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Transformer assembly line balancing and optimization based on heuristic algorithm

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Abstract:
For the poor balance of the transformer assembly line and the characteristics of the transformer assembly line with high worker density and undisciplined process sequence, a heuristic algorithm is used to solve the equilibrium problem of level 2 of the assembly line, and each workstation is redistributed according to the smallest unit with the goal of production beat optimization. The optimization resulted in a reduction of 6.6 seconds in the production beat and an increase in the equalization rate from 62.1% to 77%, thus proving that the application of the method in transformer assembly lines is effective and feasible.

Keywords: *Heuristic Algorithm; Assembly line balance; Assignment Element; Workstations*

1. Introduction

The equilibrium optimization problem for assembly lines is an NP-combination optimization problem with four main solutions: exact algorithms, heuristic algorithms, artificial intelligence algorithms, and computer simulation optimization methods. Genetic algorithms, simulated annealing algorithms, etc. are artificial intelligence algorithms that are difficult for ordinary business managers to master. The beat-based heuristic algorithm, based on a sequence diagram of task priority relationships, uses a combination of list and retrieval analysis to achieve a system design and solution that is simple to operate and easy to master for managers of small and medium-sized enterprises.

Currently, the most commonly used heuristic algorithm to solve the assembly line beat, as well as optimization of the number of workstations optimization problem. For the assembly line balancing problem, the main focus is on the product assembly lines of automobiles, machinery, and aircraft, and there is no research on the assembly line combined with transformer products. As one of the important components in electronic products, this product is characterized by many parts, complex processes, high technical content, and high labor intensity in the production line. To this end, this paper takes transformer assembly line as an example and solves the production line balancing problem of transformer assembly line using heuristic algorithm, determines the number of workstations, and decomposes each workstation into the smallest unit with production speed as the optimization target, so that the workload of each work station can be balanced.

2. Analysis of assembly line problems

A company mainly produces transformers required internally for automotive electronics, gambling machines, communication electronics, etc., with more than 80 models. The company has 8 manual assembly lines as well as 4 automated lines in-house. This paper takes the A-type automotive electronic transformer in the 05 manual assembly line body as the research object, conducts on-site research on the assembly line, understands the overall production process of the product, makes detailed analysis and records of the work content of each process, and uses the stopwatch time measurement method to measure the working hours of each process, formulates the standard operating hours, and draws the assembly process procedure diagram on this basis. The assembly process diagram of the product is shown in Figure 1.

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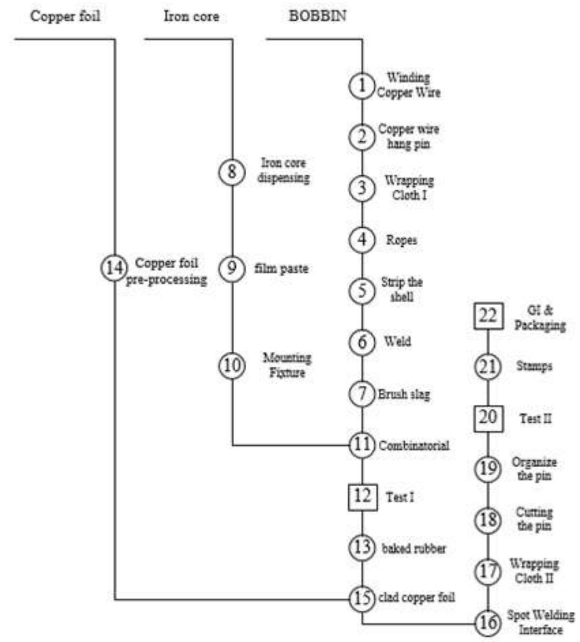

Figue1 Transformer process program diagram

For the actual production of transformer assembly line, the stopwatch timing method is used to keep time for each existing process. The stopwatch timing method requires sufficient sample capacity; the larger the sample, the more accurate the results obtained will be, but too large a sample will consume a lot of time and effort, so it is especially important to determine the number of observations scientifically. In this paper, the error-bounds method is chosen to determine the number of observations. The main point of the error bounds method is to first try to observe an operational unit several times, find its mean and standard deviation, and then seek the number of observations that should be observed according to the allowable error bounds. The error bounds method requires the value of the overall standard deviation σ in calculating the standard deviation of the mean, but this value is not available in practice, so it must be estimated. The standard deviation S of the sample is then generally used instead of the overall standard deviation σ. The formula is as follows.

$$\delta \approx S = \sqrt{\frac{(x_1-\overline{X})^2+(x_2-\overline{X})^2+(x_3-\overline{X})^2+\cdots+(x_n-\overline{X})^2}{n-1}} = \sqrt{\frac{\sum_i^n x_i^2 - \left(\sum_i^n x_i\right)^2 / n}{n-1}}$$

When the observation error range is controlled within ±5%, the confidence level is about 95%, and the formula for the number of observations is as follows.

$$n' = \left(\frac{40n}{\sum_i^n x_i} \sqrt{\frac{\sum_i^n x_i^2 - \left(\sum_i^n x_i\right)^2 / n}{n-1}} \right)^2 = \left(\frac{40s}{\overline{X}}\right)^2$$

Formula: n' :Total number of observations of the operating unit;

x_i: The i-th stopwatch reading;

n = number of trial observations.

After the above calculations can be calculated for a certain process observation times, different operating units calculated by the number of observations should be different, should be the maximum value as the number of observations. The maximum number of observations should be taken as the number of observations. The number of observations for the product line should be formulated according to the maximum number of observations. Therefore, for the A-type transformer assembly line should be observed, calculated A-type transformer assembly line of the 16 processes of the maximum number of observations for 10 times. In this paper, the 16 operational processes of A-type transformer assembly line will be observed 10 times respectively to measure the time, take the relaxation rate of 15%, the data processing of each process to calculate the working hours of each process and the utilization rate of the working hours, where the utilization rate of the working hours = the standard working hours/production beats, as shown in Table 1.

Table1 Original programme hours utilized

working procedure	Work content	Number of workstations	quorum	standard time	Utilization of working hours
1	Winding Copper Wire	1	2	47.5	100%
2	Wrapping Cloth I	1	1	16.4	34.50%
3	Organize copper wires	1	1	36.4	76.60%
4	weld	1	1	29.3	61.70%
5	Processing iron core	1	1	29	61.10%

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6	Mounting Fixture	1	1	28.3	59.60%
7	assemble	1	1	38.9	81.90%
8	Test I	1	1	35.8	75.40%
9	bake glue	1	1	28.7	60.40%
10	Copper foil pre-processing	1	1	26.7	56.20%
11	clad copper foil	1	1	26.6	56%
12	Wrapping Cloth II	1	1	26.2	55.20%
13	Organize pin feet	1	1	30.6	64.40%
14	Test II	1	1	40.9	86.10%
15	stamps	1	1	12.5	26.30%
16	General Inspection & Packing	1	1	18.5	38.90%

From Table1 above, the total operators of the assembly line are 17, the production beat CT is 47.5 s, the number of workstations is 16, the hourly production capacity of the assembly line = 3600/production beat = 3600/47.5 = 75.8, and the per capita production = hourly production/number of operators = 75.8/17 = 4.5 per hour. The total operating time of each workstation T = 472.3s, line balance rate = total operating time of each workstation / (number of workstations * CT) * 100% = 472.3/17*47.5 = 62.1%.

By analyzing the above data, it can be seen that this production line has problems such as low balance rate of the production line, serious imbalance of load between stations, and the utilization rate of working hours of each process is around 50%-80%, which is at a low level, while the utilization rate of overlaying one and sealing is 34.5% and 26.3% respectively.

3. Heuristic algorithm for assembly line balancing

3.1.Divide the smallest operating unit

Reasonable allocation of operating units, directly related to the production efficiency of the assembly line, if the operating unit is divided into too fine, it will make the operation process more complicated, and the allocation of operating units is not sufficient, it will affect the rearrangement of workstations. The principles of operation unit division are as follows:①Organize all processes that can no longer be divided theoretically into a single unit of operation;②For processes that already have a fixed way of working, the division of work units is consistent with this method;③When work units are divided, they can only be broken down to the extent that time measurements can be made. Therefore, according to the process flow and actual production of the transformer assembly line, the 16 processes in the transformer assembly line are divided into 22 operational elements based on the principle of division of operational elements, and the stopwatch timing method is utilized to measure the time of each operational element, and the standard time of each operational element is shown in Table 2.

Table2 Minimum unit of operation

working procedure	work unit	Work content	Number of persons	standard time	Immediately before operation
1	1	Winding Copper Wire	1	32.6	none
	2	Copper Wire Wrap Pin	1	14.9	1
2	3	Wrapping Cloth I	1	16.4	2
3	4	ropes	1	26.2	3
	5	Remove the case	1	10.2	4
4	6	weld	1	8	5

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	7	Brush slag	1	21.3	6
5	8	Core Dispensing	1	18.5	none
	9	film paste	1	10.5	none
6	10	Mounting Fixture	1	28.3	none
7	11	assembled	1	38.9	7、8、9、10
8	12	Test I	1	35.8	11
9	13	baked glue	1	28.7	12
10	14	Copper foil pre-processing	1	26.7	none
11	15	clad copper foil	1	12.4	13、14
	16	Spot Welding Interface	1	14.2	15
12	17	Wrapping Cloth II	1	26.2	16
13	18	pin pruning	1	13	17
	19	Organize pin feet	1	17.6	18
14	20	Test II	1	40.9	19
15	21	stamps	1	12.5	20
16	22	General Inspection & Packing	1	18.5	21

3.2.Job Element Prioritization Diagram

The main content of the work unit sequencing priority map, is a kind of can clearly describe the assembly line each individual operation of the unit sequence corresponding to the sequence of continuous operation unit, so as to provide a more convenient, intuitive, practical reference for the production of workstation reordering. According to the transformer assembly line in the main work of the distribution of elements of the law and the layout of the assembly line site environment, drawn with the assembly line of each unit of work sequence related to the elements of the priority position relationship, as shown in the following figure example 2. In the illustration, the numbers appearing in the circles are used to indicate the serial numbers between the elements of each operation, and the arrows are used to indicate the relationship between the order of the elements of each operation.

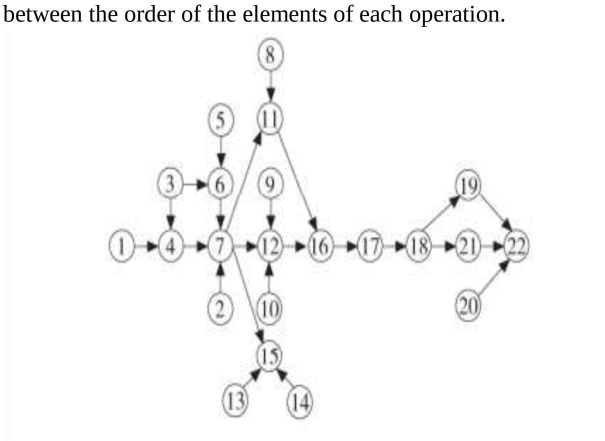

Figure2 Prioritization of operational units

3.3. Workstation rearrangement

Heuristic algorithms should follow several principles: ①Prioritize the assignment of jobs where the workstation location is important relative to the job unit; ②Prioritize the assignment of jobs with the longest job processing time; ③Prioritize the assignment of jobs with the largest number of successor jobs. These 3 basic principles have basically met the needs of the job element allocation. Determine the new production beat, in which the standard time of test 2 is 40.9s, which is the longest job unit, so set the ideal production beat to 40.9s and rearrange the workstations based on this.

Steps of heuristic algorithm:

Step 1: Starting from the first operation element on the assembly operation sequence diagram, first examine which operation elements can meet the conditions of the allocation, the selected operation unit time does not exceed the remaining time of the current station, the remaining time of the current station is the difference between the assembly line beat and the current station time.

Step 2: In accordance with the three principles of the heuristic algorithm, the first to consider the work unit that meets the tool or equipment constraints, then consider the work unit with the longest standard working hours, and again, if there are two or more work units with the same standard working hours, you need to give priority to the work unit with the largest number of jobs immediately after the work unit, and after considering the three principles, select the most

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appropriate one work element, and incorporate it into the current work unit, and add the operating time of the work element to the current workstation time.

Step 3: Compare the sum of the operating time of the current station with the assembly line beat, and if there is any remaining time, continue to step 1 If the remaining operating time is 0 or there are no feasible operating elements to be assigned to the current station, stop the assignment If the operating time of the selected operating element exceeds the remaining time of the current station, then exclude the selected element, and then go to step 1 until there are no eligible operating elements to be assigned, then stop the assignment of the station.

Application of heuristic algorithms:
Workstation 1: Default remaining time is 40.9s for the production beat. The smallest operation units 1, 8, 9, 10, and 14 have no immediately preceding production operations and are assigned to the operations to be assigned. According to Principle 1, select operation unit 8, the remaining time in the station is 22.4s, and there are 1, 9, 10, and 14 remaining assigned operation units; select operation unit 9, the remaining time in the station is 11.9s, and there are 1, 10, and 14 remaining assigned operation units; since the standard time in the remaining to be assigned operation units are all greater than the remaining time of 11.9s, therefore, operation units 1, 10, and 14 are put into the Because the standard time in the remaining work units to be allocated is greater than the remaining time of 11.9s, work units 1, 10 and 14 are put into work station 2 for allocation, and the work station 1 job sequencing is completed.

Workstation 2: Default remaining time is 40.9s for the production beat. The smallest operation units 1, 10, and 14 have no immediate preceding operations and are assigned to the operations to be assigned. According to principle 2, select operation element 14, the remaining time in the station is 14.2s, and the remaining operation units to be allocated are 1 and 10; since the standard time in the remaining allocated operation units is greater than the remaining time of 14.2s, operation units 1 and 10 are put into workstation 3 for allocation, and the workstation 2 job sequencing is completed.

Workstation 3: Default remaining time is 40.9s for the production beat. The smallest operation units 1 and 10 have no tightly preceding operations and are assigned to the operations to be assigned. According to Principle 2, select operation element 10, the remaining time in the station is 12.6s, and there is 1 remaining operation unit to be allocated; since the standard time in the remaining allocated operation units is greater than the remaining time of 12.6s, operation unit 1 is put into workstation 4 for allocation, and the workstation 3 operation sequencing is completed.

In accordance with the three basic principles for the allocation of work units, and so on, until all work units are scheduled into workstations to complete the rearrangement of workstations, the rearrangement of workstations as shown in Table 3.

Heuristic algorithms should follow several principles:
①Prioritize the assignment of jobs where the workstation location is important relative to the job unit; ②Prioritize the assignment of jobs with the longest job processing time; ③Prioritize the assignment of jobs with the largest number of successor jobs. These 3 basic principles have basically met the needs of the job element allocation. Determine the new production beat, in which the standard time of test 2 is 40.9s, which is the longest job unit, so set the ideal production beat to 40.9s and rearrange the workstations based on this.

Steps of heuristic algorithm:
Step 1: Starting from the first operation element on the assembly operation sequence diagram, first examine which operation elements can meet the conditions of the allocation, the selected operation unit time does not exceed the remaining time of the current station, the remaining time of the current station is the difference between the assembly line beat and the current station time.

Step 2: In accordance with the three principles of the heuristic algorithm, the first to consider the work unit that meets the tool or equipment constraints, then consider the work unit with the longest standard working hours, and again, if there are two or more work units with the same standard working hours, you need to give priority to the work unit with the largest number of jobs immediately after the work unit, and after considering the three principles, select the most appropriate one work element, and incorporate it into the current work unit, and add the operating time of the work element to the current workstation time.

Step 3: Compare the sum of the operating time of the current station with the assembly line beat, and if there is any remaining time, continue to step 1 If the remaining operating time is 0 or there are no feasible operating elements to be assigned to the current station, stop the assignment If the operating time of the selected operating element exceeds the remaining time of the current station, then exclude the selected element, and then go to step 1 until there are no eligible operating elements to be assigned, then stop the assignment of the station.

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Workstation 1: Default remaining time is 40.9s for the production beat. The smallest operation units 1, 8, 9, 10, and 14 have no immediately preceding production operations and are assigned to the operations to be assigned. According to Principle 1, select operation unit 8, the remaining time in the station is 22.4s, and there are 1, 9, 10, and 14 remaining assigned operation units; select operation unit 9, the remaining time in the station is 11.9s, and there are 1, 10, and 14 remaining assigned operation units; since the standard time in the remaining to be assigned operation units are all greater than the remaining time of 11.9s, therefore, operation units 1, 10, and 14 are put into the Because the standard time in the remaining work units to be allocated is greater than the remaining time of 11.9s, work units 1, 10 and 14 are put into work station 2 for allocation, and the work station 1 job sequencing is completed.

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Workstation 2: Default remaining time is 40.9s for the production beat. The smallest operation units 1, 10, and 14 have no immediate preceding operations and are assigned to the operations to be assigned. According to principle 2, select operation element 14, the remaining time in the station is 14.2s, and the remaining operation units to be allocated are 1 and 10; since the standard time in the remaining allocated operation units is greater than the remaining time of 14.2s, operation units 1 and 10 are put into workstation 3 for allocation, and the workstation 2 job sequencing is completed.

Workstation 3: Default remaining time is 40.9s for the production beat. The smallest operation units 1 and 10 have no tightly preceding operations and are assigned to the operations to be assigned. According to Principle 2, select operation element 10, the remaining time in the station is 12.6s, and there is 1 remaining operation unit to be allocated; since the standard time in the remaining allocated operation units is greater than the remaining time of 12.6s, operation unit 1 is put into workstation 4 for allocation, and the workstation 3 operation sequencing is completed.

In accordance with the three basic principles for the allocation of work units, and so on, until all work units are scheduled into workstations to complete the rearrangement of workstations, the rearrangement of workstations as shown in Table 3.

Table3 workstation rearrangement

Work Stations	remaining time	Assignments to be assigned	Distribution of work	standard time	allotment of time	Final remaining time
1	40.9	1、8、9、10、14	8	18.5	18.5	22.4
	22.4	1、9、10、14	9	10.5	29	11.9
	11.9	1、10、14	none	none		
2	40.9	1、10、14	14	26.7	26.7	14.2
	14.2	1、10	none	none		
3	40.9	1、10	10	28.3	28.3	12.6
	12.6	1	none	none		
4	40.9	1、2、3	1	32.6	32.6	8.3
	8.3	2、3	none	none		
5	40.9	2、3、4、5、6	2	14.9	14.9	26
	26	3、4、5、6	3	16.4	31.3	9.6
	9.6	4、5、6	none	none		
6	40.9	4、5、6、7	4	26.2	26.2	14.7
	14.7	5、6、7	5	10.2	36.4	4.5
	4.5	6、7	none	none		
7	40.9	6、7、11	6	8	8	32.9
	32.9	7、11	7	21.3	29.3	11.6
	11.6	11	none	none		
8	40.9	11、12、13	11	38.9	38.9	2
	2	12、13	none	none		
9	40.9	12、13、15	12	35.8	35.8	5.1
	5.1	13、15	none	none		
10	40.9	13、15	13	28.7	28.7	12.2
	12.2	15	none	none		

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11	40.9	15、16、17、18	15	12.4	12.4	28.5
	28.5	16、17、18	16	14.2	26.6	14.4
	14.4	17、18	none	none		
12	40.9	17、18、19	18	13	13	27.9
	27.9	17、19	19	17.6	30.6	10.3
	10.3	17	none	none		
13	40.9	17、20、21、22	17	26.2	26.2	14.7
	14.7	20、21、22	21	12.5	38.7	2.2
	2.2	20、22	none	none		
14	40.9	20、22	20	40.9	40.9	0
	0	22	none	none		
15	40.9	22	22	18.5	18.5	22.4
	22.4	none	none	none		

4. Evaluation of improvement effects

After balancing by heuristic algorithm, the assigned job elements, standard time, and work hour utilization for each workstation are obtained as shown in Table 4.

Work Stations	work unit	Number of operators	standard time	Utilization of working time
1	8、9	1	29	70.90%
2	14	1	26.7	65.30%
3	10	1	28.3	69.20%
4	1	1	32.6	79.70%
5	2、3	1	31.3	76.50%
6	4、5	1	36.4	89%
7	6、7	1	29.3	71.60%
8	11	1	38.9	95.10%
9	12	1	35.8	87.50%
10	13	1	28.7	70.20%
11	15、16	1	26.6	65%
12	18、19	1	30.6	74.80%
13	17、21	1	38.7	94.60%
14	20	1	40.9	100%
15	22	1	18.5	45.20%

From the above table, assembly line production beat CT = 40.9s, operating personnel for 15 people, the number of workstations N is 15, the production line hourly capacity = 3600 / production beat = 3600 / 40.9 = 88, per capita production = hourly production/number of operators = 88 / 15 = 5.9 per hour. The total operating time of each workstation T = 472.3s, and the production line balance rate = total operating time of each workstation/(number of workstations*CT)*100% = 472.3/15*40.9*100% = 77%. The utilization rate of working hours of each workstation has been greatly improved, and the total number of operators has been reduced by 2. The relevant indexes of the assembly line before and after the improvement are shown in Table 5.

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Table5 Comparison of production indexes before and after improvement

Production Indicator	before improveme nt	after improvement
Production beat	47.5	40.9
Number of workstations	16	15
Number of operators	17	15
Production line balance rate	62.10%	77%
Production capacity (unit/H)	75.8	88
Capacity per capita (units/H*person)	4.5	5.9

5. Conclude

In this paper, the heuristic algorithm is used to solve the line balancing problem of the transformer assembly line, and the number of time measurement of 16 processes in the assembly line is calculated by using the error bound method, based on which the division and rescheduling of the minimum operation unit is used, which reduces one operation process, improves the CT by 6.6s, reduces the number of operators by 2, and the line balancing rate is increased from 62.12% to 77%, which greatly enhances the production efficiency of the product. This also shows that the heuristic algorithm is of great practical significance for solving the equilibrium problem of transformer assembly line. The heuristic algorithm is a more suitable algorithm for production managers to learn and use, as the solution steps are intuitive and clear, and it is simpler and more efficient than the ant colony algorithm, 0-1 planning, and other methods. This algorithm is not only applicable to the transformer assembly line balancing problem but also has significance for other industries such as similar assembly line balancing problems.

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