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Flexible production line improvement based on Plant Simulation

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ABSTRACT: Make to Order (MTO) manufacturing companies are driven by customer orders, and MTO companies usually adopt a multi-variety, low-volume production model where production lines are laid out according to process principles[1]. However, the significant problem of the production line layout according to the process principle is low productivity, low capacity, and high inventory. To solve this problem, it is crucial to equip the line with an effective number of equipment and to make full use of the equipment capacity. Plant Simulation is a powerful software mainly used for production, logistics and engineering simulation of discrete-event systems. Plant Simulation can help us to find the bottlenecks and key equipment of the line, and to calculate the effect of the improvement through the optimisation of the production line model.

KEYWORDS: Flexible production line, Plant Simulation, Multi-species small-lot production, Productivity enhancement

I. INTRODUCTION

Harmonic reducer contains many kinds, models and sizes. Because of the customer's different demand, the company can only produce this product according to the way of many varieties and small quantities, and the arrangement of the production line is according to the flexible process layout mode. But this kind of production line will bring many difficulties and troubles. Including low production capacity, long production cycle, more inventory and so on[2]. Since the traditional method of studying the process layout of the production line is more troublesome. Therefore, the optimal assembly task allocation scheme under the production demand can be derived through simulation to improve the production balance rate and production resource utilization of the assembly line [3-4].

II. INTRODUCTION OF RELEVANT CONCEPTS

Multi-species small-lot refers to a production mode in which the object of production has a large number of product types, models and sizes, while the order or production volume of each product is relatively small, and this production mode is commonly found in small and medium-sized enterprises. Compared with the mass production mode, the multi-species low-volume production mode is less efficient and more expensive, and its production planning and organisation is more complicated due to the diversity of customer orders[5-6]. However, in the consumer market, consumer demand is becoming more and more diversified, not only for the production output of the manufacturer, but also for the diversification and personalisation of products. The ability to high efficiency, low cost, high quality, short cycle time for more varieties of small batch production has become more and more the key to victory for each enterprise. The characteristics of multi-species small-lot production include: (1) parallel production of multiple varieties; (2) sharing of production resources; (3) uncertainty of order results and production lead time; (3) uncertainty of order results and production lead time; and (4) material requirements are variable and purchasing may be severely delayed.

Workshop equipment layout includes four typical forms: product layout, process layout, group layout and fixed layout[7-8].

The principle of product layout is commonly used in mass production with fewer varieties, such as automobile production line. This layout structure is compact, simple operation, lower production cost per unit of product, less work in progress, high production efficiency.

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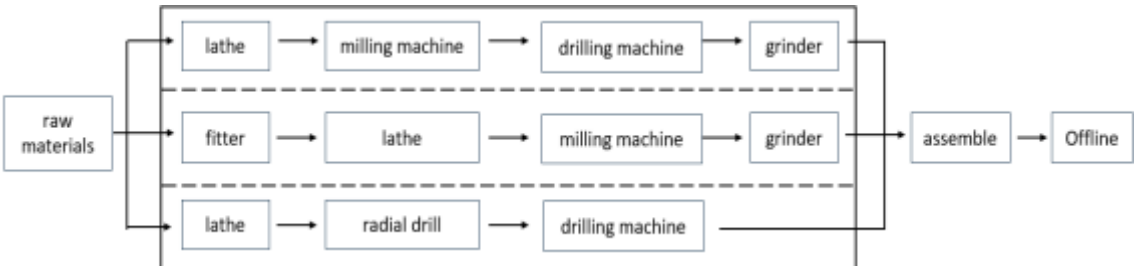
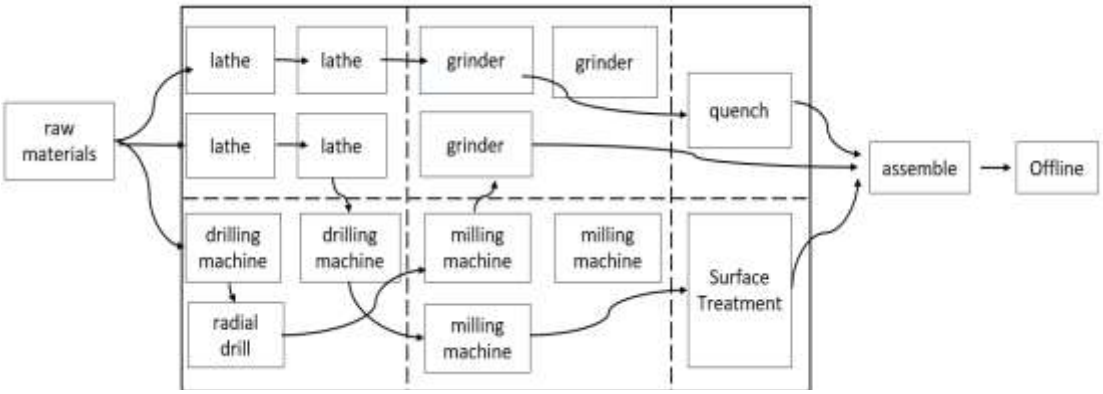


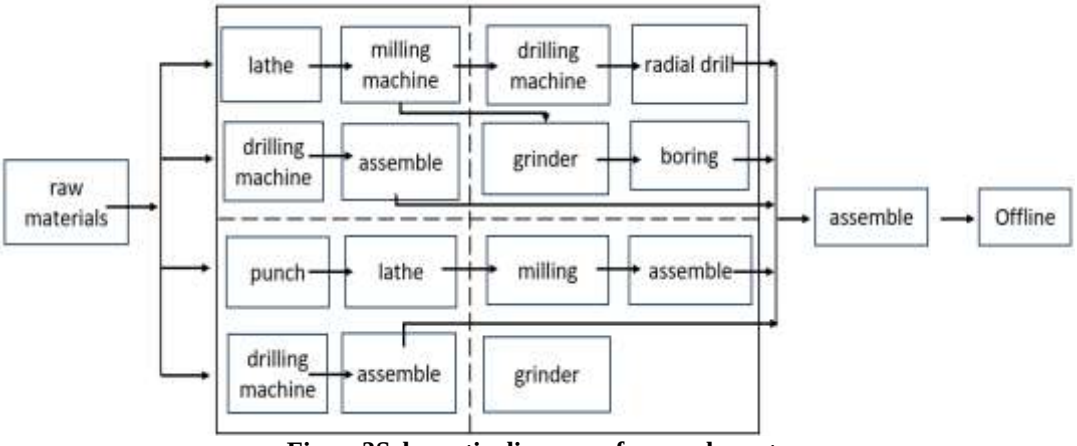
Figuer1 Schematic diagram of product principal layout

The process principal layout refers to the layout of setting up the same machines and equipment and production functions in the same production operation unit according to the process flow of product production. Its biggest advantage is that the equipment has greater flexibility.



Figuer2Schematic layout of the process principle

Group layout is a combination of product layout and process layout, which is a more advanced form of layout today. Its basic components are part families and equipment families.



Figuer3Schematic diagram of group layout

Fixed layout is mainly used for large machined parts, such as aircraft, rockets and ships. Its general significance applies only to the production of large single-piece assemblies, which will not be described here.

Choosing the right layout model is critical to the market. The following table briefly compares the characteristics of the above four types of layout form situation, in the subsequent layout design needs to be based on the actual situation to choose to adjust the appropriate enterprise production layout.

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Table1 Comparison of the characteristics of the four layout forms

Type / Features	Product Layout	Process Layout	Group Layout	Fixed Layout
Production Time	Short	Long	Short	Middle Level
Technical Requirement	Low	High	Middle Level	Low-high
Product Flexibility	Low	High	Middle Level	High
Material Handling	Simple	Complicated	Middle Level	Middle Level
Inventory Requirements	Low	High	Low	-
Equipment Utilization	High	Middle Level	Middle Level	Middle Level
Space Utilization	High	Low	Middle Level	Low
Investment Cost	High	Low	Low	Low
Investment Cost	Low	High	Middle Level	High
Equipment Maintenance	Difficult	Easy	Middle Level	-

From the above several traditional layout forms, each layout has its own advantages and disadvantages, in the MTO-type enterprises can adapt to the rapid changes in the product of the flexible layout has become more and more important, about the flexible layout in recent years has also put forward a number of other layouts, such as reconfigurable layout, fractal layout and agile layout and etc.[9-10]. The establishment of reconfigurable layout prototypes according to the changes in processing parts, to achieve all the processing activities can be parallel operations, rapid response to market demand and changes, to achieve rapid corporate restructuring is the common goal of the future layout design researchers.

Plant Simulation is a powerful system simulation software developed by Siemens for production, logistics and engineering simulation of discrete event systems.The advantage of Plant Simulation lies in the fact that it breaks away from the previous process-oriented simulation paradigm by adopting a broadly object-oriented, graphical and integrated simulation modelling approach.Plant Simulation has the following significant advantages over other simulation software[11-12]:

It is an object-oriented, graphical, integrated simulation software.

Graphical, integrated, and intuitive user environment to observe animations without waiting for the modelling to be fully completed.

Fully object-oriented, hierarchical modelling process that is easy to understand and flexible;

The high modelling accuracy allows the user to describe the model at any level of detail required, from shop floor layout to equipment structure, the plant simulation provides an infinitely accurate description;

With inheritance, modules can be inherited and copied from each other, and the relevance can be selected according to individual needs, which can greatly save the modelling time of complex systems;

III. CONCEPTSPROBLEM DESCRIPTION AND INDICATOR DEFINITION

The case plant of this paperis a typical order-oriented (Make to Order, MTO) production enterprise, whose production is driven by customer orders. The original production line of the company is designed in accordance with the layout of the process principle. The machine utilisation rate of the production line is high, which can reduce the number of equipment and adopt general-purpose equipment with a high degree of flexibility of equipment and personnel, and it is convenient to change the product varieties and quantities with a relatively small investment in equipment and diversification of the operators' work, which can improve the staff's enthusiasm and sense of occupational satisfaction. However, the workstations of the production line are relatively independent, lack of production line concept, uncertainty of logistics handling routes, and chaotic production control, which leads to a series of problems such as low production efficiency, low

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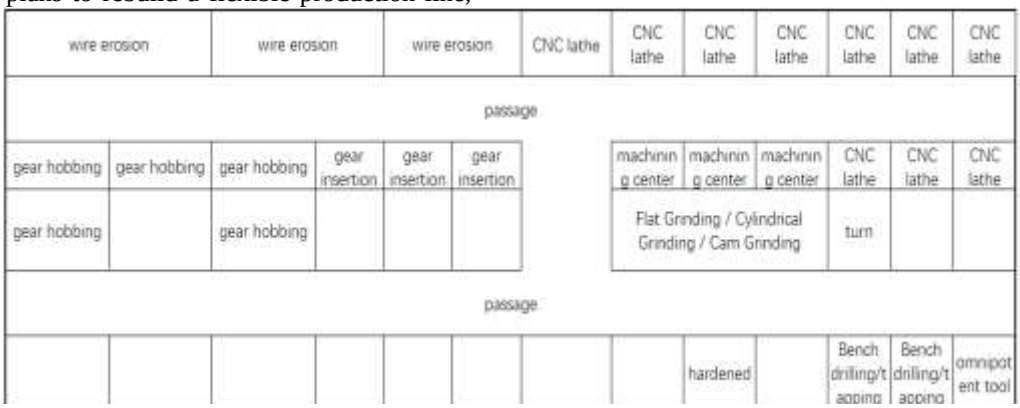
on-time delivery of orders, and long production cycle. With the increase in the number of orders and the limitation of the production line capacity, the company plans to rebuild a flexible production line, which is mainly used for the production of XBS-40, XBS-50 and XBS-60 products.



Figuer4 Layout of the original production plant

This paper carries out a preliminary simulation analysis of the production line using factory simulation software based on the collected process documents and layout documents. The basis of the thesis to judge the advantages and disadvantages of the workshop layout is to minimise the total cost of workshop logistics, so it is necessary to understand the overall situation of the workshop logistics, which mainly includes the processing technology of the product, the spacing of the workshop equipment, the types and quantities of the processed parts, and the way of material handling. Since the original production line produces a wide range of products, the product with the highest output in the year, XBS-60, was selected as the workshop logistics. The representative product XBS-60 is selected, and the related equipment for producing its three main parts (cam, flexible gear, rigid gear) are used as simulation objects to study its production capacity, equipment utilisation, production bottlenecks, etc. The equipment and parameters involved in XBS-60 are as follows:

Table2 Parameters of XBS-60 production-related equipment

Serial No.	Equipment code	Device Functions	Overall Dimensions
1	C6120	Semi-precision Turning	1600×1122
2	C6132	Turning, Convex Turning	1600×1122
3	C6140	Semi-precision Turning, Turning	1600×1122
4	T200	Turning, PrecisionTurning	1200×1000
5	CL20	Precision Turning	1100×1124
6	CV56	Benchwork	1507×1125
7	CV56A	Benchwork	1507×1125
8	GZ156	Convex Grinding	1700×1037
9	M7130	Flat Grindstone	1700×1128
10	AR120	Wire Erosion	1164×1125
11	YK3610	Hobbling	1500×1140
12	KM5112	Gear Shaper	1600×1131

The judgement of the advantages and disadvantages of the workshop layout is based on the highest capacity of the workshop, so it is necessary to understand the overall situation of the workshop logistics, including mainly the processing process of the product, the type and number of processed parts, equipment processing time. The following is the process of the three major parts of XBS-60:

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Table3 Process flow of Cam

Cam			
Process	**Equipment**	**Jig**	**Processing Time**
Through Raw Materials	-	-	-
Turning	C6132	Three-clawed	20
Precision Turning	T200	Three-clawed	20
Convex Turning	C6132	Arbor	12
Cam Grinding	GZ156	Taper Arbor	15
Wire Erosion	AR120	Arbor	15
Benchwork	CV56A	Three-clawed	5

Table4process flow of Flexible Gear

Flexible Gear			
Process	**Equipment**	**Jig**	**Processing Time**
Through Raw Materials	-	-	-
Semi-precision Turning	C6140	Three-clawed	25
Turning	T200	Three-clawed	20
Turning	C6140	Three-clawed	10
Benchwork	CV56A	Three-clawed	19
Flat Grinding	M7130	Magnetic Disk	9
Turning	T200	Arbor	40
Gear Hobbing	YK3610	Arbor	90

Table5 process flow of Rigid Gear

Rigid Gear			
Process	**Equipment**	**Jig**	**Processing Time**
Through Raw Materials	-	-	-
Semi-precision Turning	C6120	Chucks	15
Benchwork	CV56	Chucks	28
Flat Grinding	M7130	Magnetic Disk	10
Precision Turning	CL20	Workwear	20
Gear Insertion	KM5112	Workwear	60

The definition of simulation metrics helps the analysis and evaluation of subsequent simulation runs regarding the advantages and disadvantages of the layout scheme, therefore, three major simulation optimisation metrics are defined.

capacity: the same processing time, the greater the number of products produced, the greater the production capacity, the greater the economic benefits obtained by the enterprise, the enterprise production goal is to achieve high capacity and low cost, so the capacity is also an important indicator of the workshop equipment layout;

equipment utilisation: equipment utilisation refers to the percentage of total time spent on

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equipment processing in the whole process, the higher the equipment utilisation, the higher the number of products produced, the lower the waste, the higher the production efficiency of the enterprise. There are many factors affecting production efficiency, including waiting, blocking, failure, etc..

Bottleneck process: usually the slowest production beat in a process called "bottleneck", more broadly speaking, the bottleneck refers to the entire process of constraints on the output of the various factors, and the bottleneck process as the name suggests is to constrain the output of the entire production line of that part of the work steps or process. Finding the bottleneck process is important for the improvement and design of the production line.

IV. MODELING AND ANALYSIS

Process layout discrete production workshop logistics is more complex, each product has a separate process route, in order to make the modelling work smoothly, and ensure that does not affect the conclusions of the premise of the analysis, the production model needs to make the following assumptions:

①Raw materials are able to arrive on site in a timely manner and there are no stock-outs;

②Neglecting preparation time for processing;

③The equipment failure rate is 0 and the worker attendance rate is 100 per cent;

④Neglect to produce substandard products.

⑤The maximum storage stock at the line edge is 50.

Plant Simulation provides a series of basic units for constructing simulation models, which can be grouped into two categories: physical modelling units and information processing units. Some of the physical modelling and information processing modules are introduced here briefly.

Table6 Selected unit modules

Serial No.	Physical Module			Information Module		
	Icon	Name	Representative	Icon	Name	Representative
1		Entity	Products		Method	Control Programme
2		Singleproc	Equipment		Tablefile	Data Sheet
3		Connector	Process Route			
4		Source	Putting in Raw Materials			
5		Drain	Put It in Storage			
6		Buffer	Buffer Stock			

According to the XBS-60 parts process flow, you can create the following model and set the corresponding parameters. According to the XBS-60 Cam, Flex Gear and Rigid Gear Process Flow Card, create three parts, Cam, Flex Gear and Rigid Gear, in the model, and follow the cycle of 10 parts per batch, starting from the drop-off point, with a total production time of 1,000 hours. The blue path indicates cam production, the red path indicates flexible Gear production, and the green path indicates rigid Gear production. Since there is cross-interference between the equipment used in the production of the three parts, it is necessary to write a programme to control the processing time of the relevant equipment as well as the material flow.

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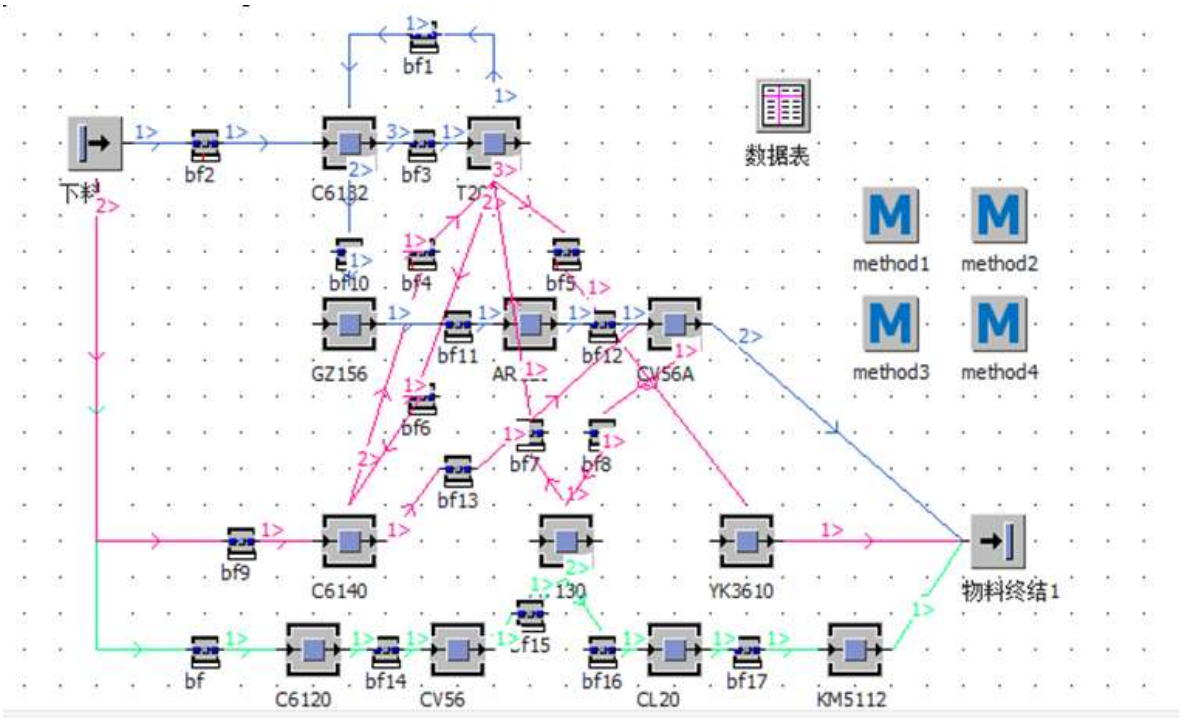

Figuer5 2D diagram of the simulation model

Start running the model with 1000 hours as a logistics calculation cycle and the simulation results are shown in Figure6

已删除 Drain 的零件的累积统计

对象	名称	平均使用寿命	吞吐量	TPH	生产	运输	存储	值已添加	部分
物料终结1	凸轮1	5:05:26:28.9540	717	1	1.77%	0.00%	98.23%	1.16%	
物料终结1	刚轮1	1:07:16:50.8537	820	1	7.58%	0.00%	92.42%	7.09%	
物料终结1	柔轮1	7:16:07:38.3710	663	1	2.96%	0.00%	97.04%	1.93%	

Figuer6Cumulative statistics of original production line parts

It can be seen that 750 cams, 952 rigid Gears and 663 flex Gears can be produced in 1000 hours. The number of XBS-60 products that can be produced in 1000 hours is 663, constrained by the production of flex Gears.

对象	工作中	设置	等待中	已阻塞	上电/掉电	失败	已停止	已暂停	未计划	部分
C6132	40.01%	0.00%	0.00%	59.99%	0.00%	0.00%	0.00%	0.00%	0.00%	
T200	95.57%	0.00%	0.03%	4.40%	0.00%	0.00%	0.00%	0.00%	0.00%	
GZ156	17.93%	0.00%	82.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
AR120	17.93%	0.00%	82.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CV56A	28.65%	0.00%	71.35%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
C6140	43.97%	0.00%	0.00%	56.03%	0.00%	0.00%	0.00%	0.00%	0.00%	
M7130	24.41%	0.00%	75.59%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
YK3610	99.60%	0.00%	0.40%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
C6120	20.50%	0.00%	79.00%	0.51%	0.00%	0.00%	0.00%	0.00%	0.00%	
CV56	38.27%	0.00%	61.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CL20	27.33%	0.00%	60.77%	11.89%	0.00%	0.00%	0.00%	0.00%	0.00%	
KM5112	82.00%	0.00%	18.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figuer7 Statistical report on original production line part

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The Plant Simulationsimulation statistics report shows that there are blocking situations in equipment C6132, C6140 and CL20, indicating that the processing capacity of the subsequent process T200 is insufficient. At the same time, except for T200, YK3610 and KM5112, whose processing time share is above 80% of the time, the processing time of the rest of the equipment is low.

In summary, the bottleneck process of the production line exists in T200, YK3610, KM5112. it can be improved by adding equipment, adjusting the existing equipment, or improving the capacity of the equipment.

The improvementof the production system are as follows:

①Increasing equipment capacity is the least costly way to improve, and by optimising the machining process and rewriting the equipment machining code, it is possible to shorten the equipment operating time. However, this method has a limited effect on the improvement of the production line.

②Adjustment of existing equipment is the effect of improving and increasing production capacity by reprogramming underutilised equipment to process in place of equipment with higher loads, but not all processing of highly loaded equipment can be replaced, so the use of this option is limited. The method is also less costly.

③Adding new key equipment is the most costly option, but the implementation of this option is usually less constrained. Additional equipment is purchased for equipment with excessive workload and frequent clogging in the front process. Adding key equipment is the most cost-effective way to increase the capacity of the production line.

The above three options in the implementation process, often a combination of three ways to use, from improving equipment capacity, adjusting existing equipment, adding new key equipment to implement, can maximise cost savings, but also maximise the capacity to improve.

V. DISCUSSION

Since options one and two should be combined with the actual to judge whether it can be implemented, so we here take option three to reflect the improvement effect. T200, YK3610, KM5112 are purchased, in the simulation model to reduce the corresponding equipment by 50% of the machining time means to add a device, reduce the machining time by 66% means to add two and so on. By repeating the adjustment, it is finally determined that it is most reasonable to add two sets of T200 and YK3610 equipment and one set of KM5112 equipment.

Table7 Parameter modification

Equipment	Pre-improvement	Improved
T200	if @.name="凸轮1" ?.ProcTime:=1200 elseif @.n=0 ?.ProcTime:=1200 else ?.ProcTime:=2400 end	if @.name="凸轮1" ?.ProcTime:=400 elseif @.n=0 ?.ProcTime:=400 else ?.ProcTime:=800 end
YK3610	处理时间: 常数 90:00 自动处理	处理时间: 常数 30:00 自动处理
KM5112	处理时间: 常数 30:00 自动处理	处理时间: 常数 60:00 自动处理

Run the improved model and generate statistical reports:

已删除 Drain 的零件的累积统计

对象	名称	平均使用寿命	吞吐量	TPH	生产	运输	存储	值已添加	部分
物料终结1	凸轮1	7:14:15.9065	1754	2	16.96%	0.00%	83.04%	16.96%	
物料终结1	刚轮1	6:36:41.1905	1764	2	25.98%	0.00%	74.02%	25.97%	
物料终结1	柔轮1	1:08:18:46.7251	1710	2	7.58%	0.00%	92.42%	5.83%	

Figuer8 Cumulative statistics of parts of the improved production line

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It can be seen that 1,754 cams, 1,764 rigid Gears and 1,710 flex Gears are produced in 1,000 hours, i.e. 1,710 in 1,000 hours of XBS-60 production, which is a 157.9% increase in capacity compared to the pre-improvement period.

对象	工作中	设置	等待中	已阻塞	上电/掉电	失败	已停止	已暂停	未计划	部分
C6132	93.67%	0.00%	6.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
T200	76.60%	0.00%	23.40%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
GZ156	43.86%	0.00%	56.14%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
AR120	43.85%	0.00%	56.15%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CV56A	68.83%	0.00%	31.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
C6140	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
M7130	55.11%	0.00%	44.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
YK3610	85.53%	0.00%	14.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
C6120	44.25%	0.00%	55.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CV56	82.45%	0.00%	17.55%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CL20	58.85%	0.00%	41.15%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
KM5112	88.22%	0.00%	11.78%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figuer9 Statistical report on original production line parts

At the same time, production blockages have all been eliminated, the utilisation of all equipment has increased dramatically, and the overall production line equipment is more balanced than before the improvements.

VI. CONCLUSION

Through the simulation of the parts production line of XBS-60 by Plant Simulation software, the bottleneck process and key equipment of the production line can be identified. Then by upgrading the equipment capacity, adjusting the equipment operation, increasing the number of equipment and other measures, the production capacity of the production line can be greatly increased, and the utilization rate of the equipment and the balance of the production line can also be improved.

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