Modern Management Science & Engineering
ISSN ISSN 2052-2576
Vol. 7, No. 1, 2025
www.scholink.org/ojs/index.php/mmse

Original Paper

Research on Production Line Balance Optimization Based on Improved Genetic Algorithm

Shanping Xu[1] & Tao Li[1]

[1] Business School, Shandong University of Technology, Zibo 255000, China

Received: August 19, 2025 Accepted: October 29, 2025 Online Published: November 18, 2025
doi:10.22158/mmse.v7n1p1 URL: http://dx.doi.org/10.22158/mmse.v7n1p1

Abstract

With the rapid development of China's manufacturing industry and information technology, higher requirements are put forward for the efficiency of electronic product production lines such as mobile phones. XY Company is a manufacturing enterprise mainly producing mobile phones and other electronic products, but its workshop production line has the phenomenon of unbalanced operation load of each station and low production line balance rate, this paper uses industrial engineering methods and dual-population genetic algorithm to optimize its production line, the results show that the optimized production line balance rate increases from 55.89% to 97.97%, the production line smoothing index decreases from 294.37 to 4.82, and the production line balance state is significantly improved.

Keywords

production line balance, two-population genetic algorithm, Industrial engineering

1. Introduction

our country In 2023, the added value of China's manufacturing industry will reach 39.9 trillion yuan, accounting for about 30% of the world, ranking first in the world for 14 consecutive years. This has laid the foundation for the development of our country's electronics manufacturing industry, but with the development of science and technology, the cycle of electronic product upgrading is getting shorter and shorter, and at the same time, user needs are more and more inclined to personalization and diversification, which brings great challenges to the production and assembly process of electronic products. Therefore, China's electronics manufacturing industry must continuously improve the current status quo of the production line to improve production efficiency, enhance the innovation ability and core manufacturing capacity of enterprises, and produce more perfect and unique products that meet customer needs, in order to continue to survive and develop in the fierce market competition. As an important part of the mass production process of electronic products, improving the production line is a crucial part of the company's production and operation activities.

As an electronic product manufacturing enterprise, XY Company's core business covers the production and assembly of electronic products such as mobile phones, and occupies an important market position in the industry. Implementing production line optimization can effectively improve the balance rate of the production line and reduce resource waste in the production process, thereby improving overall production efficiency and reducing operating costs. This improvement will help the company better respond to market changes, enhance product competitiveness, expand profit margins, and accumulate more resources and support for subsequent R&D innovation and market expansion. It can be seen that it is urgent to promote the improvement and optimization of the production line, which is also a key measure to enhance the market competitiveness of XY Company.

2. Literature Review

Since Herry Ford established the first production line on October 7, 1931, research on the issue of production line balancing has continued to this day. At present, the most common solutions are as follows.

2.1 Mathematical Exact Algorithm

Bautista and Pereira (2009) The dynamic programming method is improved by embedding heuristics, which effectively reduces the search space and optimizes the program performance when solving the problem of line balance (Bautista & Pereira, 2009). Peeters et al. (2004) proposed a method of line relaxation integer programming to determine the lower bound of the assembly line problem based on Dantzig-Wolfe decomposition, and used the branch delimitation method with improved design to solve the production line balance problem (Peeters & Degraeve, 2004). American scholar Bowman (1960) used 0-1 integer programming method to solve the problem of production line balance, but it is difficult to solve the practical problem because of the large amount of calculation (Bowman, 1960) Fathi et al. (2018) proposed an original hybrid integer linear programming model based on assumptions and constraints to solve the problem of production line material supply, and verified the effectiveness of the model through examples, providing new ideas for subsequent research (M. Fathi, A. Syberfeldt, M. Ghobakhloo et al., 2018)

2.2 Industrial Engineering Methods

Liu (2014) and others combined the principles of ECRS and action economics to determine the predetermined time standard of the operation, and with the help of the production line balance theory, the production line balance problem was optimized, and the efficiency of the steel coil packaging production line was improved (Liu & Xiao-Qian, 2014) Buchari et al. (2018) used traditional industrial engineering methods to improve and optimize the production line and replan the workstations on the entire production line, which greatly improved the production efficiency of the wood processing production line (Buchari, Tarigan, & Ambarita, 2018). Rashmi (2020) and other industrial engineering methods to determine the bottleneck station of the production line, and use quality control tools to improve the bottleneck station, which reduces the production cycle time and production cost of the production line (Rashmi, Nithya, & Tejaswini, 2020).

2.3 Heuristic Algorithms

Tonge (1960) The heuristic algorithm was proposed for the first time, and the production line balance problem with the goal of minimizing the required cost was successfully solved (Tonge, 1960) Kucukkoc et al. (2016) improved the adaptive factor of the ant colony algorithm when studying the balance problem of parallel bilateral assembly lines in the hybrid model, and found that the convergence speed and adaptability of the ant colony algorithm were improved by example testing[9]。Alvarez(2023) et al. (2023) proposed a heuristic algorithm based on local search to expand the search space of the solution by using variable length sequences, and the operation efficiency of the algorithm is better (Álvarez & Pereira, et al., 2023)

2.4 Simulation Modeling Method

Mattos et al. (2019) combined human factors engineering and simulation modeling to adjust the workstation position of the automobile assembly line according to the actual production situation, so as to reduce the workload of assembly line workers and reduce equipment downtime, and improve the production efficiency of the assembly line (Mattos, Neto, Merino et al., 2019). Bongomin et al. (2020) proposed the complex garment assembly line balance problem (ALBP) based on simulation optimization under random task time, and used Arena simulation software to simulate discrete events on the production line, which significantly improved the production line balance problem (Bongomin, Mwasiagi, Nganyi et al., 2020).

2.5 Literature Review

By summarizing the relevant literature at home and abroad, it is found that experts and scholars mainly use precise algorithms, industrial engineering methods, heuristic algorithms and simulation modeling methods in the exploration of production line balance, and various method theories have been relatively mature. However, in recent years, there has been relatively little literature combining industrial engineering methods, heuristic algorithms and simulation modeling methods to optimize production line balance. Therefore, this paper will use the above three methods, combined with the actual production of XY company's mobile phone production line, to analyze, improve and optimize its production line, and solve the problem of low production line balance rate to improve the company's efficiency.

3. XY Company's Production Line Balance Improvement Plan

3.1 Analysis of the Current Situation of XY Company's Production Line

Through the field investigation of XY Company's mobile phone production line, the production process was sorted out, and 54 processes of XY Company's mobile phone production line were sorted out: screen component station: inspecting the screen, checking the middle frame, cleaning the middle frame, pasting the airtight foam on the middle frame, installing the earpiece dust net, blowing dust and sticking TP, pasting the screen to the middle frame, pasting the conductive cloth, waiting for dispensing, dispensing, pasting TP to the middle frame, transporting to the next process, beer machine beer pressure, screen component appearance inspection, installing earpiece speakers, pasting conductive cloth and wheat sheet, waiting for installation; Rear cover component station: connect GPS buckle, attach WIFI antenna, install lenses and speakers, rear cover assembly visual inspection, wait for installation; Soldering stations for small boards and motherboards: welding motherboard buttons, installing front cameras, installing motherboard cables to the middle frame, checking the welding quality of the motherboard, installing cables and pasting front cameras, installing wires and screws, attaching buttons, installing rear cameras, welding MICs and vibration motors, waiting for installation, locking the small board to fix the MIC and motor, installing cables and pasting foam, welding horn cables, installing batteries, testing batteries, installing buttons and back covers, locking screws, testing TP and buttons; Inspection station: check the appearance of the machine, turn on test, call test, photo test, sensor test, vibration test, restore equipment, carry to the packaging area, paste IMEI, place the three-pack voucher, put the accessories, put the manual, paste the lens, put the mobile phone into the box, record the time of each process through the stopwatch test method, and finally calculate the standard operating time, and get the standard operating time of the four stations is: 357.95s, 103.55s, 550.16s, 218.2s, and the total working hours are 1229.96s. The balance rate of XY company's mobile phone production line is calculated as:

$$p = \frac{1229.86}{4 \times 550.16} \times 100\% = 55.89\%$$

The resulting smoothing index is calculated:

$$SI = \sqrt{\frac{(550.16 - 357.95)^2 + (550.16 - 103.55)^2 + (550.16 - 218.2)^2}{4}} = 294.37$$

From the above data and the calculated production line balance evaluation index, it can be seen that the balance rate of this production line is low, the smoothing index is large, and there is a lot of room for optimization.

3.2 Production Line Optimization Based on 5W1H Questioning Technology and ECRS Principles

Based on the analysis in the previous section, this section first uses the 5W1H questioning technology and ECRS principle in industrial engineering methods to analyze and optimize the existing processes, and cancel, merge, rearrange or simplify some processes.

Due to the large number of processes in this production line, taking the bottleneck process locking small plate fixing MIC and motor as an example, the workshop employees are asked questions, and the Q&A content is shown in Table 3.1.

Table 3.1 5W1H Question Form

Questions	Reply
Why does it take so long to lock the MIC and motor of the small plate?	Because the MIC and the motor itself are very small, it takes time to operate and position. The MIC receiver hole and its fragility often require manual inspection and cleaning steps.
Can I uncheck this step?	No.
Why can't I uncheck this step?	If not inspected, tiny dust, glue contamination, and even fingerprints can lead to poor sound quality, noise, and poor products.
How can I reduce pollution such as dust, glue contamination or fingerprints?	Establish a clean room environment, strictly manage personnel, and must wear anti-static coveralls, head covers, masks, gloves and special shoes when entering the clean room.
Can it be combined with the latter process?	No, the merger will create a new bottleneck process.

Through questioning, it was found that the bottleneck process locked the small plate fixing MIC and motor could not be improved, and it was a reasonable process. In the same way, all processes are asked separately, and the ECRS principle is used to improve the process, and the optimization results of the process are as follows:

(1) The inspection process and the cleaning middle frame process can be combined into the inspection and cleaning process to reduce the waiting time between the two processes.

(2) The process of pasting the sealing foam in the middle frame and the process of installing the handset dust net can be merged, and merged into the process of attaching the sealed foam to install the earpiece dust net, the sealing foam and the earpiece mesh are a set of matching parts, and during operation, both hands can work at the same time to reduce the delay time.

(3) The beer press process of the beer machine and the appearance inspection process of the screen component can be merged into the screen component pressing and inspection process, and the inspection is carried out immediately after the beer is pressed to reduce the handling.

(4) The battery installation process and the test battery process can be merged, combined into the installation and testing battery process, and the power-on test is carried out immediately after the battery is installed, which can find the battery connection defect or fault problem as quickly as possible, and achieve rapid feedback and adjustment.

(5) The process of installing the back cover of the button and the process of locking the screw can be combined, and it can be combined into installing the back cover and locking the screw, which is a typical continuous action, and it is more time-saving to merge.

(6) The process of placing the three-guarantee voucher and the process of placing the instruction manual can be merged into the process of placing the three-guarantee voucher and the instruction manual, which are all paper documents, which can be uniformly grabbed and placed by a station on the packaging assembly line to improve the packaging efficiency.

(7) The IMEI process and the lens application process can be merged, and the lens application process can be combined into the lens application and IMEI process, which can make reasonable use of both hands and save operation time.

(8) Four waiting processes can be canceled.

The stopwatch timing method is used to measure the operation time of the improved process, and the standard operating time is calculated, and the process and standard working hours of the optimized mobile phone production line of XY Company are obtained as shown in Table 3.2 below:

Table 3.2 The Standard Operating Time of each Process after the Improvement of the IE Method

Station	Process	Process	Standard operating hours/s	Operating unit standard working hours/s
Screen component station	1	Detect the screen	31.77	316.90
	2	Check the middle frame and clean the middle frame	25.78	
	3	Paste the closed foam with the earpiece dust net dust	19.36	
	4	blowing sticker TP	25.78	
	5	Paste the screen to the middle frame	38.22	
	6	Paste the conductive cloth	21.55	
	7	Dispensing	23.78	
	8	Paste TP to the middle frame	33.55	
	9	Move to the next process	8.22	
	10	Screen components are pressed and inspected	35.56	
	11	Install earpiece speakers	30.22	
	12	Apply conductive cloth and mylar sheets	23.11	
Rear cover component station	13	Connect to GPS buckle	18.89	93.33
	14	Attach the WIFI antenna	18.22	
	15	Install lenses and horns	40.00	
	16	Back cover assembly visual inspection	16.22	
Small	17	Solder motherboard buttons	36.89	498.17

board and main board welding station	18	Equipped with a front camera	17.55	
	19	Install the motherboard wire to the middle frame	29.55	
	20	Check the motherboard soldering quality	17.33	
	21	Install the cable sticker front camera	35.55	
	22	Install the wires and screw them	44.88	
	23	Stick the button	32.89	
	24	Rear camera installed	26.44	
	25	Welding MIC and vibration motor	38.22	
	26	Lock the small plate to fix the MIC and motor	48.88	
	27	Install the cables and apply the foam	34.66	
	28	Welding horn wires	47.11	
	29	Install and test the battery	30.62	
	30	Install the back cover and lock the screws	34.27	
	31	Test TP and keys	23.33	
Inspection station	32	Check the appearance of the machine	18.00	207.91
	33	Power-on test	48.00	
	34	Call test	12.67	
	35	Photo test	14.22	
	36	Sensor testing	11.33	
	37	Vibration test	11.55	
	38	Restore the device	15.11	
	39	Transport to the packing area	13.11	
	40	Attach lenses and IMEI	27.84	
	41	Place the three-pack voucher and instruction manual	10.75	
	42	Put accessories	8.89	
	43	Put the phone in the box	16.44	
	total			1116.31

After the improvement of industrial engineering methods, the production line has been reduced from 54 processes to 43 processes, and the standard operating workers of the four stations have been shortened to a certain extent, and the improvement effect of the bottleneck station is particularly obvious, and the total working hours have increased from the original 122986s shortened to 111631s, indicating that the use of industrial engineering methods to optimize the production line of mobile phones is effective. Next, the balance rate and smoothing index of XY's mobile phone production line improved by the IE method are calculated as follows:

$$p = \frac{1116.31}{4 \times 498.17} \times 100\% = 56.02\%$$

$$SI = \sqrt{\frac{(498.17 - 316.90)^2 + (498.17 - 93.33)^2 + (498.17 - 207.91)^2}{4}} = 265.05$$

Compared with the production line correlation index before improvement, it can be clearly seen that the production line balance rate has increased and the smoothing index has decreased after the improvement of industrial engineering methods.

3.3 Improvement of Production Line Balance Based on Two-population Genetic Algorithm

In the previous section, the mobile phone production line was optimized through the theoretical knowledge related to industrial engineering, but the improvement effect was not obvious. This section continues to optimize using a two-population genetic algorithm. In the genetic algorithm, the fitness function is the core index for evaluating the advantages and disadvantages of individuals, the greater the fitness, the better the individual, it contains the maximum production line balance rate and the minimum smoothing index, therefore, according to the actual production situation, the function formula is designed as shown in Equation (3-1) and set: $\alpha = \beta = 1$

$$F = \alpha \frac{\sum_{i=1}^{n} T_i}{n \times T_{max}} + \beta \frac{1}{\left[\frac{1}{n}\sum_{i=1}^{n} (T_{max} - T_i)^2\right]^{\frac{1}{2}} + 0.01} \quad (3\text{-}1)$$

Before using the two-population genetic algorithm to solve the optimization problem of XY's mobile phone production line, the following constraints are first set:

(1) All processes are assigned to workstations, and a process can only be assigned to one workstation;

(2) All workstations have at least one job element, and the job element on the workstation is not 0;

(3) The operating time of each workstation is less than or equal to the production cycle of the production line;

(3) When assigning job elements, the priority relationship should be met.

The priority relationship analysis of the process is carried out, and the following operation priority relationship matrix diagram is obtained, as shown in Figure 3.1.

$$
\begin{pmatrix}
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}
$$

Figure 3.1 Activity Priority Relationship Matrix

According to Table 3.2, the time matrix of the mobile phone production line can be obtained as T=[31.77,25.78,19.36,25.78,38.22,21.55,23.78,33.55,8.22,35.56,30.22,23.11,18.89,18.22,40.00,16.22,36.89,17.55,29.55,17.33,35.55,44.88,32.89,26.44,38.22,48.88,34.66,47.11,30.62,34.27,23.33,18.00,48.00,12.67,14.22 ,11.33,11.55,15.11,13.11,27.84,10.75,8.89,16.44]。

Based on the above data, the parameters of the algorithm are set as follows: the population size of population 1 and initial population 2 is set to 50, the crossover probability is 0.8 and 0.2, the variation probability is 0.2 and 0.05, the number of genes exchanged in the population is set to 5, and the maximum number of iterations is set to 100.

The current number of workstations of XY company's mobile phone production line is 4, and the operation results are shown in Figure 3.2:

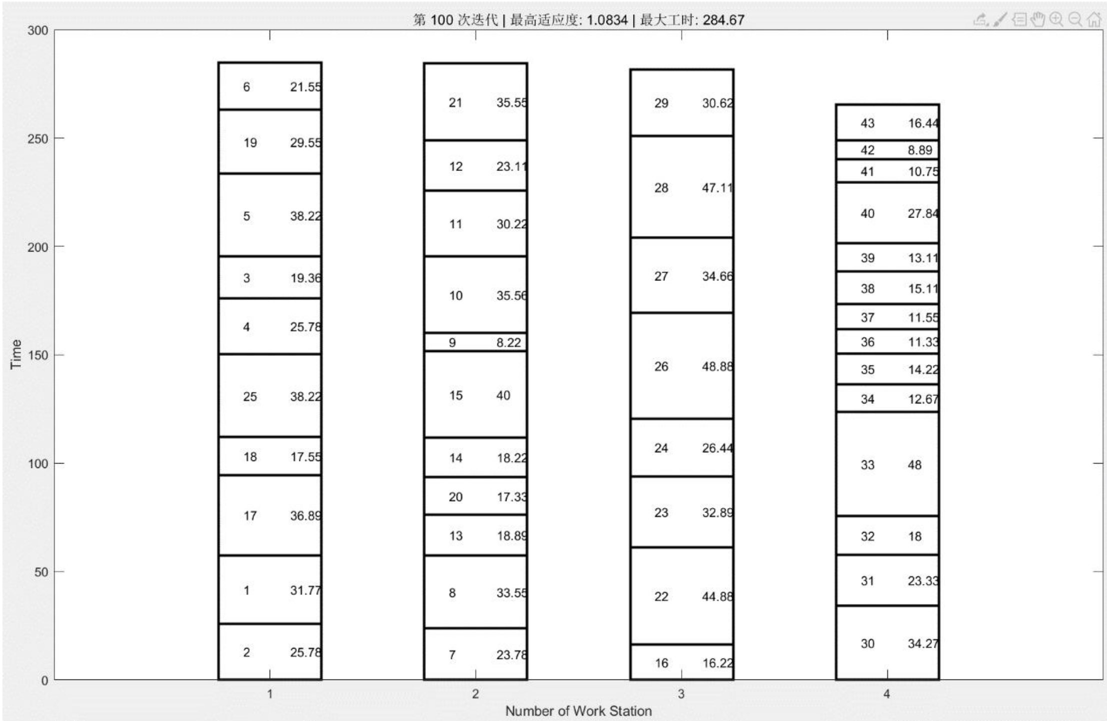

Figure 3.2 Operation Result When the Workstation Is set to 4

From this figure, we can see the distribution of each process and the working hours of each workstation, so that the balance rate and smoothing coefficient of the workstation can be further calculated. The following table 3.4 is sorted out:

Table 3.3 Workstation Allocation for 4-hour Process

Workstation serial number	The process number and processing sequence assigned by the workstation	Workstation working hours/s
1	2→1→17→18→25→4→3→5→19→6	284.7
2	7→8→13→20→14→15→9→10→11→12→21	284.4
3	16→22→23→24→26→27→28→29	281.7
4	30→31→32→33→34→35→36→37→38→39→40→41→42→43	265.5

According to Table 3.3, When the number of workstations is 4, the mobile phone production line 4 is obtained The priority order of the three processes is 2→1→17→ 18→ 25→ 4→ 3→5→ 19→ 6→ 7→ 8→ 13→ 20→ 14→ 15→ 9→ 10→ 11→ 12→ 21→ 16→ 22→ 23→ 24→ 26→ 27→28→ 29→30→31→→ 32→3334→ 35→36→37→38→ 39→40→41→ 42→43. The production cycle of the optimal solution is 284.67s, which can be obtained by calculation, the balance rate of the production line is 98.03%, and the smoothing index is 9.7. It can be seen that compared with industrial engineering methods, the dual-population genetic algorithm has significantly optimized the production line.

Generally speaking, the more workstations, the smaller the cycle speed of the production line, but too many workstations will make the production line too long and difficult to manage, and the fixed cost will increase. Therefore, in order to find the most reasonable number of workstations for XY's mobile phone production line, Matlab was used to run the results when the workstations were 5 and 6.

When the number of workstations is set to 5, the running result is shown in Figure 3.3:

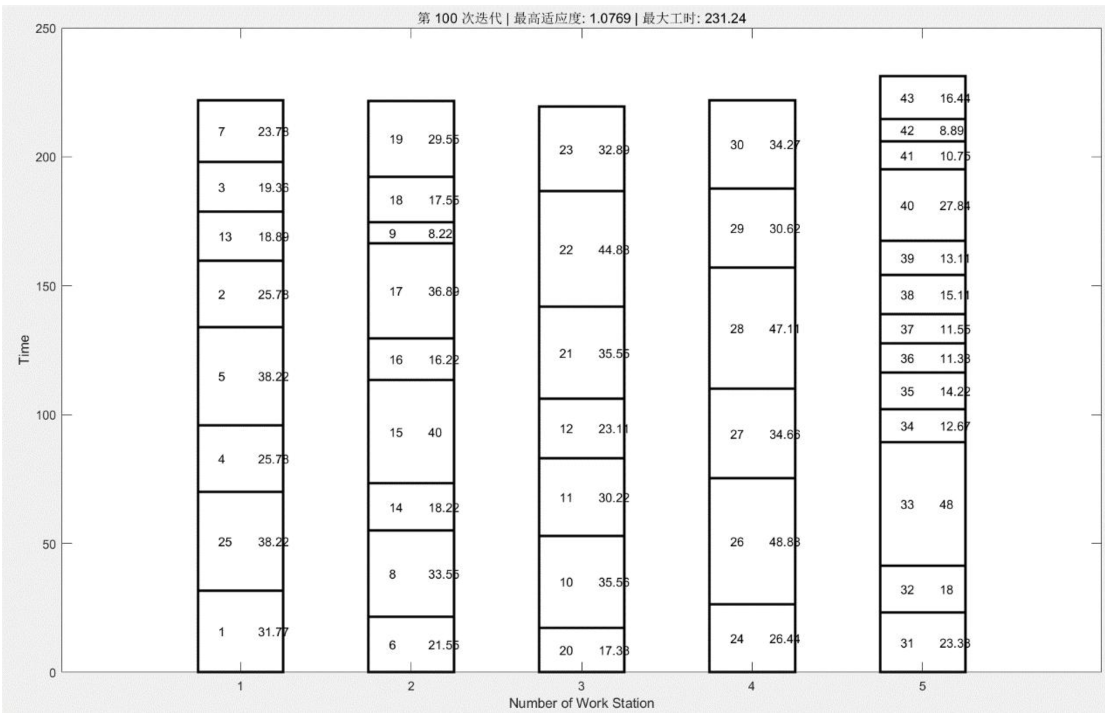

Figure 3.3 Operation result when the workstation is 5

Table 3.4 Workstation 5-hour process allocation

Workstation serial number	The process number and processing sequence assigned by the workstation	Workstation working hours/s
1	1→25→4→5→2→13→3→7	221.8
2	6→8→14→15→16→17→9→18→19	221.8
3	20→10→11→12→21→22→23	219.5
4	24→26→27→28→29→30	222
5	31→32→33→34→35→36→37→38→39→40→41→42→43	231.2

When the number of workstations is 5, The working hours of each workstation are 1→25→4→ 5→2→ 13→3→ 7→ 6→8→14→ 15→16→ 17→ 9→ 18→ 19→ 20→ 10→ 11→ 12→ 21→ 22→ 23→ 24→

26→27→28→29→30→31→3132→→3→4→34→37→38→39→40→41→42→43. The production cycle of the optimal solution is 231.24s, and the production line balance rate is 96.55% and the smoothing index is 8.96.

When the number of workstations is set to 6, the running result is shown in Figure 3.4:

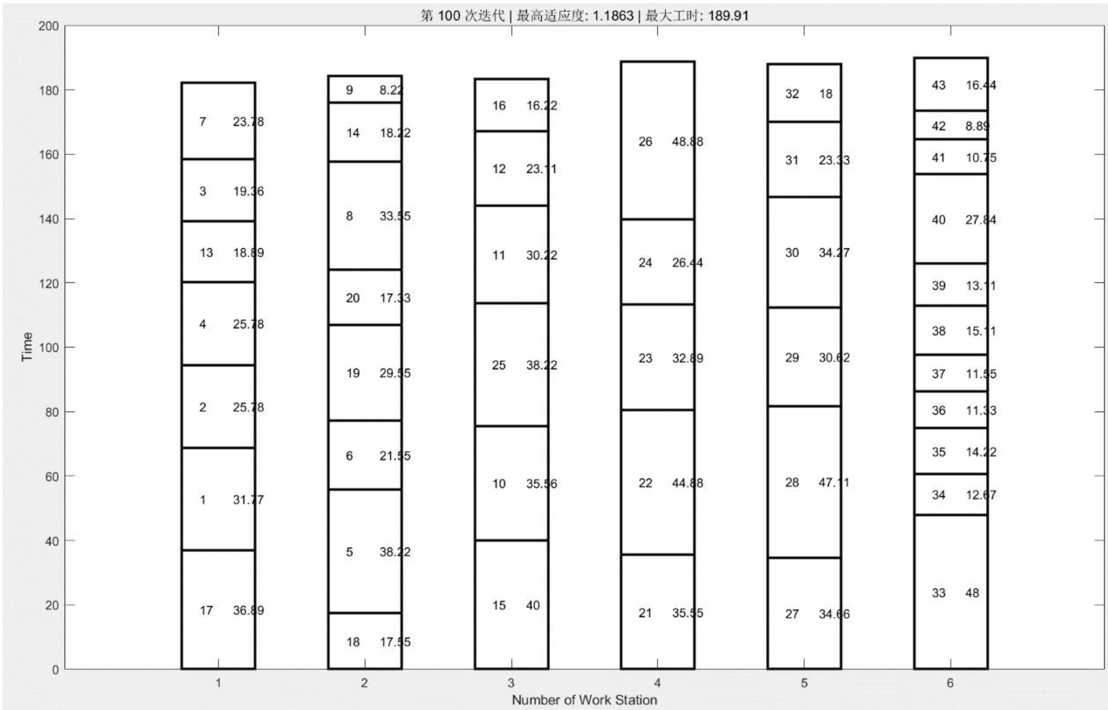

Figure 3.4 Operation Result When the Workstation is set to 6

Table 3.5 Workstation 6-hour Process Allocation

Workstation serial number	The process number and processing sequence assigned by the workstation	Workstation working hours/s
1	17→1→2→4→13→3→7	182.3
2	18→5→6→19→20→8→14→9	184.2
3	15→10→25→11→12→16	183.3
4	21→22→23→24→26	188.6
5	27→28→29→30→31→32	188
6	33→34→35→36→37→38→39→40→41→42→43	189.9

When the number of workstations is 6, The working hours of each workstation are 17→1→2→4→13→ 3→7→ 18→5→6→19→20→ 8→ 14→9→15→ 10→25→11→12→16→21→22→23→24→26→27→28→29→30→31→32→33→34→35→36→37→38→39→40→41→42→43. The production cycle rate of the optimal solution is 189.91s, and the production line balance rate is 97.97% and the smoothing index is 4.82.

The program operation results of workstations at 4, 5 and 6 are summarized and Table 3.6 is obtained:

Table 3.6 Summary of Matlab Output Results

Number of workstations	Production cycle time/s	Balance rate	Smooth index	Highest fitness value
4	284.67	98.03%	9.7	1.0834
5	231.24	96.55%	8.93	1.0769
6	189.91	97.97%	4.89	1.1863

According to Table 3.6, when the number of workstations is 6, the fitness value is the highest, reaching 1.1863, which best reflects the highest line balance rate and the lowest smoothing index, at this time, the production line balance rate reaches 97.97%, and the production line is the lowest, which is 4.89. Therefore, the optimal scheme for XY company's mobile phone production line is when the number of workstations is 6, The processing sequence of the 43 processes is 17→1→2→4→ 13→3→7→ 18→ 5→6→ 19→20→ 8→ 14→ 9→ 15→ 10→ 25→ 11→ 12→ 16→ 211 → 22→23→24→26→27→28→29→30→31→32→33→34→35→36→37→38→39→40→41→42→43.

3.4 Analysis of the Results before and after Optimization of the Two-population Genetic Algorithm

According to the above indicators before and after the improvement, the number of production line processes improved by the IE method has been reduced from 54 to 43, and the production cycle time has been reduced by 51In 99s, the production line balance rate increased from 55.89% to 56.02%, the smoothing index was 294.37 to 265.05. Next, through Matlab software, the two-population genetic algorithm was used to continue to optimize the production line, and 43 processes were redistributed to 6 workstations, so that the production cycle time was reduced to 189.91s, the time of each station of the production line was more balanced, and the balance rate of the production line was increased to 97.97%, which greatly improved the production efficiency, and the smoothing index was reduced to 4.89, which was more significant and efficient than the IE method.

4. Conclusions

The specific conclusions of the study are as follows:

(1) The field investigation of XY's mobile phone production line shows that the production line balance rate is 55.89% and the smoothing index is 294.37.

(2) In view of the imbalance of the production line, the 5W1H questioning technology and the ECRS principle are combined to optimize the production line, the number of processes in the production line is reduced by 11, the overall time consumption is reduced from 1229.86s before the improvement to 116.31s, the production line balance rate is increased from the original 55.89% to 56.02%, and the

smoothing index is reduced from 294.37 to 265.05, so that the indicators of XY Company's mobile phone production line have been improved to a certain extent.

(3) On the basis of the optimization of industrial engineering methods, the two-population genetic algorithm is used for re-optimization, and the optimal distribution scheme of the process is that when the workstation is 6, the balance rate of the production line increases from 56.02% before the algorithm optimization to 97.97%, and the smoothing index decreases from 265.05 before the algorithm optimization to 4.82, and the balance level of the production line is further improved.

References

Álvarez, M. E. P. et al. (2023). Variable-depth local search heuristic for assembly line balancing problems. *International Journal of Production Research*, *61*(9), 3102-3120.

Bautista, J., & Pereira, J. (2009). A dynamic programming based heuristic for the assembly line balancing problem. *European Journal of Operational Research*, *194*(3), 787-794.

Bongomin, O., Mwasiagi, J. I., Nganyi, E. O. et al. (2020). Simulation metamodeling approach to complex design of garment assembly lines. *Plos one*, *15*(9), e0239410.

Bowman, E. H. (1960). Assembly-Line Balancing by Linear Programming. Operations Research, *8*(3), 385-389.

Buchari, U., & Tarigan, M. B. (2018). Ambarita.Production layout improvement by using line balancing and Systematic Layout Planning (SLP) at PT. XYZ. *IOP Conference Series: Materials Science and Engineering*, *309*(1), 245-263.

D L D. Mattos, A R. Neto, D A E. Merino et al. (2019). Simulating the Influence of Physical Overload on Assembly Line Performance: A Case Study in an Automotive Electrical Component Plant. *Applied Ergonomics*, *79*.

Fathi, M., Syberfeldt, A., Ghobakhloo, M. et al. (2018). An optimization model for material supply scheduling at mixed-model assembly lines. *Procedia CIRP*, *72*, 1258-1263.

Ibrahim, K., & David, Z. Z. (2016). Mixed-model parallel two-sided assembly line balancing problem: A flexible agent-based ant colony optimization approach. *Computers & Industrial Engineering*, *97*, 58-72.

Liu, H. J., & Xiao-Qian, L. I. (2014). University T. Improvement of Horizontal Coil Packaging Line Balance Based on MOD Method. *Packaging Engineering*.

Peeters, M., & Degraeve, Z. (2004). An linear programming based lower bound for the simple assembly line balancing problem. *European Journal of Operational Research*, *168*(3), 716-731.

Rashmi, S., & Nithya, S. K. (2020). Tejaswini K.Improving the Efficiency of Production Line:An Empirical Study in Garment Industry. *IUP Journal of Operations Management*, *19*(1), 50-67.

Tonge, F. M. (1960). Summary of a Heuristic Line Balancing Procedure. *Management Science*, *7*(1), 21-42.