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Automotive air conditioning pipeline assembly line balancing and optimization based on heuristic algorithm

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Abstract:

In China, in the manufacture of automobile pipeline, mass assembly line has been an important feature. An efficient production line can make the production of enterprises smoother and faster to complete the production of products, and can effectively solve the low balance rate caused by the production process in the product inventory backlog and temporary shutdown phenomenon, which saves costs for enterprises and increases economic benefits. This paper aims at the production practice of F series products of T company, and fundamentally solves the production problem of F series products of T company, so as to improve the balance of the production line.

Firstly, the research status of precision algorithm is reviewed; Secondly, according to the actual situation of F series products of T company, the production process of F series products is optimized, and the balance of F series products is reflected by production balance degree and other indicators. Finally, the reasons for the low balance rate are analyzed through the fishbone diagram to achieve the balance of the production line to the greatest extent.

Keywords: production line balance， bottleneck process， heuristic algorithm

Introduction

Today, with the rapid development of modern science and technology, and economy, people's requirements for commodities are constantly changing. In order to meet the needs of the diversified market, the company continues to innovate, the introduction of foreign advanced production technology and management ideas. In order to improve production efficiency, enterprises often divide the production process into a number of assembly lines, forming a continuous, segmented, multi-process assembly line operation. This kind of assembly line manufacturing mode has certain defects. After the whole production process is divided into several links, the operation status of each link is different, and the operation content of each process is not the same, resulting in the inconsistency of operation time. Enterprises can use the method of industrial engineering to measure the process standard time, and determine whether the process layout of the production line is reasonable according to the balance ratio of the production line. Each production process on the production line should be scientifically and reasonably arranged to ensure that the working time of each production process is as close as possible.

T Company is an enterprise that produces all kinds of automobile air conditioning pipes. At present, the process equipment of the production workshop of T Company is relatively perfect, and most employees can master the basic operating skills. However, the production efficiency of T Company's production line is low, and the idle rate of equipment is high. This paper takes the F production line of T company as the research object, and uses heuristic algorithm to study the balance optimization of enterprise production line.

1. Research summary at home and abroad

Kucukkoc I (2015) established a multi-objective optimization model with the minimum production time and the number of operations as targets and presented a new ant colony algorithm[1]. Salveson (2015) proposed to take the minimum number of work stations and manufacturing cost as the goal, by constructing an objective function, a reasonable and feasible job set was given in actual production, and a linear programming model was established and solved[2]. Rittm and costaam (2015) modified the variable formula in integer programming to improve the priority limit and site limit. This method can effectively improve the constraints of similar problems. An example is given to analyze the equalization problem of U-shaped production line. The result shows that the method is effective[3]. Johannes Sternatz et al. (2015) studied the production balance problem in automotive flexible hybrid assembly line, proposed a line balance model based on

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reality, and applied heuristic algorithm to solve[4] it. Mura et al. (2016) optimized the configuration of a group of workstations based on the priority of the assembly line process, established a multi-objective optimization model, and applied genetic algorithm to solve[5] the problem.

Reinhart (2019) proposed a branch-and-bound algorithm for solving the balance problem of assembly and disassembly lines. This method can optimize[6] the balancing problem in the shortest time. Lahrich et al. (2019) consider the current equilibrium problem and, using the exact algorithm of polynomials, put the problem in a local search, resulting in an equilibrium problem[7]. Damian Krenczyk and Karoldziki (2020) conduct an analysis[8,9] of the representative products of the modern assembly line in the automotive industry.

Zhang Lanbin (2012) systematically sorted out and analyzed the equilibrium of cabin structure from the value stream theory. At the same time, based on the concept of lean production, product types, output planning, logistics structure, etc., were effectively improved[10]. Lv Fang and Zhou Binghai (2017) studied the working time balance of internal combustion engine assembly line. In the process of optimization, they found the bottleneck problem, made an in-depth analysis of it according to the constraint theory, and gave the corresponding optimization scheme[11]. Yang Kun (2018) conducted a field investigation of container enterprises. On this basis, the four basic principles of ECRS were used to optimize each process on the production line, and the four basic principles of ECRS were used to optimize,[12] decompose and optimize each process.

In 2006, according to the actual situation of welded steel pipe production line, Xie Wei and Zhu Jin established an integer programming model, compiled the corresponding software, solved it, and gave the optimal solution. And put forward the efficient sawing process optimization design[13]. Xie Jinhui and Chen Feng (2012) pointed out that the main problems faced by China's industrial enterprises at present are how to rationally allocate internal resources and how to reduce energy consumption. On this basis, an integer programming model with maximum power value is obtained by introducing branch-and-bound method. The experimental results show that the method is effective[14]. Xu Faping et al. (2012) believe that the essence of the pipeline problem is an optimal job assignment. On the basis of introducing the first kind of equilibrium problem into the mathematical model, an improved branch and bound method is introduced, and three branch rules are used to speed up the solution of the optimal solution so that many sub-optimal solutions[15] are obtained. Aiming at the equilibrium problem in the production process, Li Aiping and Li Liyuan (2013) proposed a mathematical model[16] of multi-objective linear programming by using the minimum input cost, the minimum idle rate of the production line, and the maximum task, taking into account the factors such as space, time and process order. Yin Lujiang et al. (2015) proposed a constraint based on the constraints of the number of stations, the number of stations, and the number of stations, and used the LINGO program to solve the problem[17] of minimum production beats under the condition that the number of stations remained unchanged. Guo Jidong and Zhang Kaibin (2020) carried out in-depth research on furniture production line, applied ECRS principle to the optimization of bottleneck process, and optimized[18] the production workshop with 0-1 integer programming mode.

2. Assembly line problem analysis

T Company produces a variety of automobile pipes, which are assembled on three assembly lines. This paper mainly focuses on the production of three lines and takes 60 series automobile air conditioning pipes as the research object.1

2.1 Determine the width

In the actual production and operation process, workers cannot always maintain the uninterrupted state of mechanized operation. For example, when operators experience work fatigue, they need to rest, go to the toilet and follow the instructions of their superiors. These actions will take up part of the employee's operating time. The operator's poor operating status needs to be converted to the release rate and release time, and then standard time is calculated.

Depending on the intensity of the work and the content of the work, the scope of the business will vary slightly from company to company. According to the actual work intensity of T company and F company, after communicating with the supervisor, we reached the conclusion that personal affairs should be relaxed by 4%, fatigue should be relaxed by 10% and procedures should be relaxed by 1%. And then determine the total relaxation rate of 15%.

According to the actual production status of the movable cabinet bus, the stopwatch test was carried out for each existing process, and the data were measured 30 times for each process. After data processing, the working hour utilization rate of each process was obtained, that is, the working hour utilization rate = standard working hour/working hour, as shown in Table 1.

Table 1 Man-hour utilization rate

Steps	Homework content	Number of stations	Number of people/units	Standard time /s	Utilization rate of man-hour
1	Blanking	1	1	30	45.5%
2	Blowing Crumbs	1	1	29	43.9%
3	Chamfer	1	1	40	60.6%
4	cleanse	1	1	39	59.1%
5	Dry	1	1	50	75.8%
6	Spiral furrow	1	1	44	66.7%
7	Welding flange	1	1	48	72.7%
8	Bend	1	1	39	59.1%

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9	Punching	1	1	43	65.2%
10	Solder the charge valve	1	1	30	45.5%
11	Clamp assembly	1	1	30	45.5%
12	withhold	1	2	60	90.9%
13	Leak Detection	1	1	35	53%
14	Assembly	1	1	66	100%
15	Final Check	1	1	56	84.9%
16	Warehousing	1	1	43	65.2%

The production time of the assembly line is 66 seconds, 17 workers, 16 workbenches, the production capacity per hour of the production line = 3,600/66 =54.5, per capita production = hourly output/number of workers =54.5. The total operation time of each station T=682 seconds, and the equilibrium ratio of the assembly line = the working time of each station/(station) ×100%=682/16×66=64.6%.

From the above data, it can be seen that the balance of the production line is low, the working time utilization rate of each workshop is low, and the working time utilization rate of each workshop is low, among which, the working time utilization rate of the chip blowing machine and the feeding machine is 43.9% and 45.5% respectively.

2.2 Divide the minimum working elements

The reasonable division of work elements directly determines the production efficiency of the assembly line, if the division is too fine, it is easy to cause the production process is more complicated, and the division is not enough will affect the rearrangement of the workstation. The principle of division of operation elements is as follows: ① All the processes that can no longer be divided logically should be divided into one operation element. ② For those that already have a fixed operation method.

The division of operation elements should be consistent with the method. ③ In the division of operation elements, it can not be subdivided to the extent[19] that it can not be measured. Therefore, according to the production status and process flow of automobile air conditioning pipeline, in accordance with the above division rules, the assembly line 16 processes are divided into 27 operation elements, the use of stopwatch time measurement method for each operation element time determination, the development of the standard time of each operation element, as shown in Table 2.

Table 2 activity list

Procedure	Job elements	Assignment content	Number of people/each	Standard time /s	Tight front work
1	1	Aluminum tube delimit length	1	5	
	2	Cutting	1	25	1
2	3	Blowing crumbs	1	29	2
3	4	Chamfer	1	40	3
4	5	Cleaning	1	39	4
5	6	Dry	1	50	5
6	7	Spiral furrow	1	44	
7	8	Flange assembly	1	5	
	9	Flange welding	1	43	8
8	10	Assemble the bending mold	1	15	
	11	elbow	1	24	8, 10
9	12	Mark hole locations	1	14	
	13	Punching	1	29	12
10	14	Charging valve installed	1	6	8
	15	Weld the charge valve	1	24	14
11	16	Glue	1	4	11
	17	Hose assembly	1	23	16
	18	Aluminum sleeve	1	3	16, 17
12	19	Assemble the clamping mold	2	10	
	20	Withholding	2	50	16, 17, 18, 19
13	21	Clamping	1	10	20

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	22	Air tightness testing	1	25	21
14	23	Assembly ring	1	3	22
	24	Fitting a dust cover	1	2	22
	25	Assemble mesh sheathing	1	61	22
15	26	Final inspection	1	56	22
16	27	Warehousing	1	43	26

2.3 Workstation rearrangement based on heuristic algorithm

The heuristic algorithm must abide by the following principles: (1) In the case of work elements, the location of the workstation is prioritized; ② prioritize the work that takes the longest time to process; 3. Prioritize the tasks that have the most follow-on tasks. [20]These three basic principles basically meet the assignment requirements of job elements. The new production beat was determined, and the maximum production beat of procedure 25 assembly mesh sheath was 61 seconds. Therefore, the ideal production beat was adjusted to 61 seconds, and the workstation was rearranged.

Workstation 1: The default remaining time is 61s for the production beat. Minimum job elements 1,7,8,10,12,19 No tight pre-job, assigned to the job to be assigned.

According to the above principle, choose 1 job unit, the remaining time in the site is 56 seconds, and the remaining tasks are 7, 8, 10, 12, 19; Select job element 7,8 and put it into workstation 1, the remaining work time is 7 seconds, and the tasks are 10, 12, 19; The remaining tasks are assigned more standard time than the remaining 7 seconds, so 10, 12, 19 are assigned to workstation 2, and workstation 1 is assigned.

Workstation 2: The default remaining time is 61s for the production beat. Minimum job elements 10,12,19 No tight pre-job, assigned to the job to be assigned. In accordance with principle two, select job elements 10,12,19, and the remaining time in the station is 21s. Because the standard time of job element 2 is greater than 21s, put it into workstation 3 for assignment.

And so on, until all job elements are dumped into the workstation, the workstation rearrangement is complete.

Table 3 working unit optimize

Workstations	Remaining time /s	Element of job to be assigned	Assignment	Standard time	Allotted time	Remaining time
1	61	1,7,8,10,12,19	1	5	54	7
	56	7,8,10,12,19	7	44		
	12	8,10,12,19	8	5		
2	61	10,12,19	10	15	39	22
	46	12,19	12	14		
	32	19	19	10		
3	61	2, 3	2	25	54	7
	36	3	3	29		
4	61	4	4	40	40	21
5	61	5	5	39	39	22
6	61	6	6	50	50	11
7	61	9	9	43	43	18
8	61	11,13,14	11	24	59	2
	37	13, 14	13	29		
	8	14	14	6		
9	61	15,16,17,18	15	24	54	7
	37	16 as	16	4		
	33	17, 18	17	23		
	10	18	18	3		

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10	61	20, 21	20	50	60	1
	11	21	21	10		
11	61	22,23,24	22	25	30	31
	36	23,24	23	3		
	33	24	24	2		
12	61	25	25	61	61	0
13	61	26	26	56	56	5
14	61	27	27	43	43	18

3. Improve performance evaluation

After the heuristic algorithm balance, the assigned work elements, standard time, and working hour utilization of each workstation are obtained, as shown in Table 4.

Table 4 rate of utilization of work hour

Workstations	Homework elements	Number of homework people	Standard time	Man-hour utilization rate
1	1 proposal	1	54	88.5%
2	10,12,19	1	39	63.9%
3	2, 3	1	54	88.5%
4	4	1	40	65.6%
5	5	1	39	63.9%
6	6	1	50	82%
7	9	1	43	70.5%
8	11 which	1	59	96.7%
9	15,16,17,18	1	54	88.5%
10	20, 21	2	60	98.3%
11	22,23,24	1	30	49.2%
12	25	1	61	100%
13	26	1	56	91.8%
14	27	1	43	70.5%

As can be seen from the table above, the production beat of the assembly line is 61 seconds, the number of workers is 15, the station N is 14, the production capacity per hour of the assembly line =3600/61=59, the per capita production = the hourly output/the number of workers =59/15=3.93 / hour. The working time of each station T=682 seconds, the assembly line equilibrium ratio = the average working time of each station total working time /(number of workstations ×CT)×100% =682/14×61=79.9%, except for 11 workstations, the working time utilization rate of each workstation reached more than 60%.

4. Analysis of the causes of imbalance

At present, the balance performance of T series products is not good. In order to carry out comprehensive optimization better, it is necessary to find the root of the imbalance. Through the communication with the production supervisor and employees, the production process of F series products of T company was analyzed from five angles of man, machine, material, law and environment. The fishbone diagram was drawn to optimize the balance for the next production line.

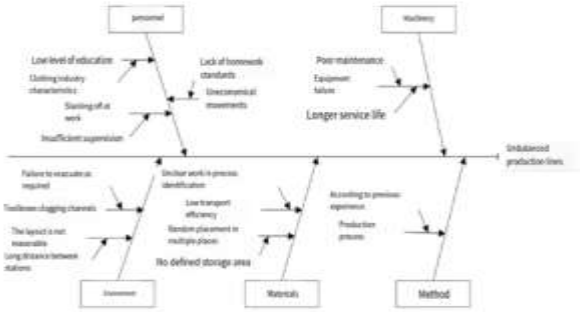

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Figure 1 fishbone diagram2

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As you can see from the fishbone chart, there are many reasons for the imbalance in the F-Series. After the discussion and analysis with the field manager, it is believed that the key problems of the production line lie in the field layout, bottleneck, job distribution, field management, etc., and this is analyzed in detail.

4.1 Unreasonable site layout

In order to ensure the smooth production, it is necessary to avoid wasting time as much as possible in the production. At present, the production workshop of F-type production line of T company, due to its technical characteristics and the limitation of capital investment, makes the loading and unloading work between other units in the production workshop often occur. According to the field investigation, the action route of some workers is confused, and there are crosses and detour, which leads to unnecessary waste and queuing when handling formalities. In addition, the accumulation of a large number of work will also cause great difficulty in handling. Therefore, the production workshop layout of F-type products is studied and planned to improve production efficiency[21].

4.2 Bottleneck process is obvious

The standard time of product F production line can be seen from the above table, the assembly time of bottleneck assembly of this production line is 66S, which is significantly different from that of other processes. Field investigation found that in production practice, most of the workers are based on the past experience and habits to operate, many operations can not follow the principle of action economy, resulting in increased load, low production efficiency. Bottleneck technology is an important factor affecting the balance of production line. It is necessary to optimize the production process. This will not only improve the balance of the production line but also increase production efficiency.

4.3 Unreasonable assignment of work

One of the characteristics of an efficient production line is that the time interval between operations should be as small[22] as possible. Some operators have heavy workloads and some operators are idle at times. In view of the above problems, we can combine the actual production situation on the site, analyze the running time and load differences of each process, adjust the running content of each process appropriately, and rearrange the operation time and operating load between the process as close as possible. The reconfiguration of operation elements on the workstation can adopt the four principles of ECRS, or according to the balance needs and constraints of the two production lines, the production line problem is abstracted into a mathematical model, and the use of software to solve.

4.4 Field management is not standardized

In the production site, there is no clear regulation on the storage location of various tools, resulting in many workers placing these tools unrelated to production activities on the ground at will after using part of the operation tools.

In view of the current domestic without a unified standard of assembly line site management, we can strengthen the assembly line site management, promote 6S training, and standardize the operation behavior[23] of the operators. Improve the operation mode and workplace layout, reduce redundant operations, clean the workplace, use easy-to-operate parts and material boxes, and reduce the work intensity [24, 25] of the operator.

5. Conclusion

By using the heuristic method, the quadratic equilibrium of vehicle air conditioning pipe assembly line is solved, and the flow chart of T company's F-type production line is given. The working time of each working part on the production line is measured by stopwatch timing method, and the standard working time of each station is calculated. The smallest working unit is decomposed and reorganized, the production time is reduced by 5S, and the balance rate is increased from 64.6% to 79.9%, thus improving the production efficiency. Finally, the unbalance phenomenon of F-series products is analyzed, which provides a reference for the subsequent improvement and optimization of F-series products.

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