Lean Improvement of Product P Assembly Line based on Value Stream Map

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Abstract. Based on the product P assembly line transformation project of a company, the main problems of the original production line are analyzed with the method of Value Stream Map. Lean improvement measures which is used in the design of new production line are put forward in the aspects of overall layout, process arrangement, production mode, material buffer, auxiliary equipment and personnel allocation to reduce some non-value added activities and wasteful behaviors. By the Value Stream Map of the improved lean production line, the evaluation indexes can be improved significantly. After the new production line is completed and put into production, the workshop stock is reduced, the production efficiency is improved, and the production cost is reduced.

1. Introduction

With the development of economy and the increasingly fierce market competition, customers have higher requirements for product personalization, diversification and delivery time. Enterprises are facing new development bottlenecks. In order to solve these problems, the production mode of enterprises must be reformed. That is to say, the past large-scale and planned production mode should be abandoned; the flexible production mode of multi variety and small batch should be developed. Enterprises should not only reduce product cost but also improve product quality. Lean production is currently recognized as the best way to meet these requirements [1] [2].

Company B is a supporting enterprise for military production. To some extent, it follows the extensive production mode of the original state-owned enterprises, such as disordered production organization, untimely planning and scheduling, massive accumulation of materials, long cycle of product manufacturing and low efficiency of personnel operation. On the one hand, facing the rapid plan change of upstream scientific research institutions, the company is overwhelmed; on the other hand, facing the short supply cycle required by downstream customers, the company can't deliver on time. So, the original mode of production organization has seriously restricted the development of enterprises.

Based on the transformation project of P product assembly line entrusted by company B, the paper analyzes the main problems in the production process of the original assembly line with the Value Stream Map. Under the theme of improving production capacity and reducing cost, in the design of the
transformation scheme, the work station and procedure has been reorganized to eliminate the bottleneck in the production, production management mode has been optimized to make full use of existing people and field resources to organize production. The new assembly line will adopt the pull production mode, which makes the general assembly of products P to pull the production of parts workshops at all levels, so as to reduce the stocks of finished products and parts. The new general assembly line needs to meet the user's requirements that the production capacity can reach more than 60 sets per month (two shift system).

2. Main problems of the original assembly line of product P

Before the transformation, the general assembly line adopts the "linear" production flow layout, and the overall layout in the workshop is shown in figure 1. The original assembly line and supporting facilities occupy 3000m² totally, mainly including sub-assembly area, material buffer area, finished product buffer area and general assembly area. Material buffer area cached assembly parts delivered. The sub-assembly area was used to assemble and cache the parts of the overall connection station. The finished product area was used to store the finished products. The tool storage area was used to store all the tools and tooling in the assembly and testing stations. Team garden was used for rest and placement of notices Kanban. The general assembly area completed all processes from assembly to test and formed the final product P.

![Figure 1. The layout and logistics route of original assembly line](image)

After the investigation of the production planning management department, through the disassembly of each process in the assembly station of the original production line, operation time of each operator in each process can be recorded, and actual average operation time and waiting time of each process can be calculated. Finally, the work hours of each station can be counted by the mountain plot and the Value Stream Map can be drawn, as shown in figure 2.

![Figure 2. The Value Stream Map of original assembly line](image)
Based on the data analysis in the Value Stream Map, value added time (AT), non-value added time (UT) and value-added rate (I) of the production process can be calculated, with the unit of hour. The specific calculation is as follows:

\[ AT = \sum_{i=1}^{k} \frac{C_i}{T_i} = 3.6 + 3.8 + 4.0 + 4.5 + 4.2 + 3.3 + 5 + 5.3 = 33.7 \text{ h} \]  
\[ UT = \sum_{i=1}^{k} \frac{C_i}{\bar{T}_i} = 48 + 3 + 3 + 3 + 3 + 3 + 3 + 3 + 3 + 360 = 435 \text{ h} \]  
\[ I = \frac{AT}{AT + UT} \times 100\% = 7.19\% \]

Following, the main problems of the original assembly line are discussed from several aspects, according to the layout and the Value Stream Map.

2.1. Low balance rate of production line
Each work station of the original assembly of product P line contains multiple processes. The balance rate of the assembly line is 79.5%, and the loss rate is 20.5%. During production, some stations cannot be produced as planned, while the production capacity of other stations is relatively surplus, resulting in the idleness of some operators and devices.

2.2. Long logistics waiting time
It can be seen from figure 2 that the main logistics time between each station on the general assembly line is too long. According to the field research, there are several reasons as follows:
- Before working, that the operators of each station need to go to the material storage area and tool storage area to get corresponding materials and tools according to the production plan takes up a certain time every day.
- If type and quality problems of materials are found during the assembly process, it also takes a certain time to get and return repeatedly.
- The main parts are transported by crane between adjoining stations. The waiting time for the crane is too long, due to the following reasons. Firstly, the low balance rate of the original assembly line makes the transfer time of each station uncertain. Secondly, there is only one crown in the workshop, and some stations need auxiliary assembly by crown. Thirdly, the number of crane workers in the production department is small and the management mode of temporary deployment is adopted.

2.3. Disconnection between logistics and information flow
According to figure 2, the predictive push production mode is applied to the production process of the original assembly line, which often causes the disconnection between logistics and information flow [3]. The production management department makes the production plan according to the forecast, and then issues the periodic production order to the assembly and each parts workshop. It makes the production become a simple process of pushing forward from front to back. The forecast error will lead to the inconsistency between the actual production and the plan forecast, which will make the continuous flow impossible between the general assembly production and the production of the parts, so a large stock of materials is used to make up for above defects. It can be seen from figure 1 that material buffer area is about 420 m², finished product buffer area is about 360 m², occupying nearly a quarter of the space of the production workshop. Too much stocks will cause a lot of time wasted in waiting, handling and counting.

In the field investigation, it is also found that a large number of materials and finished products cache covers the quality defects of some parts, but the loss has not attracted the attention of relevant departments of the enterprise.

3. Lean design of product P assembly line
According to the analysis results above, the modified assembly line has the following improvement
objectives:
- Optimize assembly process to eliminate unnecessary non-value added activities and reduce production cost.
- Convert push production mode to pull production mode.
- Optimize production layout and reduce inventory occupation.
- Increase the balance rate of assembly line. By means of process reengineering and optimization, the cycle time of bottleneck station can be reduced, and the smoothness between processes can be improved. It can realize the continuous value flow of the whole line to improve production efficiency.

3.1. Work time balance and cycle time improvement
Among all the stations of assembly line, the operation time of mechanical and electrical overall debugging stations are 5 hours and 5.3 hours respectively, which are all bottleneck stations. After transformation, the procedures of original two bottleneck stations are disassembled into three stations arranged on the new assembly line, so that the cycle time of these three stations is about 3.5 hours. The average distance among all stations of the new assembly line which add a station is compressed from 6m to 4.8m. It makes the layout more compact and shortens the transfer distance of main parts among stations.

It is found that the process of cable detection and arrangement of the electrical installation station takes a long time, by scene research. In the design of new line, a sub-assembly 1 (The sub-assembly station of original assembly line is configured to sub-assembly station 3 of new assembly line) is added. In this new station, a special cable detection template and the actual cable binding model are used to guide the operator to finish the task. In addition, a new sub-assembly station 2 is added configured one person and special tooling to complete the drilling process of some parts which are finished in the original three mechanical installation stations. In this way, the cycle time of each station in the assembly line is reduced to about 3.5 hours, and the balance rate of the assembly line can be increased to 87.5%, as shown in the figure 3 below.

![Figure 3. Comparison diagram of operation time of transformation assembly line](image)

3.2. Adoption of pull production mode
After the cycle time of the production line is basically balanced, pull production mode is implemented to reduce the caching of materials. Taking the rationality of workshop layout and production line into account, in order to solve the problem that material buffer takes up a lot of space, the “supermarket pull system” is introduced. Supermarket system is set up between the parts production workshop and the corresponding stations of the assembly line. Picking up the goods from the "supermarket" of the
station can send the delivery instruction to the upstream part production workshop. Pulling production through the flow of "picking Kanban" and "transportation Kanban" can get rid of the predictive production of parts [4] [5]. That is to say, the production and delivery instructions of parts can be transmitted through the overall 3.5-hour cycle time of new assembly line and the picking Kanban information of each station. After receiving the delivery instruction, the parts workshop will distribute the materials to the catering area of new assembly workshop (as shown in figure 4). A fixed material rack is designed for each station according to the fixed material BOM of each station in the new assembly line. The staff in the catering area are responsible for checking, catering and delivering to the corresponding stations one cycle time ahead. It changes material picking mode of original production line and reduces waiting time in the production process. As assembly parts are distributed by Kanban and cycle time information, only one set of materials and material rack, inspection and catering space for all stations need to be reserved, instead of large amount of materials in the cache area of original line. It can reduce land occupation by nearly half, compared with the material storage area of the original assembly line.

Pulling the production of parts workshop by the production of general assembly workshop can make the enterprise transform from "predictive production" to "order production" to reduce the burden of business management [6] [7]. In addition, pulling the production of parts by the general assembly can not only reduce the dependence on stock, but also force the part workshops to improve production quality in various ways. In this way, on-time delivery is realized and the loss of the enterprise is reduced.

3.3. Optimization of overall layout of assembly line

In the layout design of the new production line, the tool storage area is cancelled and a special tool cart is equipped for each station, so that the walking distance of workers can be reduced by about 500 meters in total every day. The catering area is set up, where special persons are responsible for inspection, catering and transportation of materials, so that it can reduce the waiting time of picking up and delivering materials. A centralized control room is added in the workshop and two LED screens are installed in prominent positions, which can realize informationization and visualization management of the whole line. In the layout of new assembly line, a quality problem area is added to record and handle the quality problems found in the assembly and testing process. In this way, it can not only avoid affecting timely transportation of main parts, but also provide effective support for the improvement of product quality.

With the improvement of production efficiency, the supply cycle of finished products will be shortened. After consulting with field persons and considering the number of finished product buffer, the area of the finished product storage area was reduced to 2/3, and the sending frequency of the finished product was increased to once 10 days compared with the original one which is once half a month. The lean layout and logistics line chart is shown in figure 4. Compared with the original layout, it can save about 220m² space which can be used as a reserved place for scientific research.

Figure 4. The Value Stream Map of new assembly line
3.4. Pulsating transfer of main logistics

The transfer of main parts was completed by crane among the stations of the original assembly line, which wastes a lot of waiting time and has security risk. The planning of new production line adopts an AGV car to realize the pulsating transfer of main logistics. The overall scheduling mode is as follows:

- In the production process, the information system counts work time for each station. When the work time of last station (comprehensive debugging 3 station) reaches 3.5 hours, AGV will arrive at the waiting area of last station from the charging area. After the workers give the instruction to finish the work, the AGV car will transfer the main parts to the finished product storage area;
- When the work time of the overall debugging 2 station reaches 3.5 hours, the AGV car will arrive at the entrance of this station. After receiving the work completion information, the AGV car will transfer the main parts to the overall debugging 3 station;
- Until the AGV car transfers the blank main parts from the material catering area to the mechanical installation station 1, the main parts of all stations are transferred to the front stations once within 3.5 hours in turn;
- The AGV car returns to charging area.

The average time of each transfer between adjacent stations is 10 minutes. As the whole line includes 9 stations, the AGV car needs to transfer 10 times in each cycle time, amounting to 100 minutes. The remaining 110 minutes in cycle time (3.5 hours) of the whole line is used for the AGV car charging. Thus, it realizes the main logistics pulsating transport in accordance with a certain time rule. It does not only makes workers improve operation skills to complete the task within cycle time, but also enables the information system grasp the actual production situation of the whole line constantly to avoid disconnection between information flow and logistics.

3.5. Reduction of station operators

In the assembly process of original mechanical installation and electrical installation stations, due to some heavy assembly parts, more people are allocated to finish the assembly task by manual handling. In the new line, these stations are equipped with some auxiliary devices to reduce labor intensity, and the number of operators working in each mechanical and electrical installation station can be reduced to 2. The original overall debugging stations composed of three stations with three persons in each station are divided into three stations with two persons in each station. The number of workers in sub-assembly station 1 remains unchanged. The newly added sub-assembly two and three stations need one person for each station, two persons added totally. Two operators are arranged in the material catering area to complete the tasks of unloading, inspection, catering and transportation. In addition, one person is allocated as administrator to realize Andon management of the whole line by information system. So, the new assembly line can reduce two persons per shift as a whole.

3.6. Value stream map of new assembly line

According to the adjusted layout above, the new product P assembly line put into production with the new equipment and production mode application. In order to make workers adapt to the new production mode, two sets of material caches are set in the "supermarket" beside each station, so as to avoid production break caused by abnormal materials. After a certain time production, the relevant data of new assembly line are counted. The Value Stream Map is drawn as figure 5 below:
Figure 5. New assembly line layout and logistics roadmap

After the transformation, the following evaluation indexes of assembly line have been improved significantly:

- Value added time (AT), non-value added time (UT) and value add rate (I).

\[
AT = \sum_{i=1}^{k} C/T_i = 3.4 + 3.5 + 3.2 + 3.5 + 3.3 + 3.3 + 3.5 + 3.5 = 30.4 \, h
\]

\[
UT = \sum_{i=1}^{k} C/T_i^w = 24 + 0.25 + 0.25 + 0.25 + 0.25 + 0.25 + 0.25 + 0.25 + 0.25 + 240 = 266h
\]

\[
I = \frac{AT}{AT+UT} \times 100\% = 10.3\%
\]

The value added time is shortened from 33.7h to 30.4h. The non-value added time is shortened from 435h to 266h, reduced by 58%. The value-added ratio increased from 6.72% to 10.3%, increased by 53.3%.

- The assembly production area of product P is reduced by about 220m².
- After the transformation, the balance rate of the production line has raised to 87.5%, increased by about 10%.
- The number of operators per shift has been reduced by 2.
- The production capacity has been increased by about 30%, which reaches 60 sets per month required by customers.

4. Conclusion

Based on the transformation project of product P assembly line, this paper analyzes some problems of the original assembly line by means of lean production principles and Value Stream Mapping. In lean research of the new production line, overall layout, process arrangement, production mode, material buffer, auxiliary equipment and staffing are improved to reduce some non-value added activities and eliminate some waste. At present, product P has been mass produced on the new assembly line and the production efficiency has been significantly improved. The application has reduces the labor intensity, saves the cost for the enterprise, and improves the staff awareness of lean production. The research provides a good demonstration for the transformation from extensive production operation to lean production operation.
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