Optimization and Simulation of Production Line Layout Based on Plant Simulation

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***Abstract*—Manufacturing industry plays an important role in the country, and the optimization of factory facility layout design in basic manufacturing industry will affect the problem that needs to be solved urgently. The problem of facility layout optimization is not only an engineering research problem, but also more complex in practice, with high practicality. However, its interdisciplinary characteristics are also very obvious. Based on the principle of discrete system simulation, the initial model of the camshaft production line is established on the basis of determining the camshaft production process and the specific parameters of each machine tool. Secondly, according to the established model, discuss the working efficiency of each equipment, the working condition of the station, the failure efficiency of the production line and the bottleneck process, etc., run the model and analyze the results. According to the analysis of the simulation results of the model, it is gradually improved. Finally, the mass production of camshaft production line is discussed, and the initial population, individual fitness function, genetic parameters, etc. are analyzed. On this basis, genetic algorithm is used to optimize the scheduling problem, and the results are compared with the previous ones to verify whether the results are effective.**

Keywords—Multi objective optimization, Production rhythm, Genetic algorithm, Production scheduling

I. INTRODUCTION

In the environment of Industry 4.0, production management technology plays a particularly important role in the upgrading and transformation of traditional manufacturing production lines, and the main problems that may exist in the current environment of large-scale production lines include unscientific layout, poor logistics, high handling intensity, unbalanced beat and many other problems. Among them, the process production line is the basic unit of workshop production, and due to the difference in scale, the layout problem can be divided into facility layout, factory layout, workshop layout and equipment layout. In recent years, with the rapid change of demand, equipment and products are rapidly updated, and layout update has become a new problem.

Compared with other manufacturing industries, the production process of automobiles and their affiliated manufacturing industries is complex and the production system is huge, so the preliminary planning of its production line must be thoughtful and meticulous to ensure that it can achieve high efficiency, lean and flexible production operation state after it is put into production, and meet the requirements of enterprise production. If the traditional optimization method in the production field is used, it must be formed through long-term experiments and verification, which will greatly consume human, material and financial resources[1]. In order to reduce consumption and effectively reduce the various risks borne by production units due to unclear understanding of new or expanded production lines, it is very necessary to model the production line and simulate the analysis in the early stage, and after the early simulation, appropriate and efficient planning can be selected, so that the production capacity can be fully exerted and the economic benefits are improved.

This paper takes the traditional layout of a camshaft production line as an example, based on the operation characteristics of the production system, combined with the common characteristics of the layout problem, the Plant Simulation simulation platform is used to model and study how to rationally and effectively use the manufacturing resources of the workshop.

II. MODELING OF DISCRETE EVENT SYSTEM

A. Discrete Systems Policy and Strategy

Events in a discrete event system can be organized at different levels. It can usually be organized from three different levels: events, activities, and processes, that is, three typical processing methods for handling discrete event models: event scheduling method, activity scanning method, and process interaction method. The three typical processing methods adopt three different strategies, resulting in three different modeling methods: event-oriented simulation modeling methods, activity-oriented modeling methods, and process-oriented modeling methods[2]. The activity scanning method uses activity as the basic unit of the analysis system, using a fixed time promotion mode, and the activity must be under certain requirements to occur. In the process of using this method, each time the time is pushed forward, it is judged whether the condition is met, and the activity is executed. This approach is good for modeling and easy to understand. The active scanning algorithm steps are shown in Figure 1.

B. Scheduling optimization algorithm

In order to solve the production scheduling problem caused by large batches and various types of actual production, the commonly used optimization scheduling algorithms include genetic algorithm, particle swarm algorithm, annealing algorithm, etc. The genetic algorithm was first proposed by John Holland in 1975 and gradually developed into a computational model that simulates Darwin's theory of evolution and Mendel's theory of genetics to solve optimization problems such as production scheduling, which is essentially a search method. Genetic algorithms have outstanding optimization ability for production scheduling and other problems, and theoretically can find the global optimal solution, usually containing five parts[3]:

(1) Genetic representation of solutions.

(2) Methods for creating initial populations.

(3) Judgment function.

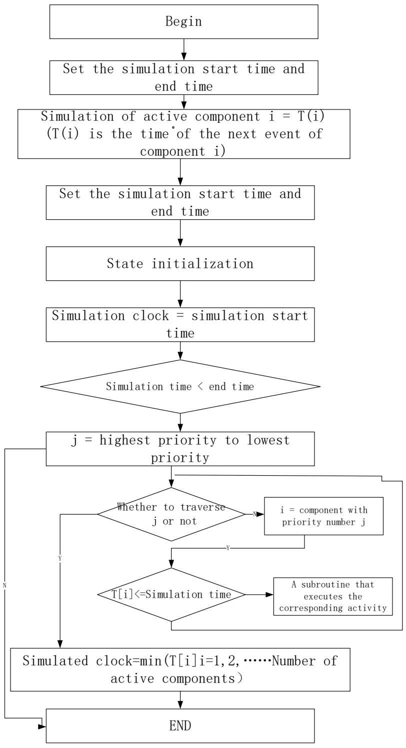

Figure 1 Flow chart of active scanning algorithm program

(4) Genetic operators.

(5) Algorithm parameter values.

The main genetic procedures are:

(1) Encoding: A method of converting the solution of a problem into a search space that genetic algorithms can handle.

(2) Individual fitness evaluation: according to certain rules to find the fitness of individuals to judge the advantages and disadvantages of individuals.

(3) Selection: Select individuals on the basis of their merits and weaknesses.

(4) Crossover: is the main method of generating new individuals.

(5) Variation: determines the local search ability of the algorithm.

(6) Control parameters: population size, cross probability, mutation probability, etc.

The genetic algorithm flowchart is shown in Figure 2.

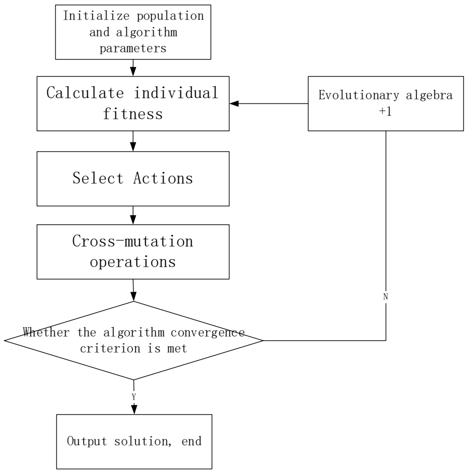

Figure 2 Genetic algorithm flowchart

III. Analysis and Establishment of Camshaft Production Line Model

A. System model analysis

Taking camshafts in the main parts of automobiles as the research background, the production line is as follows:

(1) Product name: camshaft

(2) Working conditions: 300 days/year, 3 shifts/day, 21 hours a day

(3) Process flow: The processing process of camshaft includes roughing, finishing, polishing, testing, etc., the details are shown in Figure 3.

(4) Station configuration: The inspection station (OP13), marking station (OP14) and encapsulated steel ball (OP16) in each station of the camshaft production line are manually operated, and the rest of the stations are equipped with automatic processing machine tools.

(5) Material workpiece transportation mode: conveyor belt transportation and manipulator automatic loading and unloading, conveyor belt speed of 60 meters per minute.

(6) Workpiece detection method: online manual inspection.

The camshaft production line process and key processing equipment configuration are shown in Table I[4].

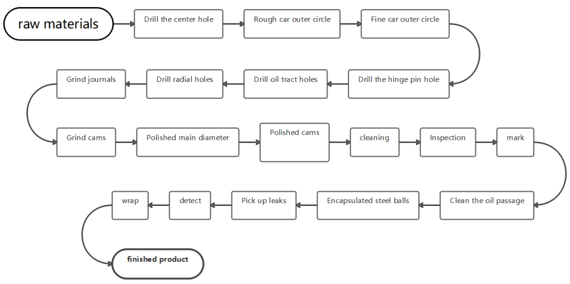

Figure 3 Camshaft processing process flow chart

TABLE I LIST OF MACHINE TOOLS AND WORKERS FOR CAMSHAFT PRODUCTION LINE

Station No.	The operation name	Processing cycle /s
OP01	Punch holes in unison	35
OP02	Rough car outer circle	75
OP03	Fine car outer circle	70
OP04	Drill-end face system	30
OP05	The thrust surface of the car is drilled with radial holes	32
OP06	Milling boss, drilling radial holes	36
OP07	Deburring	38
OP08	Grind the end face	32
OP09	Grinding spindle diameter outer circle	68
OP10	Grind cams	33
OP11	Main diameter polishing	28
OP12	Cam polished	29
OP13	cleaning	54
OP14	Detect marking	30
OP15	Press-fit steel balls	13
OP16	Antirust	40

The first task discussed in this article is the layout optimization and scheduling of camshaft production lines, and the subtleties in specific links such as robot loading and unloading are not delved in-depth, so they are only used to model in 2D mode on Plant Simulation. The initial model is shown in Figure 4 and consists of a loading area, a production area and a bottom-line area.

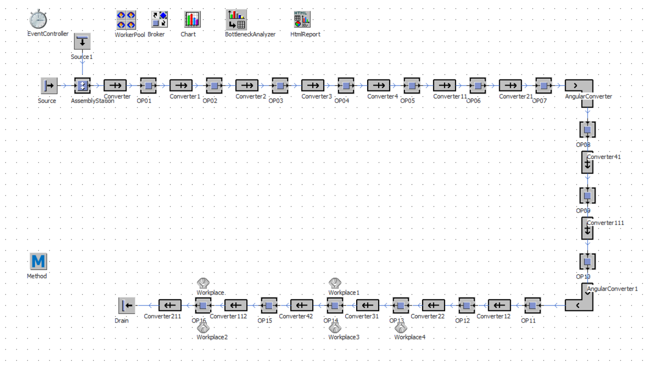

Figure 4 Structure diagram of camshaft production line simulation model

B. Simulation data analysis

The processing status of each equipment of the camshaft production line, including the working rate, waiting rate, blocking rate and failure rate of the equipment, is an important reference for discussing the advantages and disadvantages of a production line design. This chapter first assumes that the failure rate of the device is 0, and analyzes the operating status of each device. Let's discuss the situation where the station failure rate is not 0. The difference in the processing time of each machine tool and the manual station has a great impact on the output of the production line, so the focus is on the working status of the machine tool and the labor station. There are a total of sixteen stations in the production area, of which three are manual stations and the remaining thirteen are single-machine stations. Figure 5 shows the resource statistics. The model simulation ran for 7 days, the output of camshafts in the production line was 7383 pieces, and the data results of each station were shown in Table II.

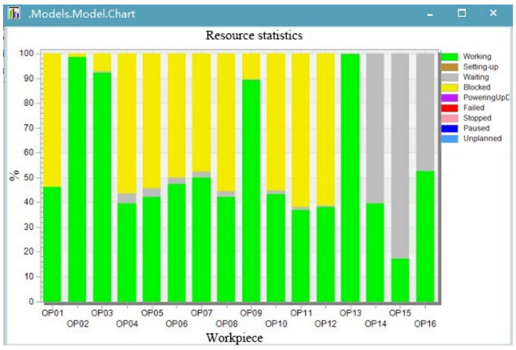

Figure 5 Equipment utilization chart of camshaft production line

TABLE II STATISTICS OF SIMULATION RESULTS

Station No.	Working rate(%)	Idle rate(%)	Blocking rate(%)
OP01	46.11	0	53.89
OP02	98.79	0	1.20
OP03	92.20	0.53	7.27
OP04	39.51	4.17	56.33
OP05	42.13	3.39	54.47
OP06	47.39	2.55	50.06
OP07	50.02	2.21	47.77
OP08	42.12	2.32	55.56
OP09	89.49	0.30	10.20
OP10	43.43	1.35	55.22
OP11	36.84	1.23	61.93
OP12	38.15	0.57	61.28
OP13	99.97	0.03	0
OP14	39.46	60.54	0
OP15	17.10	82.90	0
OP16	52.61	47.39	0

Through Table II, the working rate, equipment idle rate and blocking rate of each equipment in the production area can be obtained. The working rate of OP02, OP03 and OP09 in each equipment is close to or more than 90%, and it is in a high-efficiency operating state. The idle rate of OP14 station, OP15 station and OP16 station is close to or exceeds 50%, which is in a state of extremely low efficiency. The congestion rate of OP01 station, OP04 station, OP05 station, OP06 station, OP07 station, OP08 station, OP10 station, OP11 station and OP12 station is more than 50%. This has caused a great waste of production line processing resources. The main causes of bottlenecks are as follows:

(1) Production line balance problem: the streamlined layout of the production line, due to the different processing time of each station and the single-station processing mode adopted by the station, it is easy to form a blockage before the station with a longer processing time, and the station with a shorter processing time will have a longer wait.

(2) Process problems: Due to the existence of manual stations in the production line, the processing time is long and blocked.

IV. ANALYSIS AND ESTABLISHMENT OF CAMSHAFT PRODUCTION LINE MODEL

A. GA genetic algorithm scheduling optimization

Workshop production scheduling problem (JSSP) is a major topic in the production operation scheduling of enterprises, auto parts production has the characteristics of large batch, fast process, flexible production, etc., and the flexible production scheduling problem of large batch auto parts belongs to a kind of flexible workshop scheduling problem. According to the idea of camshaft production line scheduling optimization, the flexible workshop scheduling optimization is realized through iterative methods based on genetic algorithms.

- Coding of the workpiece to be processed

Encoding is the first key step to be completed using the GA algorithm, and the encoding strategies of the GA algorithm are: integer coding, binary coding, real number encoding and mixed coding. Usually the use of binary coding is very likely to converge to obtain a global optimal solution, for production scheduling problems, only need to encode the workpiece, so the use of integer coding, such as coding {3, 5, 7, 4, 1, 6, 2}, the corresponding workpiece order is {J3, J5, J7, J4, J1, J6, J2}, the code number is the corresponding workpiece number. Due to the different specific parameters such as performance requirements and dimensions, the processing technology and processing time of the workpieces to be processed will also be different, The specific processing time of the workpiece at each station is shown in Table III[4-8]

TABLE III WORKPIECE PROCESSING CYCLE

Station No.	J1(s)	J2(s)	J3(s)	J4(s)	J5(s)	J6(s)	J7(s)	J8(s)	J9(s)	J10(s)	J11(s)	J12(s)
OP01	35	39.6	60	90	20	37	40	50	60	32	43	54
OP02	75	0	100	190	68	70	60	90	140	50	65	80
OP03	70	35.4	0	178	72	73	35	20	146	63	67	54
OP04	30	37	92	78	63	32	34	82	58	45	56	46
OP05	32	23.8	100	83	36	33	24	90	63	36	46	31
OP06	36	30.3	97	90	21	34	31	37	70	42	33	47
OP07	38	46.1	0	98	38	30	35	40	78	35	31	43
OP08	32	0	86	83	30	38	40	66	64	30	39	48
OP09	68	30	92	75	0	63	30	72	57	40	45	53
OP10	33	30	71	50	60	30	30	41	32	57	30	31
OP11	28	44.7	0	85	34	25	45	50	67	45	46	20
OP12	29	0	68	45	0	22	20	58	27	0	20	28
OP13	17	28.2	96	73	54	14	30	46	55	54	18	30
OP14	15	11.2	60	55	26	20	14	43	37	26	26	23
OP15	13	33.4	90	40	30	15	16	25	22	30	8	25
OP16	19	0	0	0	0	18	13	20	0	0	15	10

- Determine the fitness function

In genetic algorithms, the fitness function is used to distinguish between good and bad problem solving, and genetic algorithms select individuals based on fitness. The production scheduling optimization problem is the minimum adaptability as the target direction, the optimal solution is sought through multiple operation iterations, and the time to complete the production order under a certain workpiece sequence is sought to be the shortest, and the fitness function is:

$$Min\, T = \sum_{i=1}^{12} T i$$

where T represents the total time of order processing and represents the processing time of the ith type of workpiece.

- Determine the operator and algorithm parameters

The basic principle of genetic algorithms is Darwin's principle of natural selection, and selection is the driving force for optimal solutions. The selection methods mainly include proportional selection, sorting selection, and optimal preservation strategy. Among them, the plant simulation software is commonly used in the proportional selection method, also known as betting table selection. That is, the greater the fitness of the individual, the greater the probability of being selected.

Cross-arithmetic refers to the process in which the parent selects two chromosomes with a certain probability of crossing to exchange some genes in a certain way. The cross operators included in Plant Simulation software have partial mapping and sequence crossing, which can maintain a certain chance of inheritance and inheritance of excellent genes, and this paper adopts the order crossover method.

The mutation operation of genetic algorithms is when the parent randomly changes certain sites on the chromosome with a small probability to produce offspring that are not similar to the previous sequence. The mutation operator is used in conjunction with the cross operator to enable the genetic algorithm to realize the optimization process of the optimization problem with excellent search ability. Figure 6 shows the specific parameter settings.

The number of generations that change the processing order of the workpiece is 50 generations, and there are 20 individual digits within each generation. Set the time for the line to fulfill the order to the fitness with a weight of 1. The optimization direction is set to the minimum value. Taking the initial sequence shown in Table IV as the workpiece processing sequence, the order is set to process 20 pieces of each workpiece, and the production line completes the order in 2 hours and 34 minutes. Through the genetic algorithm to analyze a variety of workpiece sorting and combination schemes, the optimal scheme of production scheduling is obtained, and the time to complete the order is 2 hours and 20 minutes. According to the convergence curve of the GA algorithm Figure 8, it can be seen that in the optimization process of the 50th generation, the optimal solution is found around the 30th generation, and the encoding has not changed after the 30th generation, and the encoding is: {2, 7, 11, 5, 1, 4, 10, 12, 3, 8, 6, 9}.

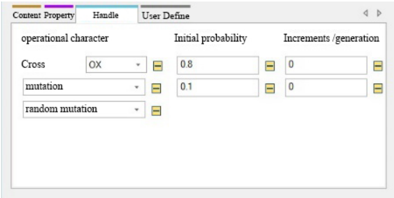

Figure 6 Crossover and variation parameter settings

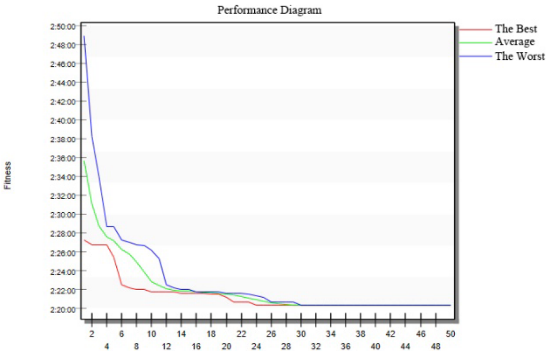

Figure 7 Convergence curve of genetic algorithm

B. Production line model optimization and analysis

According to the analysis results of the preliminary improvement plan above, this section will optimize the problem of waste of processing resources caused by the long waiting time of OP13, OP14, OP15, OP16 and other processes:

(1) Increase parallel production lines. The reason for the low station working rate of OP13 and later is that the processing time of the first 12 stations is longer than that of the subsequent single product, so adding an OP01 to OP12 production line in parallel with the original line can effectively balance the processing time.

(2) Improve the transportation speed of parallel production lines. Increasing the transport speed of parallel production lines can effectively reduce the processing time of single products in parallel production lines.

The optimized model is shown in Figure 8.

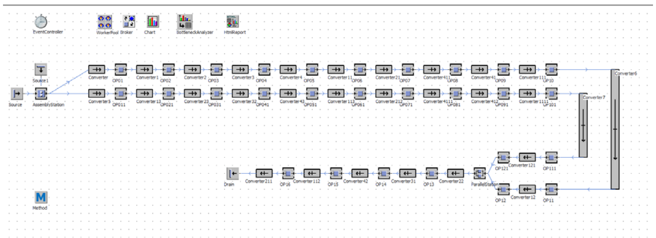

Figure 8 Camshaft production line optimization structure diagram

After optimization, the data of OP13, OP14, OP15, OP16 and other stations for 7 days of model simulation operation are shown in Table IV, and the utilization rate of equipment after model optimization is shown in Figure 9.

TABLE IV SIMULATION RESULTS OF THE OPTIMIZATION MODEL

Station No.	Working rate(%)	Idle rate(%)	Blocking rate(%)
OP13	87.76	12.24	0
OP14	77.44	22.56	0
OP15	67.11	32.89	0
OP16	98.08	1.92	0

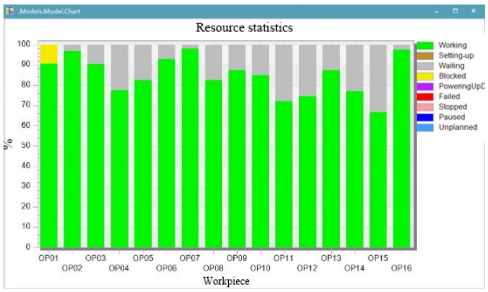

Figure 9 Equipment utilization after model optimization

Compared with the original model, the camshaft production line performance mainly has the following changes:

(1) Increased production. Based on the output of the production line within 7 days, the output increased from 15898 to 31796 pieces after the optimization model was completed.

(2) Processing resources are fully utilized. The working rate of OP13, OP14, OP15, OP16 and other stations has increased significantly, as shown in Table V.

TABLE V COMPARISON TABLE OF WORKSTATION WORK RATE

Station No.	Pre-optimization work rate(%)	Optimized work rate(%)	Station serial number
OP13	44.57	87.76	OP13
OP14	39.33	77.44	OP14
OP15	34.08	67.11	OP15
OP16	49.81	98.08	OP16

V. CONCLUSION

Starting from the simulation theory of discrete event system, based on the research data of camshaft production process and various equipment, this paper uses the Plant Simulation platform to establish the simulation model of camshaft production line. The operation results of the simulation model are analyzed, the effects of equipment working rate, blocking rate, waiting rate and failure rate on yield are mainly analyzed, and the scheduling problem is optimized by genetic algorithm, and the model is gradually improved based on the analysis results. The main ones include:

(1) Based on the research data of camshaft production process and various equipment, the plant simulation platform is used to model the camshaft production line.

(2) Based on the established camshaft production line simulation model, the production efficiency, station working conditions and bottleneck process of the camshaft production line are simulated and the results are analyzed. And based on the analysis results, the model was gradually improved.

(3) The mass production of camshaft production line was analyzed, the production scheduling of 12 different workpieces was discussed, and the optimization of them was discussed and optimized based on the genetic algorithm, and the effectiveness of the scheduling optimization of the genetic algorithm was verified.

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