

(4) shelf parameter settings

Shelves in the parameter settings to ensure good simulation results. So in this paper, the specifications of the shelf is set to 3 rows and 3 columns.

(5) Setting the simulation running time

According to the analysis of the production status quo above, it is understood that the production workshop of wear-resistant guide rods in Company X implements a 7-hour working system. Therefore, theoretically, the employees work 25200s per day, set the running time of the model to 25200s, and the running of the simulation model will stop automatically at 25200s.

4.3.3. Operational Simulation Modelling and Analysis Conclusion

After setting the parameters of the simulation model of the wear-resistant guide bar production line, click the "Run" button in the interface to run the simulation model. After the simulation model has finished running, through the function of "Statistics and Report", the indicators that need to be counted can be analysed in order to analyse the running situation of the model. The report of the model is shown in Figures 4 and 5.

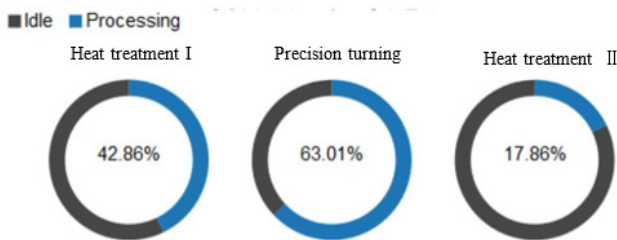


Fig 4. Production status of key processes before improvement

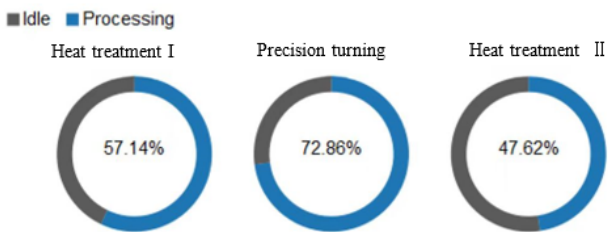


Fig 5. Diagram of production status of key processes after improvement

From the simulation results in Figure 4 and Figure 5, it can be seen that: compared with the pre-improvement period, the equipment utilisation rate of heat treatment I, fine turning and heat treatmentII processes have been improved to a certain extent, and the whole is in a good operating state; among them, the utilisation rate of heat treatment II has been increased by 29.76% compared with the pre-optimisation period; and

semi-finished products and parts circulate smoothly in the front and rear workstations of fine turning. The optimised equipment reduces the waste caused by waiting and blocking, and improves the balance rate of the wear-resistant guide bar production line.

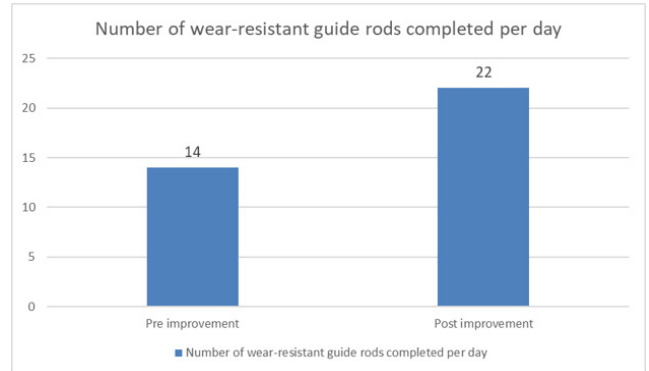


Fig 6. Comparison of the number of products completed per day before and after the improvement

From the simulation results in Figure 6, it can be seen that after the improvement, under the premise of other external conditions do not change, the number of products that can be completed per day increased from 14 to 22, an increase of 57.14%, and the production efficiency has been greatly improved.

4.4. Mapping Future Environmental Value Streams

According to the improvement effect, we can draw the future environmental value stream diagram as shown in Figure 7, and bring the time and energy consumption lines in the diagram into equations (1) and (4) to get the value-added rate of energy consumption and the value-added rate of time of the improved wear-resistant guide rod production line. It can be clearly seen that through the establishment of inventory supermarket, controlling the quantity of work-in-process in the production process and the improvement of internal processes, the value-added rate of time and value-added rate of energy of the wear-resistant guide rod production line of Company X has been significantly improved. The specific improvement effects are shown in Table 2. below.

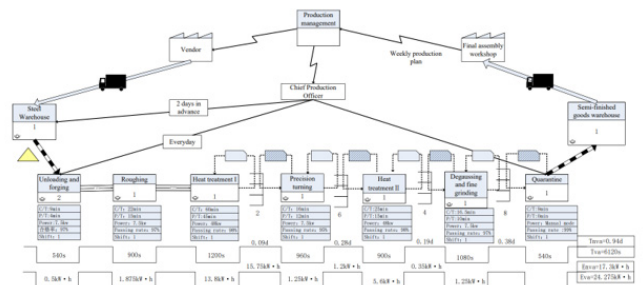


Fig 7. Future environmental value stream map

Table 2. Comparison of Improvement Effect

State of affairs	Pre-improvement	Post improvement	Improved results
Energy Value Added Ratio (EVA) /%	43.92	58.39	↑14.47
Time-value-added rate /%	2.21	7.53	↑5.32
Production capacity/piece	14	22	↑57.14%
Non-value added energy /kW·h	36.875	24.275	↓12.6
Non-value added time /d	3.49	0.94	↓2.55

## 5. Conclusion

This paper focuses on the optimisation and improvement of the wear-resistant guide rod production line in Company X. Using environmental value stream mapping, industrial engineering techniques and lean production tools, the production line was thoroughly analysed and improvement measures were implemented. Firstly, through research and drawing environmental value stream mapping, it is found that the production line has the problem that the energy value added rate and time value added rate are far below the qualified standard. Using 5W1H questioning techniques, ECRS principles, lean manufacturing improvement tools and Flexsim simulation techniques, the main problems in the production line, such as lack of stock supermarkets and irrational heat treatment processes, were identified and improved in terms of both energy and time dimensions. Improvement measures included the establishment of fast production channels, the addition of stock supermarkets, the merging of processes, etc., and the transformation of the production line from push production to pull production, as well as the introduction of Kanban management. As a result of the optimisation, the key indicators of the production line, such as energy value-added rate, time value-added rate and production capacity, were significantly improved, non-value-added time and waste were reduced, and production efficiency was increased, bringing economic and environmental benefits to the enterprise.

Although the study achieved significant improvements, there is still room for improvement. Future research could consider incorporating factors such as staff operating standards, equipment management systems, and layout and logistics into the analysis in order to develop a lean

production management system that is more in line with the characteristics of small and medium-sized enterprises and to achieve continuous improvement.

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