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ASSEMBLY PROCESS ANALYSIS AND OPTIMIZATION OF GENERAL ANTENNA PRODUCTION LINE

Lin ZENING[1], Tong YIFEI[2], Wu XIAOWEI[3], Jiang TAO[4]

To improve the assembly efficiency of general antenna products, a typical antenna product and its production line were studied through structural optimization, layout analysis, demand analysis, hierarchical analysis among other methods. The research reveals 6 bottleneck processes in antenna assembly, and the overall balance rate is only 34.025%, which does not meet the production beat of less than 0.704 min per antenna. The process was optimized by optimization of personnel layout and the structure of parts. The results showed that the overall balance rate increased by 29.212% after optimization, which allows reduced enterprise cost and increased profit.

Keywords: assembly efficiency; Structural optimization; Bottleneck process; balance rate; Cost

1. Introduction

Up to this day, with the rapid development of science and technology and the rapid growth of market economy, many equipment manufacturing enterprises have faced fierce competition among themselves [1]. However, many manufacturers are not competitive. Through observation, it can be found that most of these enterprises have a series of problems in the assembly line, such as long production cycle, unreasonable assembly process, long waiting time for workers and inappropriate station position [2]. In this case, the difficulty for enterprises lies in how to make rational use of their own resources, to achieve close coordination between people and various elements, efficient operation, so as to give full play to the best efficiency. As a technology that can effectively reduce production costs and improve productivity efficiency, lean production is being mastered and utilized by hundreds of manufacturing enterprises [3,4].

Since the first production line was built in 1913, scholars at home and abroad have done a lot of research on the balance of production line from different angles. For example, Mustafa Fatih Yegul etc. [5]proposed an optimization

[1] College of Intelligence Science and Technology,National University of Defense Technology,changsha 410073,China, e-mail: 1252162684@qq.com
[2] Corresponding author. Prof, School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China e-mail: 465819860@qq.com
[3] Angeei Electronic Technology CO., LTD,Suzhou 215600, China, e-mail: daviswoo@angeei.com
[4] College of Intelligence Science and Technology,National University of Defense Technology,changsha 410073,China, e-mail: jiangtao@nudt.edu.cn

method based on simulation combined with myopic search, ant colony algorithm, simulated annealing algorithm and response surface method for the optimization of production line configuration. Rahani R etc. [6] proposed that value stream analysis is an effective lean improvement tool, which can be applied to floor production operations to reduce wip inventory and mold change time. Akpnar, Senerl and Mirac Bayhan G[7] proposed hybrid genetic algorithm based on multi-objective genetic algorithm, which was formed by integrating sequential hybrid heuristic algorithm, position weighting technology and genetic algorithm.

Yu Yang etc.[8] analyzed the shortcomings of traditional production lines, established relevant mathematical models and applied NSGA-II algorithm to solve them. Finally, they proved through practice that the number of employees could be reduced by transforming production lines into units on the premise of not increasing product circulation time. Lv Ji-xiao and Chen Chang-ming[9] took an automobile air conditioning pipeline manufacturer's line balance improvement and motion analysis as an actual case to show how to find and eliminate numerous waste and imbalance phenomena existing in the production process of the enterprise through line balance and motion analysis. Zhou Xiao-hui and Hong Zeng-lin[10] used the model Arrangement of predetermined Time Standard to measure and analyze a simulated assembly process in detail. The results showed that the model Arrangement of predetermined Time Standard could not only improve the standardization of the operation, but also improve the balance rate of the production line.

Ni Ting-ting, Li Chen-xin etc.[11] combined value stream analysis tools with kanban and other tools to establish a workshop production scheduling optimization model based on fewer varieties and smaller batches, so as to optimize the workshop production scheduling process and quickly respond to market demand. Feng Lei and Wang Jing-jing [12] took one of the production lines of an air conditioning enterprise as the research object, and found out the bottleneck position on the assembly line through time measurement. Make use of 6S management and other related knowledge to break through the bottleneck process and improve the efficiency of the production line by 22.03%.

Therefore, a general antenna product and its production line of AJY company named DP2450LNW-145B17U7 were analyzed and optimized, so as to improve the efficiency and assembly balance rate, and provide improvement ideas and methods for other enterprises with the same or similar situation.

2. Correlation analysis of general antenna and its production line

The general antenna product model DP2450LNW-145B17U7 and its production line were studied. The assembly line of the product consists of two parts: one part is made of solder, which is carried out by 7 employees in the solder processing workshop.The other part is assembled by 15 employees on the DP production line.

2.1 Analysis of antenna assembly process

As a basic IE technique, process procedure analysis can improve the unreasonable and uneconomic phenomenon in the production process by investigating and analyzing the current working process, so as to improve the working efficiency [13].Because the antenna wire by the enterprise homemade, so need to consider in the production process.According to the current work flow, the process procedure diagram can be drawn as shown in Fig.1.

In order to better find the bottleneck process in the assembly process, the stopwatch method was used to measure the time.Since this time study is for work improvement, the number of observations can be determined according to the operation cycle.The staff assembled 200 pieces each time, which took more than 1 hour. Therefore, the number of observations was thrice.Since the stripping wire process,the assembly of upper and lower firmware and rivet process are operated by automatic machines, the time of these two processes is constant, and the rest of the processes need to be removed outliers, so as to obtain the working hours.

Taking the solder dipping operation as an example to exclude outliers, calculate the actual time and standard working hours, the data measured for three times were 5.05,5.1 and 4.85 minutes respectively, and it was known that n=3.

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} , \tag{1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (Xi - \overline{X})^2}{n}} , \tag{2}$$

Which shows that $\overline{x}$=5min， σ=0.108。

Upper Control Limit and Lower Control Limit is that

$$UCL= \overline{x}+3\sigma , \tag{3}$$

$$LCL= \overline{x}-3\sigma , \tag{4}$$

From equations (3) and (4), it can be known that UCL=5.324min，LCL=4.676min。

The three values are all within the range and non-normal value, the average time is the normal time, and it can be known that the normal time is 5min.The same goes for the rest of the process.

After time measurement, the Gantt diagram of working hours of the process can be obtained based on the process diagram, as shown in Fig.2.Among them, the two processes of assembling upper firmware and lower firmware, swinging zinc alloy column and cutting solder are carried out synchronously with the production of solder. In Gantt diagram, the time consumed by each station is the time of this process and the time of material flow.

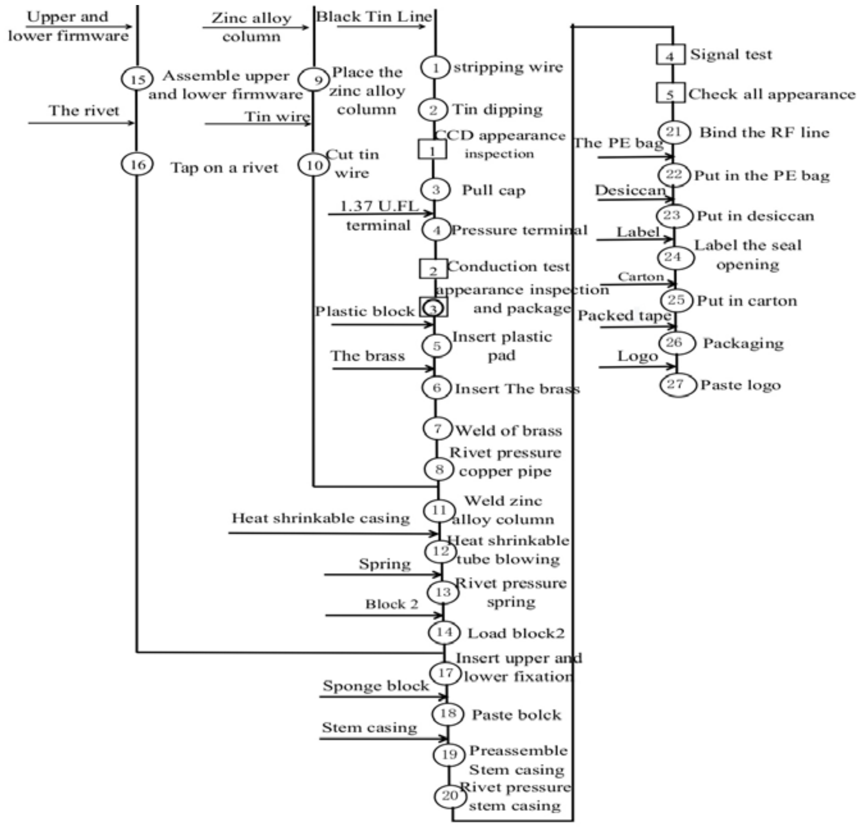

Fig.1 .DP2450LNW-145B17U7 Product process Flow Diagram

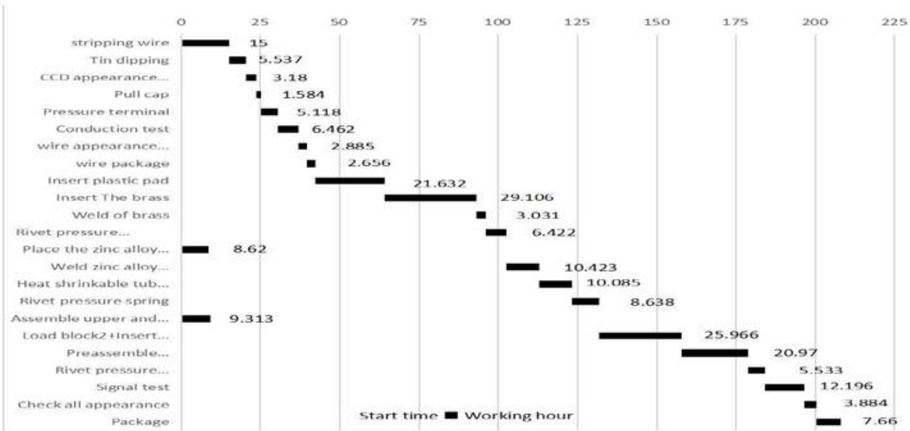

Fig.2 Gantt chart of working hours

Based on the Gantt chart, the assembly time of 200 antennas in each batch is 207.968min. Considering the release time and considering the production line, the release rate is set at 15%, so the standard working time of a single antenna is 1.196min.Due to the consistency of the discharge rate, the subsequent time calculation is based on the measured normal time.

The maximum bottleneck process time in the assembly line, namely the production beat, is represented by CT. It is assumed that the overall balance rate and the balance rate of the DP production line are Z and Z1 respectively, and the working hours of each process are Xi(I =1,2...21), the total number of processes is Y(parallel processes are not included in the calculation).

$$CT=MAX(X_i), \tag{5}$$

$$Z=(\sum X_i)/(CT*Y), \tag{6}$$

Based on Gantt chart, it can be known from equations (5) and (6),

CT=29.106min(Copper tube insertion station)

$Z=207.968/(29.106*21)\approx 34.025\%$,

$Z_1=165.546/(29.106*13)\approx 43.751\%$

According to the calculation results, the current equilibrium rate is too low and must be optimized.In order to better find the bottleneck process, the bar chart of current working hours can be obtained based on the measured working hours, as shown in Fig.3.

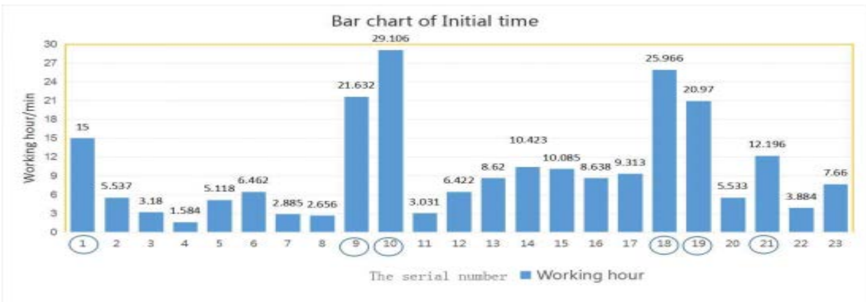

Fig.3 A histogram of existing working hours

Based on Fig.3, it can be seen that the 6 processes with serial Numbers 1, 9, 10, 18, 19 and 21 are bottleneck processes, and the serial Numbers correspond to the processes from top to bottom of the Gantt diagram, that is, the bottleneck processes are stripping wire, threading plastic pad block, threading copper pipe, mounting pad block 2,mounting upper and lower fixation, preassembly sheath, and screening inspection.

The analysis shows that:(1) the production of tin wire takes a long time, considering the introduction of automatic wire machine;(2) the two processes of threading the plastic pad block and mounting the pad block 2,mounting upper and lower fixing should be considered to change the upper firmware structure to save time;(3) for the copper pipe threading process, the station takes 29.106 minutes, which is the longest process in the product assembly process. It is considered to improve the production capacity and balance rate of production line based on personnel layout and rearrangement, and the other two bottleneck processes are the same.The above 6 bottleneck processes will be optimized in the future.

2.2 Personnel and layout analysis

Based on the actual production line, the layout diagram and annotation table are shown in Fig.4 and Fig.5.According to the above analysis, it is considered to adopt the full-automatic wire machine for wire rod production. If the full-automatic wire machine can save personnel and labor hours, the layout shall be readjust. Therefore, focus on DP production line layout.

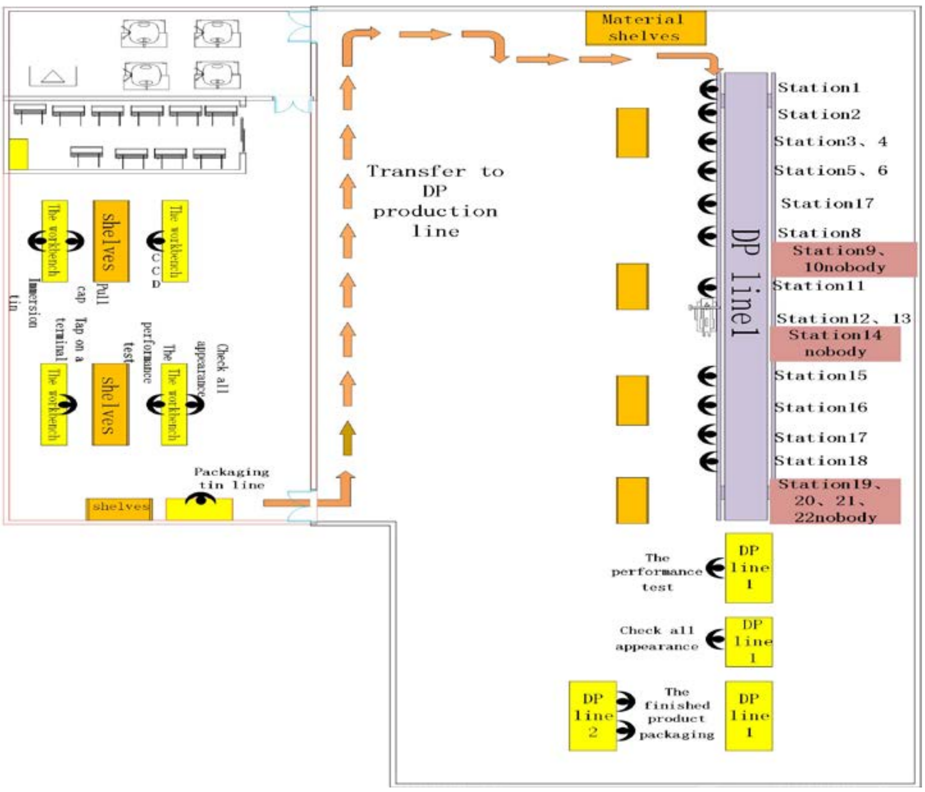

Fig.4 Layout of existing production line personnel

Station/ pattern	Explanation	Station/ pattern	Explanation
1	Insert plastic pad(one person)	11	Heat shrinkable tube blowing(one person)
2	Insert The brass(one person)	12、13	Placing tunnel furnace(one person)
3、4	Weld of brass(one person)	15	Rivet pressure spring(one person)
5、6	Rivet pressure copper pipe(one person)	16	Load block2+Insert upper and lower fixation(one person)
7	Place the zinc alloy column+Cut tin wire(one person)	17	Preassemble Stem casing(one person)
8	Weld zinc alloy column(one person)	18	Rivet pressure stem casing(one person)
	Represents the automatic assembly of fixed components		Represents tunnel furnace
	Indicating table		Represents shelves
	Express semi - automatic stripping machine, a total of 10		Represents the fully automatic wire machine, 2 straight line 2 turntable

Fig.5 Layout diagram comments

Analysis based on the personnel layout diagram is as follows:

(1) the existing DP production line adopts a linear assembly line layout, and there are bottlenecks in the front and back processes, which leads to a large number of employees in a waiting state, resulting in low productivity, serious idle talk, and the unreasonable use of automated assembly lines.

(2) based on the site layout, it can be seen that although DP production line 1 has its own packaging station, the product packaging of production line 1 is also transported to the packaging station of DP production line 2 for packaging due to the low production efficiency of the previous process, so the original layout occupies the extra space.

(3) the station of DP production line is too long, resulting in the idle station in the layout drawing, which occupies space and increases the distance of personnel handling, which should be improved here.

(4) by observing the production line, tunnel furnace size is bigger, take two stations, and because from the entrance to the tunnel furnace put in from exports after placing the tray removed, resulting in the need to spare for a station, or if a station after staff in operation will be affected, so it should be considered positioned to reduce its footprint location.

(5) third, the fourth process is welding copper pipe and riveting copper pipe respectively. These two processes are not bottleneck and not complicated, and are completed by one person. Therefore, these two processes do not need to occupy two stations respectively, and one station should be cancelled for each.

2.3 Demand analysis

In any enterprise, corresponding production shall be carried out according to customer requirements.Before the product assembly process optimization, the customer needs for the product must be clearly defined, and to meet customer needs for improvement.The production department arranged production according to the customer's order requirements. It is known that the customer ordered 32,000 antenna products of DP2450LZN-145B17U7 in April, 19.In order to meet this month's customer demand, the enterprise must calculate the production cycle.The company has two DP production lines, so each line should assemble an average of 16,000 antennas.It is assumed that the actual daily working hours are ST, the customer demand tempo is TT, the daily working hours are WT, the daily meals and lunch breaks are LT and RT, the customer demand this month is D root, the monthly working days are D, and A is the allowance rate.(TT’s unit is min, while ST, LT and RT’s unit are h)

$$ST = (WT - LT - RT) \times (1 - A) \quad , \tag{7}$$

$$TT = \frac{ST \times 60 \times \mathrm{d}}{D} \quad , \tag{8}$$

It is known that the enterprise has a total lunch and lunch break of 0.5h per day and works 9 hours per day, in which the width ratio of antenna products assembled by employees is 15%. Therefore, it can be known from equations (7) and (8) that ST=7.225h and TT=0.704min.

Based on the customer demand tempo, the final improved production beat must be lower than 0.704min in order to meet the customer's demand without overtime work and staff increase.

From what has been discussed above, the problems to be solved in this optimization are as follows :(1) the general upper firmware structure needs to be changed to improve the production process;(2) the original layout of DP production line personnel and station does not match the production beat and needs to be rearranged.

3. Assembly process optimization

3.1 Optimization and feasibility analysis of tin wire production

Through the introduction of fully automatic wire machine, its process rearrangement is stripping wire →pressure terminal and photographic inspection → conduction test → appearance inspection → tin dipping →CCD appearance inspection → outgoing (qualified and defective products to the corresponding position).According to the measurement of multiple working hours, the working time of the automatic wire machine is 15min/200 pieces.It takes 0.476min to move the wire from the position of the current automatic wire machine to the shelf at the packaging place. Then, the total wire production time is 18.132min. Compared with the former semi-automatic wire stripper, the efficiency is improved by 57.258% and 5 employees are reduced.Next to adopt automatic wire machine cost analysis to see whether the introduction of the machine is feasible.

The enterprise introduces a straight automatic wire machine at the price of 400,000 yuan. This equipment will be regarded as the fixed assets of the enterprise, with an estimated service life of 10 years, no residual value after 10 years, and an annual depreciation rate of 10%.Before using the fully automatic wire machine, the total antenna production time was 1.03984min/ piece.The actual working hours of the enterprise per day ST=7.225h, from which it can be calculated that the output of each DP production line used in the former semi-automatic wire machine is 417 per day.The company works 26 days per month (not including overtime), so the original production capacity of this product is 10,842 units per month.After the selection of automatic wire machine, the production capacity of each DP line of the product increased to 12,273 per month.It is understood that the enterprise DP type antenna profit is 0.3 yuan/each (material, water and electricity costs have been deducted).At present, the enterprise has two production lines of DP, and it is known that the capacity of automatic wire machine can reach 800 per hour, so it is fully enough to assemble the production line of DP, and it can also be used by other production lines.In the case of only considering the profit of DP type products, the total monthly sales profit of fully automatic wire machine is 7363.8 yuan (2 DP production lines).After consulting the relevant personnel, the annual maintenance cost is 10,000 yuan, and the staff salary is 15 yuan/hour.At this time, the automatic wire machine only one employee, the annual salary of 42,120 yuan.

The net present value method is adopted to calculate, assuming that the annual net cash flow is W, the net present value is NPV, the present value is P, the annuity is A, the depreciation expense is V, the depreciation rate is I, and the depreciation life is t.

$$NPV=W^*(P/A, i, t)-V, \tag{9}$$

W=7363.8*12-10000+40000-42120=76245.6 yuan， From equation (9), we know NPV=68496.2 元 > 0， Therefore, it is feasible to recommend the equipment.

3.2 Structural optimization of upper firmware

For the product firmware, in order to no longer need to install white plastic pad block into the copper tube, consider make the plastic gasket directly fixed to the upper firmware, the original inner table of the upper firmware into a groove, integral mold out.Because of the existence of other types of antenna with a diameter of 7 copper tube, in order to ensure the general type, it will be general on the inner wall of the firmware is add enhancing bar, when the copper tube with an internal hole of 5, when the copper tube with an external hole and reinforcement of 7 fixed.The internal structure diagram of the existing upper firmware and the modified upper firmware is shown in Fig.6.

Fig.5 Before improvement (left) after (right) internal structure diagram

3.3 Optimize production line and personnel layout

According to the product assembly situation and the condition of improving the assembly balance rate, the following scheme is proposed based on the range of two-handed operation in ergonomics (without considering the wire production workshop) :

Solution 1: in order to improve the balance rate of the assembly line and increase the staff of the bottleneck process, the layout is shown in Fig.6.Each station conveyor belt is independent, can be controlled by the station personnel switch, conveyor belt can be reversible, reduce the handling.In Fig7, which station 1,2 and 3 that are processes of the upper and lower fixing and RF line , and the rest are the same.The total working time of the scheme was 65.855min and Z1=73.172%, which increased by 24.996% compared with the balance rate of the initial rearrangement. However, a device and 8 employees were added in the process.

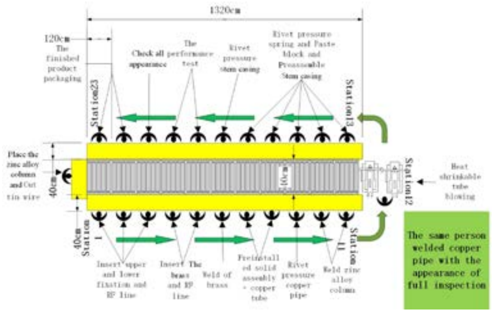

Fig.6 Optimize production line and personnel layout for solution 1

Solution 2: adopt the method of merging processes for optimization, and the layout is shown in Fig.7.At this time, Z1=66.91% and CT=18.02min, and the balance rate was 18.734% higher than that of the initial rearrangement solution.The total working time was 108.51min, 23.223min was shortened, and 5 employees were reduced.

Solution 3: the assembly line adopts a U-shaped layout, and the combination of processes and one person take up multiple stations is selected. The layout is shown in Fig.8.The process of the layout solution take 76.795min (include 0.15min for the handling time at the tunnel furnace and 0.1min for the handling time between the other stations), with one less person, CT=10.49min and Z1=91.509.At this time, the balance rate increased by 43.333%.

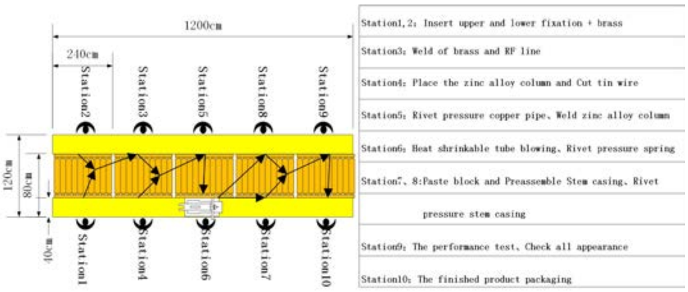

Fig.7 Optimize production line and personnel layout for solution 2

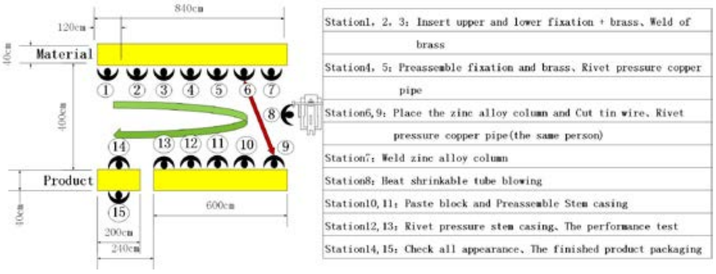

Fig.8 Optimize production line and personnel layout for solution 3

3.4 Select the optimal layout

According to the feasibility, safety, comfort and economic benefit of the scheme, communicate with relevant personnel, get the corresponding evaluation index, and then select the best scheme by AHP（Analytic Hierarchy Process）.The hierarchical structure model is established as shown in Fig.9, relevant judgment matrix is constructed, maximum eigenvalue and corresponding eigenvector are calculated by MATLAB, and the calculation process of matrix is listed in Fig.10 [14].The calculation of significance can be obtained from the judgment matrix process table, as shown in Fig.11.

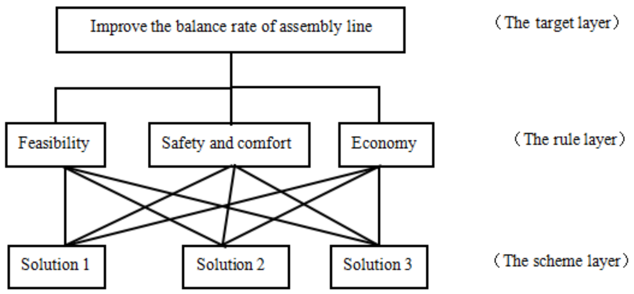

Fig.9 Hierarchical structure model

A	B1	B2	B3	Wi	
B1	1	1/3	1/5	0.105	λmax=3.0385;
B2	3	1	1/3	0.258	CI=0.01925<0.1;
B3	5	3	1	0.637	RI=0.58;
					CR≈0.033<0.1

B1	C1	C2	C3	Wi	
C1	1	1/3	1/5	0.105	λmax=3.0385;
C2	3	1	1/3	0.258	CI=0.01925<0.1;
C3	5	3	1	0.637	RI=0.58;
					CR≈0.033<0.1

B2	C1	C2	C3	Wi	
C1	1	7	3	0.649	λmax=3.0649;
C2	1/7	1	1/5	0.072	CI=0.03245<0.1;
C3	1/3	5	1	0.279	RI=0.58;
					CR≈0.056<0.1

B3	C1	C2	C3	Wi	
C1	1	5	1/3	0.279	λmax=3.0649;
C2	1/5	1	1/7	0.072	CI=0.03245<0.1;
C3	3	7	1	0.649	RI=0.58;
					CR≈0.056<0.1

Fig.10 Matrix calculation process

Bi / bi / C_j / C_j^i	B1	B2	B3	$C_j = \sum_{i=1}^{3} b_i C_j^i$
	0.105	0.258	0.637	
C1	0.105	0.649	0.279	0.356
C2	0.258	0.072	0.072	0.091
C3	0.637	0.279	0.649	0.552

Fig.11 The calculation of significance

The results show that the order of advantages and disadvantages of the three schemes is:

C3> C1 > C2, and solution 3 is obviously superior to solution 2 and 1, so solution 3 is selected as the optimal scheme.

4. Comprehensive optimization scheme

Considering the change of product structure, the introduction of new equipment and production line layout comprehensively, the optimized personnel layout and assembly drawing of the production line are shown in Fig.12 and Fig.13.

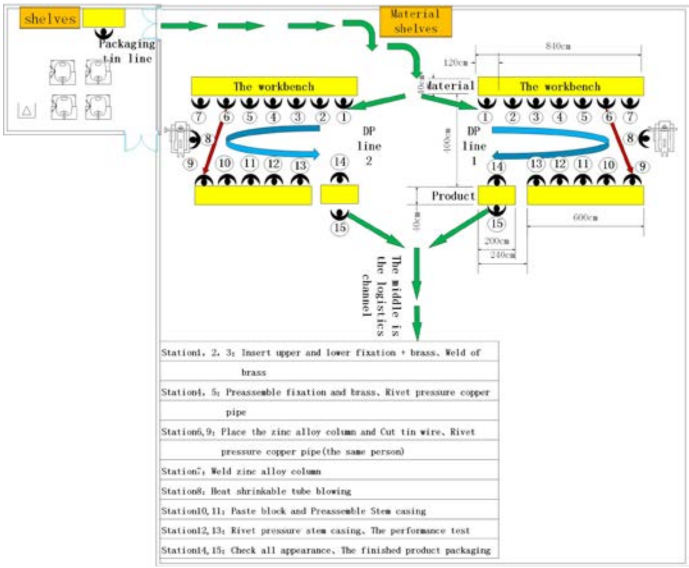

Fig.12 Overall scheme layout

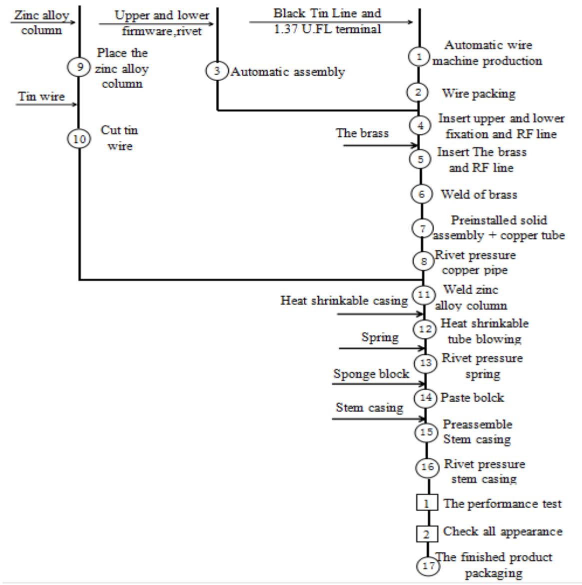

Fig.13 Optimized product assembly drawing

Through the stopwatch method to determine the time, the time bar graph is shown in Fig. 14.According to the histogram of working hour, the overall optimized total working time is 94.991min (without considering the parallel process), the average time of each antenna is 0.475min, and the standard time is 0.546min after considering the emplacement rate.At this time, CT=15.15min and Z=62.7%.

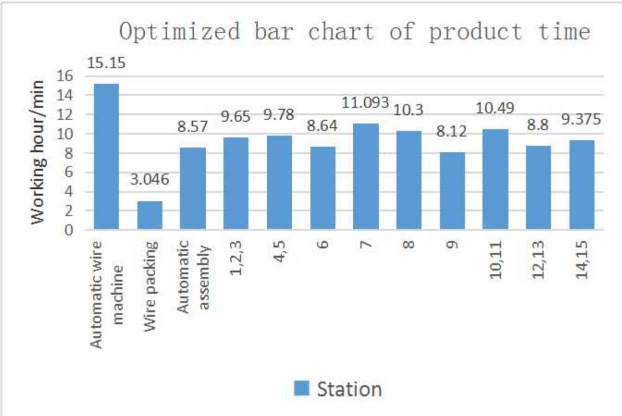

Fig14 Optimized bar chart of product time

5. Effect comparison

(1) the total working time after improvement is 112.164min shorter than that before improvement (as shown in Fig.15).At this point, the average time of each antenna is 0.479min, and the standard working time is 0.551min/each antenna, which can meet the customer's needs with a beat of 0.704min and complete the production task.

(2) The overall balance rate is 29.212% higher than the current method.Among them, the balance rate of DP production line was increased by 43.701% compared with the current method (as shown in Fig.16) and WIP(work in process) was reduced.

(3) after the optimization of the production line, the number of employees was reduced from 22 to 15. The known salary of the production line employees was 15 yuan/hour, which was equivalent to reducing the labor cost by 294,840 yuan per year.After optimization, the production capacity of each DP production line is increased to 787 per day, and the annual output of two DP production lines is increased to 491088 per year, which can increase the sales profit by 58960.8 yuan per year.During the generation of water and electricity in addition to the material has been deducted from the cost, automatic wire machine maintenance costs of 10,000 yuan per year, comprehensive consideration, the average cost of

the enterprise saved 254,840 yuan per year, and on this basis increase 58960.8 yuan profit.

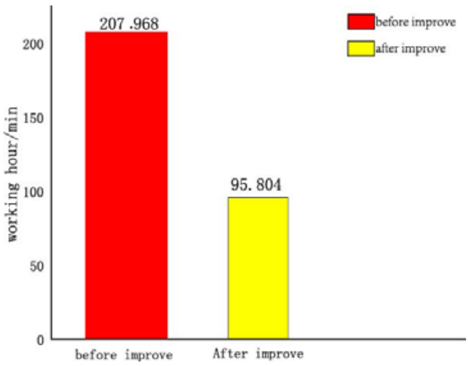

Fig.15 comparison of working hour

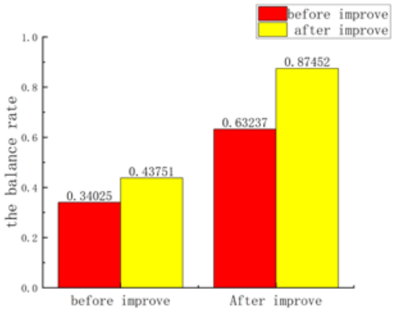

Fig.16 comparison of balance rate

6. Conclusions

This article implemented the program analysis and the layout analysis to conduct the research, and in this process unifies the customer demand for the analysis. Through introducing automatic wire machine, changing the structure of upper firmware and adopting analytic hierarchy process to select the best layout scheme, the overall optimization scheme was finally obtained. The optimization results show that this optimization scheme is feasible, which not only improves the balance rate and efficiency of general antenna products, but also probable increases the sales profit and indirectly reduces the cost.

Since there is currently no article on optimization of assembly line of general antenna products, the optimization scheme in this paper can provide optimization ideas and methods for other antenna enterprises, so as to increase their competitiveness.

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