Analysis on Balance Improvement of Cross Grate Cooler Assembly Production Line Based on MOD Method

Yue Guo*, Xiwen Feng*
Shandong University of Science and Technology, the Ministry of Mine disaster Prevention and Control jointly built the cultivation Base of the State key Laboratory, National Demonstration Center for Experimental Mining Engineering Education 266590, China
*Corresponding author e-mail: fxw6380@163.com, aguoyue0622@163.com

Abstract. Based on the principle of production line balance and TOC theory, the problems of low production balance rate and long product delivery time of assembly line are solved based on MOD method. Mainly uses the TOC theory to carry on the analysis to the bottleneck process, carries on the standardization improvement to the bottleneck process through the MOD method; Find out the non-standard and unnecessary actions, and use the action economic principle to improve these non-standard actions to make them standardized and standardized. After improvement, the balance rate of the production line was increased from 30.9% to 38.7%.

1. Introduction
With the increasingly fierce market competition, customer demand shows a trend of diversification. With the support of government policies and the good development prospects of the industry, the competition of enterprises with assembly line mode as the main production mode has become more and more fierce. Therefore, more and more enterprises begin to pay attention to the balance of production lines. By improving the balance rate of the production line, enterprises can solve a series of problems, such as low production efficiency, waste of action and so on. In this paper, taking the cross grate cooler assembly line of Company A as the research object, the MOD method is used to analyze and rationalize the operation of the workers in the bottleneck process of the assembly line, so as to complete the bottleneck process with the simplest action. Improve the balance rate of the production line and realize the rational allocation of field resources.

2. Method of MOD
The model timing method, is based on the human factor experiment, taking the time consumption of the lowest energy consumption movement as the time unit of the movement, and the time value of the finger movement with the lowest grade, the fastest speed and the least energy consumption in a normal person [1]. Set it as 1MOD. This movement is equivalent to the distance of the finger moving 2.5cm, and the average movement time is 0.129 s, that is, 1MOD=0.129s. However, this conversion relationship is not applicable to all types of enterprises, because the products, working environment and working basis of each enterprise are different, so in practice, the MOD value suitable for the characteristics of the enterprise should be determined according to the actual situation of the enterprise [2].
Because the MOD method considers the action and time of the human body together, this paper subdivides the actions of different parts of the human body, and defines different motilin symbols, as shown in Table 1.

### Table 1. MOD method verb prime number table.

| Classified                  | Content                                      | Symbol |
|-----------------------------|----------------------------------------------|--------|
| Upper limb movements        | Finger movement                              | M1     |
| movements (basic movements) | Wrist movement                               | M2     |
|                             | Forearm movement                             | M3     |
|                             | Arm movement                                 | M4     |
|                             | Straight arm movement                        | M5     |
| Reflex action               | A reflex action that is repeated many times in a row | M1/2  |
| Termination action          | Touch                                        | M1, M2 |
|                             | A grasp that does not require attention       | M3     |
|                             | Complex grasping                             | G0     |
|                             | Simple placement (not visual)                | G1     |
|                             | More complex placement, such as alignment (necessary visual) | G3 |
|                             | Placement with assembly purpose (asymmetric) | P0     |
| Lower limb movement.        | Footstep action                              | P2     |
|                             | Pedal action                                 | P3     |
|                             | Thigh movement                               | P5     |
|                             | Walking action                               |        |
| Other actions               | An action performed independently (other actions stop while this action is in progress) |        |
|                             | Visual observation (find out)                | F3     |
|                             | Correction (recapture)                       | W5     |
|                             | Judgment and reaction (consideration).       | E2     |
|                             | Press (press)                                | R2     |
|                             | Rotation action                              | D3     |
|                             | Bend over-stand up                           | A4     |
|                             | sit down-get up                              | C4     |
|                             | Body movements that can be performed at the same time |        |
|                             | Weight factor (weight bearing action)        | B17    |

### 3. Application of MOD method in Assembly production Line of Cross grate cooler

#### 3.1. Balance analysis of production line

The balance of the production line, also known as the synchronization of the process, is a technical means and method to analyze the load of all the processes in the production line, and then adjust and distribute the load between different processes to make the operation time of each process as close as possible. Its ultimate goal is to eliminate all kinds of waste between different processes and in the same process and improve the production efficiency of the production line. This method of improving inter-process capability and balancing the process is also known as "bottleneck improvement".

The formula for calculating the balance of production line [3] is:

\[
\text{Line balance rate} = \frac{\text{Total time of each process}}{\text{Number of processes} \times C.T} \times 100\% = \frac{\sum_{i=1}^{n} t_i}{\text{Number of processes} \times C.T} \times 100\% \tag{1}
\]

In the formula: C.T is the time of the longest process on the production line; n is the number of processes on the production line; t_i is the time of the i process, where i = 1, 2, 3, ..., n.

The formula for calculating the equilibrium loss rate of the production line is as follows:
3.2. Analysis of present situation of production Line

3.2.1. Analysis on the present production situation of Company A. The assembly production line of Company A cross grate cooler is mainly composed of 10 working procedures, which are as follows: pre-assembly, welding, painting, installation of driving guide rail, assembly, installation of vents, installation of ADP, installation of C-type wear resistant plate, commissioning, inspection and packaging. The process flow chart is shown in figure 1.

Because in many projects of the company, the cross grate cooler has a series of practical problems such as long delivery period and high production cost. Therefore, through the observation and analysis of the on-site production, it is found that there are some phenomena in the process of operation, such as non-standard operation, waste of action, moving back and forth and loose work [4]. At present, 1.5 cross grate coolers can be assembled every day. In this paper, the working hours of each process of the production line are measured, and the working time of the previous processes is improved as shown in Table 2.

In the whole production process, the work-in-process must go through the previous process of processing and assembly, in order to delay the next process to continue to work [5]. The processes are all continuous production without interruption. Since the installation of vents, the installation of ADP and the installation of type C plates are completed by the same two workers in the same location, they are defined as process VI; According to the workplace, process 1 is defined as pre-assembly, process 2 as welding, process 3 as painting, process 4 as installation drive guideway, process 5 as assembly, process 7 as commissioning, process 8 as testing, and process 9 as packaging.

Starting with pre-assembly, it takes a standard time of 1404 minutes to assemble a product, and then a finished product every 413.5 minutes. The production speed of the product is restricted by process 5. According to principle 2 of the constraint theory (the utilization degree of the "non-bottleneck" process of the system is determined by the "bottleneck" process [7]), the bottleneck process of the system affects the production efficiency of the whole system. If we do not take the improvement of process 5 as the core, no matter how to improve the efficiency of the other seven processes, it will not play a role in increasing the production speed of the whole system. Because of the great difference between the production capacity and production content of each process, it is necessary to optimize the whole assembly process and give priority to the optimization and improvement of the bottleneck process in order to achieve the effective control of the bottleneck. Improve the effective output efficiency of the system.

According to the operation time of each process before improvement in Table 2, the operation time bar chart of each process can be drawn as shown in figure 2. According to figure 2, it can be clearly
found that because the bottleneck process takes more time and far exceeds other processes, as long as the bottleneck process is reasonably and feasible improved, the balance loss rate of the whole production line can be reduced. And then shorten the delivery time of products, and further enhance the efficiency and reputation of the company [8].

| Numble | Process name              | Average operating time/min | Number of operators |
|--------|---------------------------|-----------------------------|---------------------|
| 1      | Preassembly               | 241.5                       | 2                   |
| 2      | Soldering                 | 260                         | 1                   |
| 3      | Spray paint               | 26                          | 1                   |
| 4      | Install drive guideway    | 30                          | 2                   |
| 5      | Assembly                  | 413.5                       | 2                   |
| 6      | Install vent              | 92                          | 2                   |
| 7      | Install ADP               | 48                          | 2                   |
| 8      | Install C-shaped board    | 150                         | 2                   |
| 9      | Test run                  | 51                          | 3                   |
| 10     | Detection                 | 60                          | 1                   |
| 11     | Packaging                 | 32                          | 2                   |

The balance rate of the production line and the balance loss rate of the production line are calculated for the data in Table 2. The results are as follows.

It can be calculated according to formula (1), the balance rate of the company's production line is 30.9%; It can be calculated according to formula (2) balanced loss rate of production line is 69.2%. The working time of bottleneck process is 413.5min. The production line is extremely unbalanced, and the balance loss rate of the production line is too high, so it is necessary to analyze the specific problems existing in the field and make reasonable improvement.

3.2.2. Problem analysis. According to the 5W2H questioning method in industrial engineering, it can be found that there are serious problems in the production process, which can be shown in figure 3.
3.3. Application of MOD method

According to the fishbone diagram of the production line efficiency, it can be seen that the main factors affecting the efficiency of the production line are human factors, such as tedious operation of bottleneck process, non-standard operation of staff and low enthusiasm for work [9]. Based on the above reasons, this paper uses MOD method to analyze the bottleneck process, as shown in Table 3.

Because in the process of assembly, it is necessary to assemble 6 large bending plates, 6 bearings, 6 grounding wire blocks, 6 rubber plates, 6 lower guide rails, 6 large oil cylinders and 6 small oil cylinders, and the operation is the same as the installation of large bending plates. I won't go into details here. And all screws need torque, computable value of MOD:

\[
\text{Value of MOD} = (4 + 3 + 24 + 5 + 4 + 5 + (4 + 3 + 3 + 5 + 6 + 3 + 5 + 4 + 3 + 72 + 5 + 4 + 25 + 5) \\
\times 6 \times 7 + 4 + 3 + 3 + 4 + 3 + 6 + 3 + 5 + 2 + 8 + 24 + 2) \times 2 + 32726 = 45348
\]

Normal time = value of MOD \times 0.129s = 5849.892s

Standard time = Normal time \times (1 + Allowance) = 7019.87s = 117min

In formula, combined with the working intensity of the production line and the on-site working environment, the width rate is located by 20% [8].
Table 3. Bottleneck process MOD analysis table.

| Left hand action | Symbolic mark | MOD value | Symbolic mark | Right hand movement |
|------------------|---------------|-----------|---------------|---------------------|
| Reach for the wrench | M3G1 | 4 | M3G1 | Reach for the wrench; |
| Move to your chest | M3P0 | 3 | M3P0 | Move to your chest; |
| Rotating screw | (M1G0M1P0)×12 | 24 | H | Hold on; |
| Place the wrench in position | P5 | 5 | P5 | Place the wrench in position; |
| Reach for the brush | M3G1 | 4 | H | Hold the barrel; |
| Brush antirust oil | M3G1M2P2B17 | 25 | H | Hold the barrel; |
| Place the brush in position | P5 | 5 | P5 | Place the brush in position; |
| Reach out and grasp the large bending plate | M3G1 | 4 | M3G1 | Reach out and grasp the large bending plate; |
| Move to your chest | M3P0 | 3 | M3P0 | Move to your chest; |
| Judge large bending plate | D3 | 3 | D3 | Judge large bending plate; |
| Place large bends to position | P5 | 5 | P5 | Place large bends to position; |
| Reach for the screw | M3G3 | 6 | H | Hold on; |
| Move to your chest | M3P0 | 3 | H | Hold on; |
| Place screws to position | P5 | 5 | H | Hold on; |
| Reach for the wrench | M3G1 | 4 | M3G1 | Reach for the wrench; |
| Move to your chest | M3P0 | 3 | M3P0 | Move to your chest; |
| Rotating screw | (M1G0M1P0)×36 | 72 | H | Hold on; |
| Place the wrench in position | P5 | 5 | P5 | Place the wrench in position; |
| Reach for the brush | M3G1 | 4 | H | Hold the barrel; |
| Brush antirust oil | M3G1M2P2B17 | 25 | H | Hold the barrel; |
| Place the brush in position | P5 | 5 | P5 | Place the brush in position; |
| Reach for the nameplate | M3G1 | 4 | M3G1 | Reach for the nameplate; |
| Move to your chest | M3P0 | 3 | M3P0 | Move to your chest; |
| Judgment nameplate | D3 | 3 | D3 | Judgment nameplate; |
| wait for | BD | 4 | M3G1 | Reach for a screwdriver; |
| wait for | BD | 3 | M3P0 | Move to your chest; |
| Reach for the screw | M3G3 | 6 | H | Hold on; |
| Move to your chest | M3P0 | 3 | H | Hold on; |
| Place screws to position | P5 | 5 | H | Hold on; |
| Rotating screw | M1G0M1P0 | 2 | H | Hold on; |
| Hold on | H | 8 | M3P5 | Screwdriver alignment screw; |
| Hold on | H | 24 | (M1G0M1P0)×12 | Tighten screw; |
| Correction | R2 | 2 | R2 | Correction; |

The bottleneck process is the assembly process, and the most parts and screws need to be installed in the assembly process. In the specific operation process, skilled staff need to move the parts and the corresponding screws and nuts before installing each part, and carry it many times, which greatly increases the working time of the process. Then align the screw holes of the parts with the screw holes in the installed position, and then install the screws. In the process of aligning the screw holes, because of the heavy parts, the success rate of one alignment of the screw holes is relatively low, which generally requires 2 to 3 times. Therefore, the working time of the process is greatly increased [10]. There is a waste of action in the process of installing the screw after alignment, for example, the employee first picks up the screw and installs it in the screw hole, then picks up the wrench and tightens the screw, then puts down the wrench, and then carries on the installation of the next screw. It's a waste of too much homework time to get it back and forth [11].

Through the economic analysis of the installation action of the staff through the MOD method and combined with the human factor engineering factors and process requirements, the above problems are improved as follows: (1) according to the MOD analysis, correct the original unnecessary action waste, Simplify and standardize the movement of both hands; (2) before installing the parts, all the parts to be installed and the corresponding screws and nuts are transported to the areas accessible to both hands, and the screws are inserted into the screw holes of the parts first, so that the screws can be directly
aligned with the screw holes during installation. Tighten the screw, omitting a lot of unnecessary steps;
(3) Design an auxiliary tooling, put the parts on the pneumatic fixture, step on the bottom of the
tooling with your foot, align the parts with the theme and stick tightly, so as to avoid lifting
the parts for a long time [12].

After the improvement, through the on-the-spot observation, it is found that the staff can complete
the work efficiently and accurately, and the work enthusiasm of the staff is also improved. The working
time of each process after improvement is shown in figure 4.

Through standardization improvement, the working time of the bottleneck process is 117 minutes,
which reduces the 296.5min compared with the 413.5min before the improvement. According to the
improved data, the balance rate of the production line and the balance loss rate of the production line
can be calculated, the balance rate of the improved production line is 38.7%, and the balance loss rate
of the production line is 61.3%.

3.4. Comparison before and after improvement
The results of the comparison of the data before and after the improvement are shown in Table 4. Through improvement, the balance rate of the production line has been increased by 7.8%, the balance
loss rate of the production line has decreased from 69.1% to 61.3%, and the loss rate has been reduced
by 7.8%. The working time of the bottleneck process has been reduced from the original 413.5min to
117 minutes, which has been reduced by 296.5 minutes and reduced by 71.7%. The bottleneck process
has been greatly improved.

| Project name                  | Before improvement | After improvement | Data variation |
|------------------------------|--------------------|-------------------|----------------|
| Production line balance rate | 30.9               | 38.7              | 7.8            |
| Balance loss of production line | 69.1            | 61.3              | -7.8           |
| Bottleneck operation time     | 413.5              | 117               | 296.5          |

4. Conclusion
Through the on-site survey, it is found that the production line is out of balance, and then the actual
standard time of the bottleneck process is analyzed by MOD method. Finally, the site is improved
according to the comparison of the two time. After optimization and improvement, the balance rate of
the production line has been increased from 30.9% to 38.7%, the balance loss rate of the production line
has decreased from 69.1% to 61.3%, and the working time of the bottleneck process has been reduced from the original 413.5 min to 117 min. The production capacity increased from 1.5 sets per day to 2 sets per day. From the above data, it can be seen that the standardization improvement has greatly improved the efficiency of the production line. In addition, through the on-site staff MOD training, so that the enthusiasm of employees has been greatly improved. Observing, discovering, analyzing and improving the production line can be accomplished through the theory and method of industrial engineering. The most important thing is that compared with other improvement methods, the MOD method in industrial engineering has the advantages of low investment and easy to carry out. It can improve the balance rate of the production line, and then improve the timely delivery rate of products, so that enterprises can maintain strong competitiveness.

References

[1] Yi Shuping, Guo Fu. Basic industrial engineering [M]. Machinery Industry Press, 2014.212.
[2] Wu Aihua. Production planning and control [M]. Machinery Industry Press, 2013.
[3] Wang Huanyu. Research on bottleneck Identification and drift of production Logistics in Manufacturing Workshop [D]. Hefei University of Technology, 2013.
[4] Gong Xuxia. Research on Assembly Line balance Optimization for discrete Manufacturing Enterprises [D]. Tianjin University, 2014.
[5] Cao Yuhang. Research on Optimization of production equipment Management in the third Workshop of B Steel Pipe Company [D]. Xi’an University of Petroleum, 2019.
[6] He Manhui, Zheng Kai. Study on balance improvement of PC Assembly production Line by MOD method [J]. Modern Manufacturing Engineering, 2017 (07): 51 / 55.
[7] Yan Sen, Ye Zhuang. Study on workshop site layout based on human factor engineering [J]. Scientific and technological Innovation and Application, 2018 (14): 55.
[8] Gao Jin. Research on improvement of Front Brake production Line in X Enterprise based on IE Technology [D]. Shandong University, 2014.
[9] Qin X M, Jin Y. A Heuristic Method for Two-sided Assembly Line Balancing Problem [J]. Journal of Shanghai Jiaotong University, 2005, 10 (1): 61-65Xiaofeng Ren, Xiangming Hu, Di Xue, et al. Novel sodium silicate/polymer composite gels for the prevention of spontaneous combustion of coal [J]. Journal of Hazardous Materials, 2019, 371: 643-654.
[10] Ran Vijay Kumar Singh. Spontaneous heating and fire in coal mines [J]. Procedia Engineering, 2013, 62:78-90
[11] Sui Jing. Research on production process improvement of HL Motor based on Lean production [D]. Shandong University, 2019.
[12] Guo Fu, Qian Shengsan, Li Xingdong, et al. Planning textbook for Industrial Engineering Specialty in the 21 ~ (st) Century, Human Factor Engineering [M]. Machinery Industry Press, 2006.