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Optimization of Mixed-flow Production Line in Sheet Metal Workshop of Carving Machine Company

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Abstract:

In order to solve the "bottleneck" problem of the mixed-flow assembly production line of the precision carving machine manufacturing enterprise, the optimization of the mixed-flow production line in the sheet metal workshop of the precision carving machine manufacturing factory was discussed. The authoritative literatures were synthesized and the advantages and disadvantages of the algorithms and simulations were analyzed. Assembly line production is the general trend of the manufacturing industry, and as a high-precision equipment production line, precision carving machines tend to be intelligent and virtualized. In this paper, an adaptive genetic algorithm is applied to solve specific problems in the sheet metal workshop. The mixed flow production line of various parts in the sheet metal workshop is optimized and researched, and the optimized results are finally obtained. After studying this problem with the multi-objective optimization mathematical model and genetic algorithm proposed in this paper, the production cycle is 26.5 hours, and the assembly line smoothness index is 93.67%.

Keywords*: Mixed-flow production, Genetic algorithm, Carving machine.*

I. PREFACE

FJSP (Flexible Job Shop Scheduling Problem) was proposed by Brucker and Schlie in 1990. So far, various optimization algorithms have been used to solve such problems, such as Willian et. combine empire competition algorithms and tabu search algorithms to solve FJSP with the goal of minimizing production cycle. Li Congbo and others established a model with the minimum total energy consumption and minimum completion time as the optimization goals, and used a multi-objective simulated annealing algorithm to optimize FJSP[1]. Jiang Tianhua applied a hybrid gray wolf optimization algorithm to solve FJSP. Based on the gray wolf algorithm,

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genetic operators were added to improve the global search ability of the algorithm, and a variable neighborhood search algorithm was added to enhance the local search ability of the algorithm[2].

Qi Ershi, proposed the main study was the cooperation between workers and workstations[3]. The main elements considered were the efficiency and proficiency of workers and the coordination of production cycle, and the cycle was ignored. Time and rest time of workers (can be relaxed), if the case was optimized with workers as the main body, job measurement will be inevitable. There were many influencing factors that had been researched through job measurement. The factors that were considered in this way would be too complicated, and the establishment of algorithm models was also easy to be confused. However, the peak-cutting and valley-filling algorithm used in this article was a good method to find the optimal solution, which can better control the function convergence.

Tong Xiaoying, used cross mapping and random mutation to cross and mutate to obtain higher quality population, and adopted Plant Simulation software to calculate local optimal solution through genetic algorithm. The first two articles used chromosome selection in Russian roulette[4].

Zhao Jianhui, only assumed that four different commissioning sequences were simulated in Flexsim, and then the optimal solution was selected. The algorithm design was too limited. If new equipment was added to the production line, the scheme is not flexible[5].

Huang Peng, added a smoothing index, and used weights to measure the complexity of the process[6].

Tu Tianhui, had expanded the application of Flexsim software to make the simulation results have more realistic visual effects. CAD and CATIA software were used to build simulation models and import them into Flexsim[7].

II. BACKGROUND

Carving machine company mainly produces JD01, JD02, JD03, JD04 (see Figure 1) four types of precision carving machines, due to different models of precision carving machines, sheet metal production process requirements are also different.

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Fig 1: Typical product

Among them, the bed, floor, lead screw base, workpiece placement table, electric control cabinet, chip removal box, water tank, and packaging box are produced by the sheet metal workshop. Carving machine Manufacturing Company adopts a two-shift work system, with an annual production time of 312 days, each shift is from 8 am to 5 pm, the lunch break is from 12 am to 1 pm; the night shift is from 6 pm to 2 am (see Figure 2).


Fig 2: Carving machine manufacturing factory

The number of front-line production staff in the sheet metal workshop is determined according to the number of equipment and process requirements. The staffing situation is shown in Table 1.

Table 1. Equipment and personnel allocation of sheet metal workshop

Machine name	amount	Production staff
Pickling and peeling machine 1	40	40
Cold tandem rolling mill 2	40	40
Continuous annealing unit 3	40	40
Trimming machine 4	30	30
Laser cutting machine 5	36	36
Bending machine 6	18	18

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Deburring machine 7	18	18
Automatic welding robot arm 8	12	12
Manual welding table 9	6	6
Spray area 10	5	20
Total	213	230

2.1 Sheet Metal Parts Process

Because the precision carving machine factory produces 4 different types of precision carving machines, different types of precision carving machines have different requirements for precision, and the process requirements for the production of sheet metal parts are also different. As different products in the mixed production line are processed, the sheet metal parts are processed differently and the processing time is different. If a product or similar product is continuously processed and produced, it will cause some stations to be tight and the temporary storage area to be blocked, resulting in a "bottleneck area", and some station resources will be idle. The occurrence of this kind of situation will also cause overproduction of the same kind of products and affect the plan of the enterprise. At the same time, the supply of parts and components for this product is a severe test. In the process of assembling all products, the assembly line adjusts the production order of different types of products to ensure that the use rate of each component is uniform, and there is no shortage of certain components, that is, the difference in the amount of the actual usage and ideal use of each component is minimized.

In addition, in order to control costs, sheet metal workshops, such as bed and floor, need to be beautiful in appearance. The raw materials used are finished steel plates purchased outside. For cost control, the workpiece placement table, electric control cabinet, and chip removal box will be carried out by the sheet metal workshop itself. Continuous cold rolling is to produce steel plates. The following is an example of two typical sheet metal parts of the bed and the water tank. The production process is shown in the figure: (Figure 3)

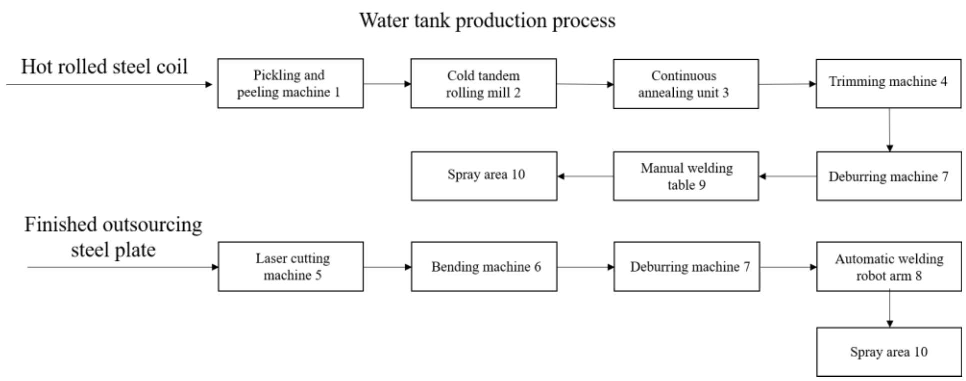

Fig 3: Typical production process

2.2 Mixing Pipeline Arrangement

Hybrid Flow Shop Scheduling Problem (HFSSP), also known as flexible flow shop scheduling problem, is a generalization of classic flow shop scheduling. Within a certain period of time, a variety of different types of products can be produced on the same production line. This

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production method can be the same as the traditional production method, with a large number of standardized products, and can also produce small batches of personalized products according to customer needs. Products would meet the needs of the market, as long as they satisfy the user's diverse needs of the product. Mixed-flow assembly production can enable enterprises to respond faster to the market environment and minimize production costs.

The following table (Table 2, unit / h in the table) indicates the HFSSP problem. There are 10 processing stages. The number of machines in each stage can be seen in Table 1. Each pack chontains 100 bags of raw materials. In the table, 1-picking peeling machine, 2-cold rolling mill, 3-Capl unit, 4-trimming machine, 5-laser cutting machine, 6-bending machine, 7-deburring machine, 8-automatic welding arm, 9-hand welding table, 10-spray area.

Table 2. Time of each process

	1	2	3	4	5	6	7	8	9	10
JD01 bed					5	1	5	3		3
JD01 floor					3	1	4	2		3
JD01 lead screw base					3		4		8	1
JD01 workpiece table					3		3		8	1
JD01 electric control cabinet					4	3	5		6	2
JD01 chip removal box	10	4	10	11			11		7	2
JD01 water tank	10	3	8	10			5	5		2
JD01 packaging box	5	1	5	6			5	3		
JD02 bed					8	3	7	3		3
JD02 floor					5	2	6	2		3
JD02 lead screw base					6		5		8	1
JD02 workpiece table					4		4		5	1
JD02 electric control cabinet					4	3	5		7	2
JD02 chip removal box	12	5	11	13			12		6	2
JD02 water tank	11	5	12	11			6	8		2
JD02 packaging box	5	1	5	6			5	3		
JD03 bed					7	2	6	4		3
JD03 floor					4	1	5	3		3
JD03 lead screw base					5		4		7	1
JD03 workpiece table					3		3		7	1
JD03 electric control cabinet					5	2	6		6	2
JD03 chip removal box	10	4	13	14			13		8	2
JD03 water tank	10	5	11	12			6	6		2
JD03 packaging box	5	1	5	6			5	3		
JD04 bed					8	2	7	4		3
JD04floor					5	3	6	3		3
JD04 lead screw base					5		7		9	1
JD04 workpiece table					5		5		8	1

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JD04 electric control cabinet					3	2	6		7	2
JD04 chip removal box	13	5	13	13			11		8	2
JD04 water tank	12	6	11	11			8	9		2
JD04 packaging box	5	1	5	6			5	3		

The product demand ratio of precision carving machines JD01, JD02, JD03, JD04 is D1: D2: D3: D4 = 1: 1: 1: 1.

Each part of different types of carving machine is represented by Jmn, m is the type of carving machine, and n is the type of parts. For example:

J11 = JD01 bed, J12 = JD01 bottom plate,..., J18 = JD01 packing box.

III. MATHEMATICAL MODELS FOR DESIGNING MIXED PRODUCTION LINES

3.1 Mathematical Model

The parameters and variables of the sheet metal workshop mixed-flow production line scheduling problem are shown in the following table, see Table 3

Table 3. Meaning of parameters and variables

Variables	Meaning
m	Types of parts on each carving machine product, n = 1, 2, ..., n
D	Total product demand
k	Station number on a certain process in mixed flow production line, k = 1, 2, ..., k
k_n	Machine number on the nth process
n	Process number on mixed production line, n = 1, 2, ..., n
CT	Production cycle of mixed production line
t_{mn}	Working time of parts in n processes
WT	Number of theoretical workstations
WR	Actual workstations
W_{nk}	k-th workstation machine number of the n-th process
T_{nk}	Working time of the k-th workstation machine in the n-th process
x_{mik}	Assignment matrix， x_{mn}=1,the m-th part is assigned to the i-process k machine X_{mn}=0, the m-th part is not assigned to the i-k machine
J_{rj}	Part type code, r is the type of carving machine, j is the type of each part

Genetic algorithm model establishment:

(1) Minimum production cycle

In order to quickly meet the market demand for enterprise products, it is possible to increase the production capacity of enterprises to produce more qualified products within the planning period. The method which is chosen is to optimize the production cycle of the mixed flow assembly line, and to minimize the actual production cycle of the mixed flow assembly line. By reducing the interval between two adjacent parts, we can produce more products during the entire planning period, so as to improve the ability of the enterprise to quickly meet consumers. If the job task Jmn is assigned to the k-th machine of the i-th operation, the total working time of machine k is:

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$$T(S_k) = \sum_{m=1}^{M} \sum_{n=1}^{N} t_{mn} x_{mik} \tag{1}$$

From this, the total operating time of the entire production line is

$$CT = \max_{1 \le k \le K} \left\{ \sum_{m=1}^{M} \sum_{n=1}^{N} t_{mn} x_{mik} \right\} \tag{2}$$

In order to optimize the "bottleneck" problem, that is, the minimum value of the actual production cycle on the production line is required, and the maximum value of the total operating time of the task at each station is minimized.

$$\min CT = \max_{1 \le k \le K} \left\{ \sum_{m=1}^{M} \sum_{n=1}^{N} t_{mn} x_{mik} \right\} \tag{3}$$

(2) Minimum number of machines per process

Since this problem has ten different processes, it is necessary to arrange k machines for production in each process. For production cost considerations, the fewer the number of machines, the lower the cost.

$$\min \sum_{k=1}^{k_1} k_1, \min \sum_{k=1}^{k_2} k_2, \ldots, \min \sum_{k=1}^{k_n} k_n \tag{4}$$

(3) Assembly line smoothness index L

Assembly line smoothing refers to L used to measure whether the work load distribution between various work sites is uniform. It is the third type of problem in mixed-flow assembly lines. The smaller the assembly line smoothing index L, the closer the processing time between workstations is. The assembly line smoothing index L is

$$\min L = \sqrt{\frac{\sum_{k=1}^{K} \left(\sum_{m=1}^{M} \sum_{n=1}^{N} t_{mn} x_{mnk} - \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} t_{mn} x_{mik} / k \right)^2}{\sum_{i=1}^{4} \sum_{k=1}^{k_n} k_n}} \tag{5}$$

(3) Objective function

Because this article is a multi-objective optimization, there are two objective functions. After one objective function produces the optimal solution, the other objective function may be a compromise solution. Decision maker determine whether the solution is optimal or not, and the decision maker may be biased towards any goal. function. Therefore, the two objective functions are given weights, and here we set the weight w_i to $w_1 = 0.8$ $w_2 = 0.2$.

$$makespan = \min \sum_{i=1}^{I} w_i f_i = \min(0.8 \min CT + 0.2 \min L) \tag{6}$$

3.2 Constraints

(1) Each workpiece is assigned and processed on at most one machine at any time;

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$$\sum_{k=1}^{m} x_{ik}, \forall i \quad (7)$$

(2) Each machine can only process one workpiece at a time;

$$\sum_{k=1}^{n} y_{mk}, \forall m \quad (8)$$

(3) Workpiece production time cannot exceed the cycle time

$$\sum_{i=1}^{n}\sum_{h}^{H} q_h t_{ih} x_{ih} \le \frac{C}{k}, \forall k \quad (9)$$

(4) When arranging parts into a certain process machine, try to keep the same kind of parts on one machine, because switching between different processes will reduce the worker's proficiency and thus reduce production efficiency. Switching time between different types of parts is 0.5h

(5) The variables in the formula are all 0/1 decision variables

$$x_{ik} \in \{0,1\}, \forall i,k; y_{mk} \in \{0,1\}, \forall k,m \quad (10)$$

IV. GENETIC ALGORITHM SOLUTION

4.1 Genetic Algorithm Operation Process

Genetic Algorithm (GA) is an intelligent optimization algorithm that simulates natural selection and biological evolution. A new generation of individuals is formed by the reproduction of the mother. Most of the individuals in the new generation will be similar to the mother due to chromosomal crossover. A few individuals will be different from the mother due to mutation. As the executor of natural selection[8], in the process of changes in living resources and the external environment, and the individual's continuous competition, individuals with strong adaptability are left behind, and individuals with poor adaptability are eliminated.

In 1965, John H. Holland first cited the evolutionary mechanism of organisms to solve problems, and his students also proposed the concept of "genetic algorithms" for the first time in their thesis[9]. In 1975, Holland gave a general overview of genetic algorithms. In recent decades, more and more researchers have joined the research of genetic algorithms, and have obtained rich research results.

The genetic algorithm operation flow can be represented by Figure 4

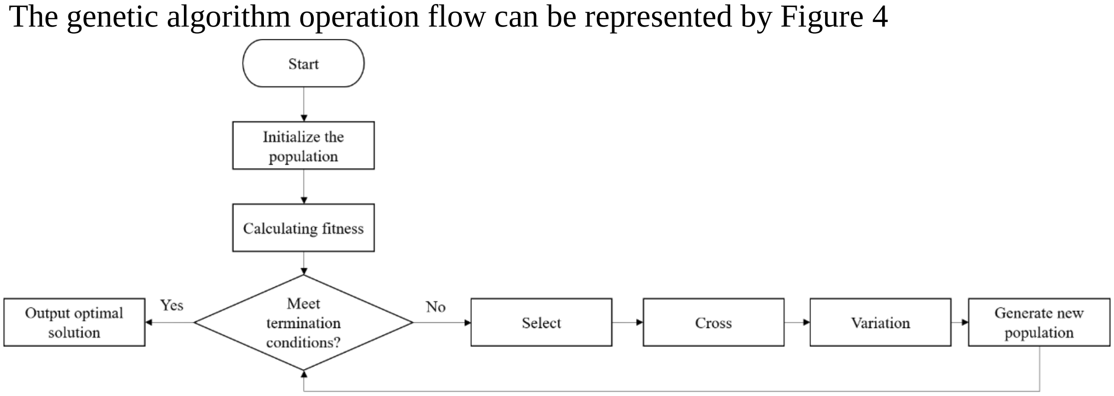

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Fig 4: Genetic Algorithm Operation Flow

4.2 Encoding

Coding is the basis of genetic algorithms. Due to the large variety of products in the sheet metal workshop, the production operation time of different parts of different product types is encoded into a matrix:

$$R=\begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{bmatrix}$$

Because the scheduling problem of the mixed-flow production line in this sheet metal workshop is very complicated, the ultimate goal is to complete the task with the minimum number of machines in the minimum operation time, and when the task of each part is assigned to the k machine in n process, the number of machines is uncertain And to find the minimum number of machines in each process, the objective function of the minimum number of machines can reach 10, so it is not possible to establish simple linear or non-linear constraints. Under the same conditions in each process, it is possible to the job scheduling problem in each process is regarded as a flow shop problem (that is, a certain number of workpieces are processed on some same machines, and the jobs can be processed in any order, which is called free-sequence jobs or open jobs). Since it is impossible to reach the minimum working time on each machine at the same time, the optimal solution is finally determined by the variance. Take step 1 as an example

$Step1$: set k1 = 1, the number of machines in 1 process is 1.

$Step2$: Extract the first column of the R matrix a (i) = R (I, 1) to get the total time of machine 1 operation T_{11} in 1 process.

$Step3$: When $k_1 = k_1 + 1$, the number of machines in step 1 is $k_1 + 1$.

$Step4$: a (i) = R (I, 1), the working time on machine k_1 in step 1 is $T_{11}, T_{12}, T_{13}, \ldots, T_{1k_1}$.

$Step5$: Repeat $Step2, Step3, Step4$, if variance $\sigma_n^{\ 2} = \dfrac{\left(\sum_{m=1}^{M} T_{mn} - \dfrac{\sum_{m=1}^{M} t_{mn}}{M} \right)^2}{M} \leq 1$, then end the loop.

4.3 Establishment of Fitness Function

In the evolutionary process, genetic algorithms use fitness to determine the standard of the superiority and inferiority among individuals in a population, and use it as a basis for subsequent genetic operations. Different individuals in the population represent feasible solutions to actual problems. These feasible solutions are mapped to corresponding function values through the fitness function, and this function value is the corresponding fitness. The level of fitness determines the survival rate of individual chromosomes in the evolution process, and also affects

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the convergence speed of the algorithm. The general fitness function is transformed from the objective function. The objective function in this paper is a minimization optimization model, and the target values are non-negative. For evolution, the greater the fitness, the better the individual. So the fitness function takes the inverse of the objective function.

$$fitness = \frac{1}{makespan} \tag{11}$$

4.4 Population Initialization

Initialize the population and generate a certain number of chromosomes as the initial population in order to carry out the future evolution process. The iterative process of the genetic algorithm needs to select the appropriate number of populations. Too large populations make the program run too long, and too small populations will cause the algorithm convergence is too early and the result is not necessarily the optimal solution. Therefore, the number of populations is determined to be 200 in this paper to ensure that there is an optimal solution for the huge data volume of the sheet metal workshop problem.

*Step*1: When j=1, *c=P_chrome(R)* function the i-th row of generate new population *pop*.

*Step*2: j=j+1, When i reaches a population capacity of 200, the cycle ends.

4.5 Cross

This article uses two-point crossover, and uses the coding example in Table 4 to divide the chromosome into three parts: head, body, and tail. Chromosomes 1 and 2. An example of crossover is shown in Figure 5.

*Step*1: Set two crossing points randomly in two individual encoded strings that are paired with each other.

*Step*2: Swaps the chromosomes of two individuals between the set two intersections.

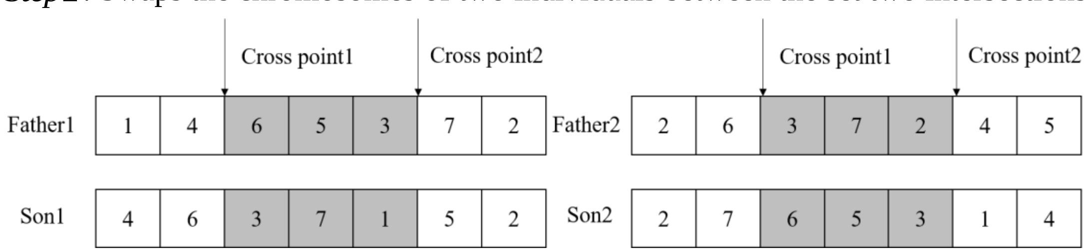

Fig 5: Cross Example

4.6 Variation

This paper uses the method of chromosomal gene position swap. A random position is selected and mutate.

Positions m1 and m2, get the new individuals by swapping the genes of the two mutation positions. Then judge whether the new individual satisfies the priority relationship of the priority matrix, and if it is satisfied, it is regarded as a new individual. An example mutation is shown in Figure 6.

*Step*1: For each gene position of an individual, it is designated as the mutation point by the

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mutation probability.

*Step*2 : For each specified mutation point, negate the gene value or replace it with other allele values to generate a new generation of individuals.

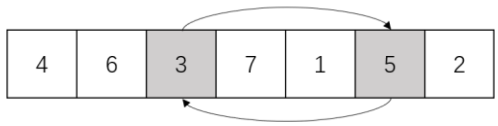

Fig 6: Example of mutation

V. CALCULATION RESULTS AND ANALYSIS

5.1 Number of Machines Results

Due to the huge amount of data in this problem, the process of convergence of the number of machines and the number of iterations are shown by taking steps 1, 2, 3, and 4 as an example. The minimum number of machines for 3 steps is 2, and the minimum number of machines for 4 steps is 5 (Figure 7).

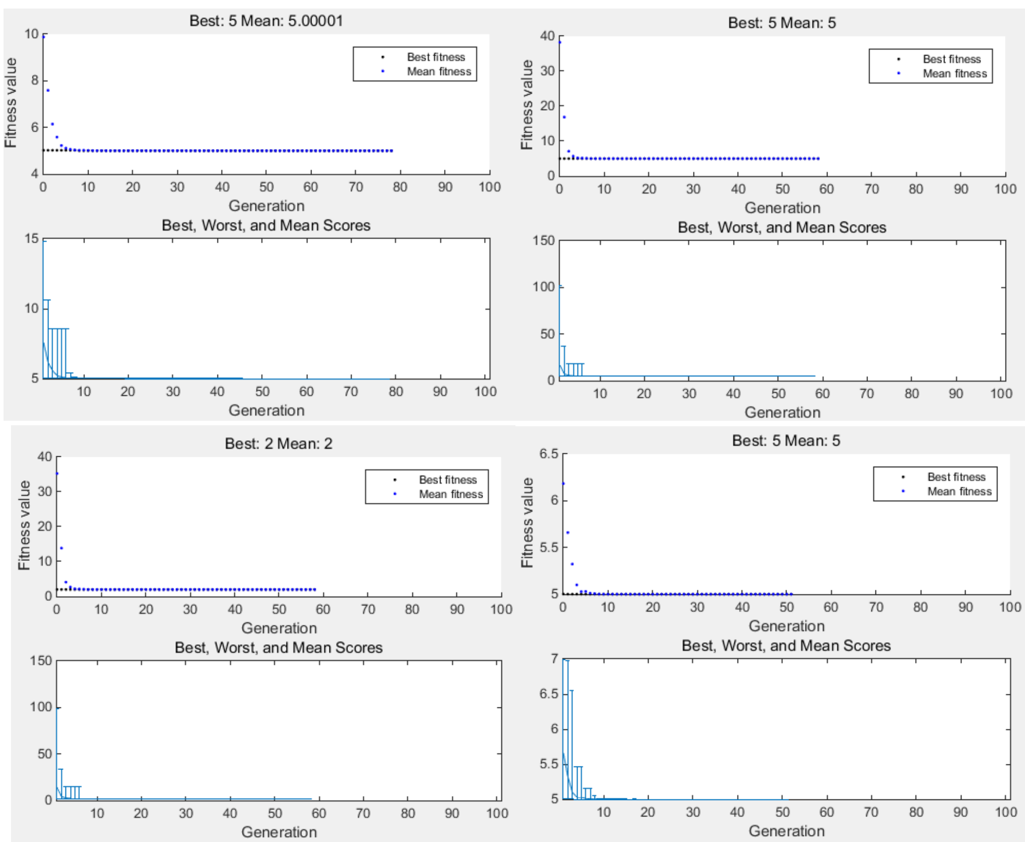

Fig 7: Convergence process

5.2 Assignment Results

The results after iteration are shown in Table 5. J_{ri} represents the part code. It can be seen that the production time of each machine is between 20 and 26. Such an operation is scheduled when the last part is produced, and all parts are completed. All production is completed, ensuring the

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fastest operating efficiency and the smallest production cycle.

Table 5. Job Assignment Results

Machine	Job assignment	Time
1-1	J_{16},J_{46}	23
1-2	J_{36},J_{26}	22
1-3	J_{27},J_{17}	21
1-4	J_{37},J_{47}	22
1-5	$J_{18},J_{28},J_{38},J_{48}$	20
2-1	J_{16} , $J_{26},J_{36},J_{46},J_{18},J_{28}$	20.5
2-2	J_{17} , $J_{27},J_{37},J_{47},J_{38},J_{48}$	21.5
3-1	J_{16},J_{36}	23
3-2	J_{36},J_{26}	24
3-3	J_{27},J_{17}	20
3-4	J_{47},J_{37}	22
3-5	$J_{18},J_{28},J_{38},J_{48}$	20
4-1	J_{16},J_{36}	25
4-2	J_{26},J_{46}	26
4-3	J_{17},J_{37}	22
4-4	J_{27},J_{47}	22
4-5	$J_{18},J_{28},J_{38},J_{48}$	24
5-1	J_{21},J_{31},J_{41}	25
5-2	$J_{11},J_{12},J_{22},J_{32},J_{42}$	22
5-3	$J_{13},J_{23},J_{33},J_{43},J_{35}$	24.5
5-4	$J_{14},J_{24},J_{,34},J_{44},J_{15},J_{25},J_{45}$	26.5
6-1	$J_{11},J_{12},J_{15,}$ $J_{21},J4_{.22},J_{25,}$ $J_{31},J_{32},J_{35,}$ J_{41},J_{42},J_{45}	25.5
7-1	$J_{11},J_{21},J_{31},J_{41}$	25
7-2	$J_{11},J_{21},J_{31},J_{41}$	25
7-3	$J_{12},J_{22},J_{32},J_{42},J_{14}$	24.5
7-4	$J_{13},J_{23},J_{33},J_{43},J_{24}$	24.5
7-5	$J_{15},J_{25},J_{35},J_{45},J_{34}$	25.5
7-6	$J_{18},J_{28},J_{38},J_{48},J_{44}$	25.5
7-7	$J_{17},J_{27}J_{37},J_{47}$	25
8-1	$J_{11},J_{21},J_{31},J_{41},J_{12},J_{22},J_{32},J_{42}$	24.5
8-2	J_{27},J_{37},J_{47}	23
8-3	$J_{17},J_{18},J_{28},J_{38},J_{48}$	17
9-1	J_{13},J_{23},J_{33}	23
9-2	J_{43},J_{44},J_{46}	25.5
9-3	J_{14},J_{24},J_{34}	20
9-4	$J_{15},J_{25},J_{35},J_{45}$	26
9-5	J_{16},J_{26},J_{36}	21
10-1	$J_{11},J_{21},J_{31}J_{41},J_{12},J_{22},J_{32},J_{42}$	24.5

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10-2	J_{13},J_{23},J_{33},J_{43},J_{14},J_{24},J_{34},J_{44},J_{15},J_{25},J_{35},J_{45},J_{16},J_{26},J_{36},J_{46}	25.5
10-3	J_{17},J_{27},J_{37},J_{47}	8

According to the data in Table 5, there is a Gantt chart (Figure 8) which shows the relations between the job assignment and time.

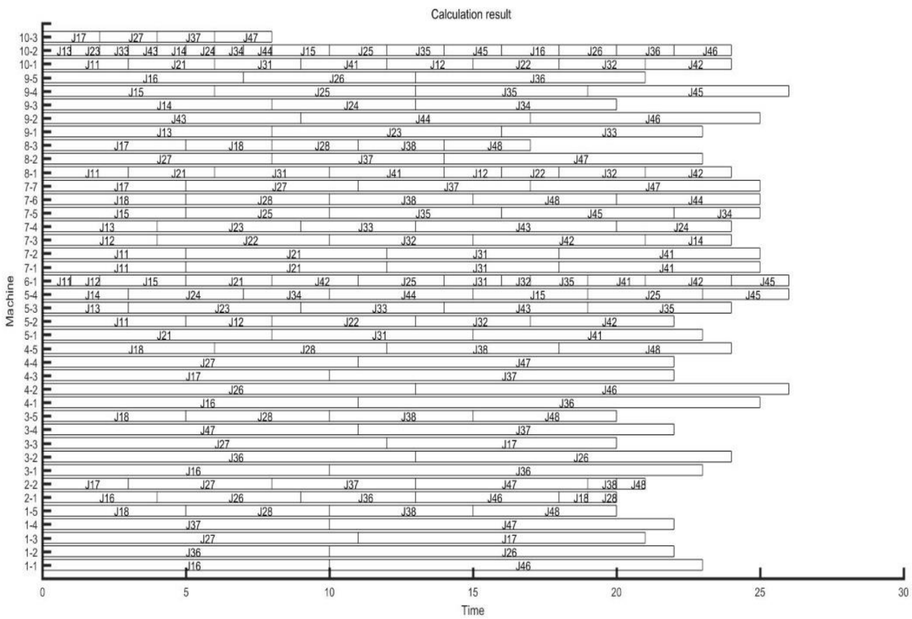

Fig 8: Calculation result

It can be seen from the table and the figure that most of the operating time of each machine is between 20 and 26.5 hours, that is to say, at 26.5 hours, all parts of all types of carving machines can be completed. The number of machines is less than 6 (see Table 6). This arrangement greatly reduces production costs and improves production efficiency.

Table 6. Number of machines per process

Process	Machine number
Pickling and peeling machine 1	5
Cold tandem rolling mill 2	2
Continuous annealing unit 3	5
Trimming machine 4	5
Laser cutting machine 5	4
Bending machine 6	1
Deburring machine 7	7
Automatic welding robot arm 8	3
Manual welding table 9	5
Spray area 10	3

VI. CONCLUSION

Facing the increasingly diversified market demands of modern society, high-efficiency production lines have profound practical significance for manufacturing enterprises, especially high-end cutting-edge enterprises such as carved machine manufacturing companies. How to rationally produce mixed production lines in existing factories, improve the production capacity of enterprise products, and meet the needs of consumers has gradually become an important issue for manufacturing enterprises. The Carving Machine Factory, as a company producing high-precision equipment, intelligence is the general trend. This paper discusses the production line optimization problem of the sheet metal workshop of the precision engraving machine manufacturing plant, synthesizes various authoritative documents and analyzes the advantages and disadvantages of algorithms and simulations, and combines the current problems faced by the enterprises of the precision carving plant. Optimize the analysis and research of the gold shop assembly line. The main conclusions are:

(1) This paper studies the multi-objective optimization method of the production line of the sheet metal workshop of the carving machine manufacturing company, and establishes a multi-objective mathematical model that optimizes the production cycle, the minimum number of machines, and the balance of each workstation;

(2) Based on the operation of traditional genetic algorithms, this paper combined with the establishment of initial population, selection, crossover, mutation and other operations to improve the company's specific problems.

(3) The test analysis of the genetic algorithm suitable for this specific problem in this case shows that the genetic algorithm proposed in this paper has better solution quality and efficiency in solving multi-objective balanced optimization problems.

(4) After studying the production line of the sheet metal workshop of Carving Manufacturing Company with the multi-objective optimization mathematical model and genetic algorithm proposed in this paper, the production cycle is 26.5 hours, and the assembly line smoothness index is 93.67%. Good effect and practical value.

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