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The intelligent upgrade design of assembly line based on human-machine cooperation

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Abstract: With the rapid improvement of people's consumption level, the traditional production line had been difficult to meet the existing production needs. In this paper, the assembly Lego building block production line was taken as the research object, and the collaborative robot was introduced to intelligently transform the traditional production line. Based on the production mode of lean production, the production planning system was improved and the planning management needs of different processes was met. After the transformation, the C/T value of the production line was 11.5 s, and the daily output was 2509/shift, which was 25.45% higher than the original production line of 2000/shift. UPPH increased from 87/h to 165/h, an increase of 89.66%. The balance rate was 98.70%, which balanced the work intensity of workers. The intelligent upgrading of production line played an important role in improving the production management level and comprehensive competitiveness of enterprises.

1. Introduction

Under the background of consumption upgrading, the demand of consumers presents diversified characteristics. The competition among enterprises was more and more emphasized based on customer demand. It had become an inevitable choice to produce diversified and personalized products. The external market had posed a severe challenge for manufacturing enterprises to be able to produce multiple varieties of products, achieve rapid iteration and delivery small batch rapidly and flexibly. The traditional production line had been unable to meet the existing production needs, so it was in urgent need of transformation [1]. The efficiency improvement of assembly production line included the upgrading of production layout and local station. The layout of equipment production operation in the workshop was very important. In 1990, a research team led by MIT 's Professor James Womack [2] created the term ' lean '. Now, lean production had been widely used in industrial production. In this study, the production line equipped with Lego building blocks was taken as the research object, Lean production was adopted to reduce the complicated processes in the production process, so that the layout could be as simple as possible. Using rapid changeover to improve the production line, greatly reducing the time required for product model switching. Referring to the design concept of anti-dead method, measures such as optimal design of assembly parts were taken in local processes to minimize the instability of manual participation. Through the research and development of multi-arm cooperative robots, Dr. Wu Qilin [3] and others had upgraded the structure lightweight design, kinetic control, and artificial intelligence technology of existing cooperative robots. Now the current cooperative robots had the capability of packeting and palletizing efficiently. By observing the operation characteristics of all stations on the assembly line, the bottleneck restricting efficiency was found out, and the specific stations were upgraded, and the cooperative robot was used to replace the workers to complete the operation [4-5].

2. Research methods

2.1 Lean production

Lean production was used to optimize the supply chain, reduce unnecessary processes and transportation mostly. Its high degree of automation, while emphasizing human-machine collaboration, in the production line improvement could play a significant effect.

2.2 Anti-dead method

The anti-stale method was a method for improving the rate of qualified products in production, and adding equipment to prevent the occurrence of unqualified products in molds and tooling fixtures. The anti-stale design of the manual operation part of the production line could effectively reduce the incidence of unqualified products and improve production efficiency and safety assurance.

2.3 Quick changeover

Quick changeover was a method used to improve activities and make them safer, more ergonomic and simpler in the shortest possible time. Shortening the changeover time could make the switching between product models faster and more flexible. As a result, productivity was increased, fewer equipment was left idle, more net production time and shorter product transit time were available [6].

3. Production line design

3.1 Traditional production line

The Lego car that needs to be assembled was shown in Figure 1. The traditional production line mainly includes three processes, truck base and cab assembly, truck wheel assembly and product inspection and packing, product box stacking. The traditional assembly line was assembled by pure manual method. There were 3 assembly personnel, including 1 person per process. The working time was 8 hours per day, the middle rest was 20 minutes, and the daily output was about 2000. Considering the labor cost, one-time input cost and the feasibility of process operation, the production beat C/T was about 12.6 s [7].

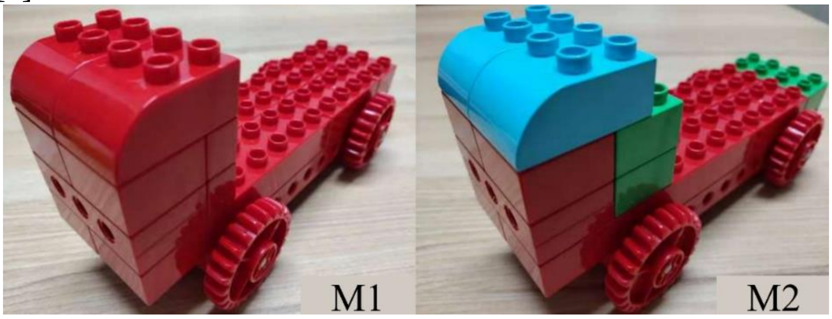

Figure 1: Lego car model

3.2 Intelligent production line

3.2.1 Production line man-machine distribution analysis

Considering the feasibility of labor cost, one-time input cost and process operation, the traditional pure manual assembly line was divided into human-machine cooperation tasks. Two assembly personnel assembled the truck base, cab and wheel, and cooperated with the robot to palletizing the product box. The assembly process was re-planned to balance the work intensity of the two assembly personnel as much as possible.

3.2.2 Collaborative robot operation process design

The collaborative robot mainly performed the product box palletizing process, and sorted out the process of the robot performing the palletizing task. The steps were as follows.

Step 1: The gripper of the cooperative robot moved from the initial position to the top of the product packaging box.

Step 2: After the cooperative robot gripper was moved down to the appropriate position above the packaging box, I/O communication was performed, and the gripper was opened and the packaging box was clamped.

Step 3: The collaborative robot carried the packaging box up to the set position and then moved it above the stack board directly.

Step 4: The collaborative robot moved the packaging box down to the stack plate area for stacking. When stacking, it was required that 1 stack plate contained 20 product packaging boxes, and the stack arrangement was 2*2*5. The stack plate was placed on the AGV car.

Step 5: The collaborative robot moveed up to the set position and then translated to the top of the product packaging box, waiting for the next grab.

The palletizing process flow required rigorous logic control, and multiple links such as handling and stacking needed to be completed. The trajectory planning of the robot was designed by the operation process of the robot performing the palletizing task, as shown in Figure 2.

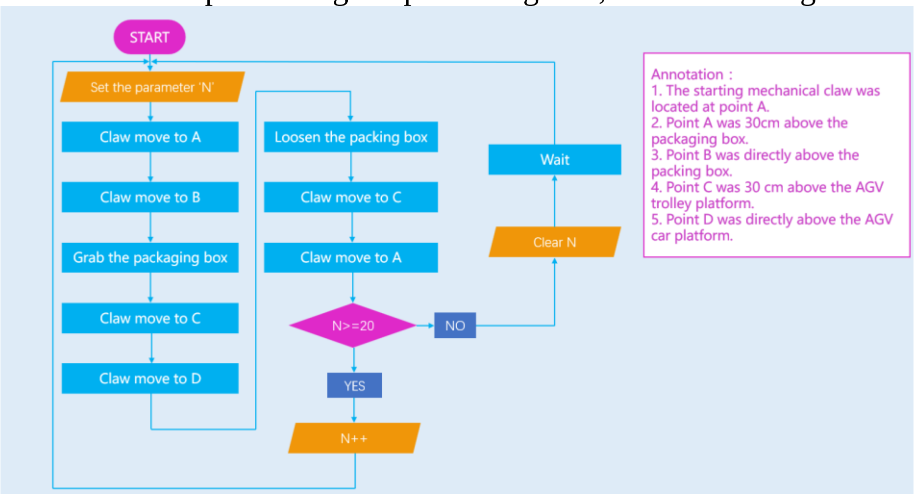

Figure 2: Process logic diagram

3.3 Quality control design

In order to improve the quality of product production, it was necessary to carry out anti-dead design for the whole manual operation part of the production line. For example, the axle was designed to be D-shaped, as shown in Figure 3. The material box was numbered according to the assembly sequence, as shown in Figure 4 [8]. In order to reduce the internal time, some improvements had been made in the replacement. The replacement tool was arranged next to the station in advance to facilitate the replacement of workers at any time [9].

Figure 3: D axle

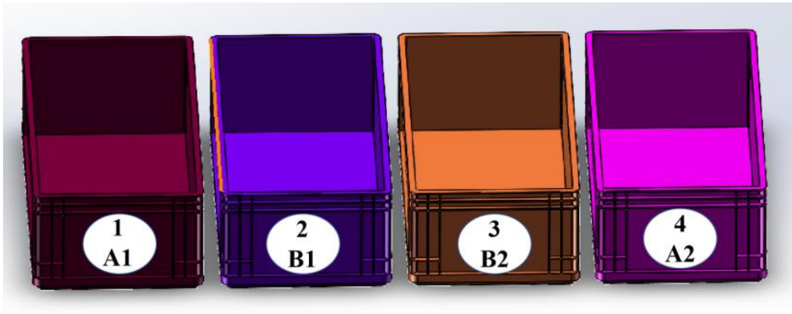

Figure 4: Material box

3.4 Production line layout

The U-shaped design was used to plan the layout of the production line. Station 1 was located in front of the material transfer port, and station 2 was behind station 1. Station 3 was L-shaped with station 1 and station 2, which was conducive to station 1 and station 2 personnel to check the production of collaborative robots in time. The line logistics and the production line side were convenient for logistics personnel to load and unload. There should be no obstacles at the running track of AGV car. The overall production line layout scheme was shown in Figure 5.

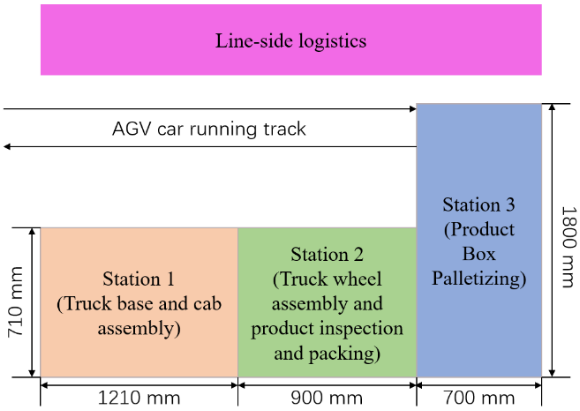

Figure 5: Layout diagram of production line

4. Program analysis

4.1 Production efficiency

After the intelligent upgrading of the production line, the average time and bottleneck of each process were obtained, as shown in Table 1.

Table 1: Production time of each process

Process	Mean time(s)	Bottleneck(s)
1	11.2	11.5
2	11.5	
3	8.0	

Table 1 is concluded that the production beat C/T of the modified production line is about 11.5 s. Daily production formula:

$$\text{Daliy output} = \frac{\text{Productive time}}{\text{Productive beat}} \tag{1}$$

Production efficiency formula:

$$\text{Production efficiency} = \frac{\text{Production quantity}}{\text{Production time}} \tag{2}$$

The daily output is calculated to be about 2509/shift, compared with the original production line, the daily output increases by 509/shift the production efficiency is about 330/h. The production efficiency is 25.45% higher than that of the whole manual operation production line. To a certain extent, the yield has been increased, and the production efficiency has been significantly improved.

4.2 UPPH

UPPH formula:

$$\text{UPPH}=\frac{\text{Work load}}{\text{Time}\times\text{Head}} \tag{3}$$

After the transformation, the current production line has invested 2 manpower, the investment time is about 7.6 h/class, and the workload is about 2509/class. It is calculated that the UPPH of the modified production line is about 165/shift. Compared with the full manual production line, it increased by 78/shift. The improvement of production efficiency has effectively enhanced the core competitiveness of enterprises.

4.3 Equilibrium rate

Equilibrium rate formula:

$$\text{Equilibrium rate} = \frac{\text{Single product man-hour}}{\text{Bottleneck}\times\text{Head}} \tag{4}$$

According to Table 1, the process bottleneck time is 11.5 s. The working time of a single product is 22.7 s. The balance rate after transformation is calculated to be 98.70%. Process one and process two are equivalent in time, which can balance the workload of personnel, and will not produce a long period of product empty block in production.

5. Conclusions

Taking the Lego car toy assembly line as the research object, combining the analysis of the traditional artificial workstation with the economical cooperative robot in the market, the intelligent upgrading of the traditional production line was completed. The manual operation of process 1 and process 2 was retained, and the collaborative robot was introduced into the product packing and palletizing of process 3. At the same time, the anti-stale design of the full manual operation part of the production line was carried out, such as the design of the material warehouse, the design of the card slot, etc. The man-machine safety quality control design was carried out for the robot operation part, the main equipment was selected and the equipment layout was optimized. On this basis, the rapid change design of the process, the confirmation of job responsibilities, the preparation of standard documents and the steps of switching operations were carried out. The intelligent upgrading of the equipment production line had increased the production efficiency of the production line by 25.45%, and the output of each production line in each shift was 2509 products. Balance the workload, the balance rate was 98.70%, UPPH increased from 87/h to 165/h, an increase of 89.66%.

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