Simulation Optimization of the Painting Production Line Based on Plant Simulation

Jidong Teng[1], Yongcan Piao[1], Dawei Huang[1], Wei Ai[1], and Yu Huang[2,*]

[1] Mmi Planning & Engineering Institute Ix Co., Ltd., Changchun, Jilin Province, China

[2] Beijing Digital Factory Technologies Co., Ltd., Nanjing, Jiangsu Province, China

*Corresponding Author: Yu Huang

Keywords: Simulation, Painting Production Line, Plant Simulation

Abstract: in Order to Solve the Problems of Insufficient Production Capacity and Lack of Buffer Blockage in y company's Painting Production Line, Researchers Carried out a Field Research and Collected Data on the Overall Layout, Process Flow and Equipment Parameters of the Production Line. the Simulation Model of Painting Production Line Was Established by Using the Plant Simulation Software. by Analyzing the Simulation Data Output, Causes of Insufficient Production Capacity Were Found to Provide Optimization Solutions and Measures. Comparing with the Results Before Optimization, the Capacity of the Optimized Painting Production Line Was Significantly Improved; the Buffer Blocking Was Reduced to Varying Degrees. the Research Provides y Company with Technical Supports in Making Effective Decisions on the Production Organization Management.

1. Introduction

Since 2015, with the Proposal and Implementation of the "Made in China 2025" Strategy, the Pace of Manufacturing Transformation and Upgrading Has Accelerated. through Computer-Aided Planning and Optimization, the Automobile Industry Has Built Digital Workshops and Factories to Continuously Construct the Digital, Networked and Intelligent Production Process. as One of the Four Major Processes of Automobile Manufacturing, Painting is an Important Part of the Whole Vehicle Production Process. the Painting Workshop Has Complex Logistics Planning and Design, with Many Processes and High Degree of Mechanization and Automation. Whether the Painting Production Line Can Operate Continuously and Orderly Directly Affects the Quality of Automobile Body Coating, and Can Decide Whether the Production Capacity of the Painting Production Line Can Meet the Demands in Some Sense.

The Painting Production Line is a Typical Discrete Event System, Which Has the Characteristics of Randomness and Concurrency. Compared with a Series of Heuristic Algorithms Such as the Mathematical Planning, the Genetic Algorithm and the Ant Colony Algorithm, the Simulation Method Can Reduce the Difficulty and Complexity of the Research, and Has Higher Feasibility and Operability. At Present, Software Which Can Realize the Simulation of Automobile Production Line Includes Witness, Flexsim, Automod and Plant Simulation. the Plant Simulation is an Object-Oriented Simulation Software. in Addition to the Rich Object Library, It Can Also Realize the Simulation of Control Strategy through the Simtalk Language. Its Hierarchical, Structured and Modular Modeling Mode Makes the Modeling Process More Flexible. the Application of Simulation Software in the Production Organization Management Can Provide Reasonable Suggestions and Technical Supports for Enterprises to Make Effective Decisions.

2. System Overview

The Unpainted Car Body Produced by the Welding Workshop Enters the Painting Workshop through the "Welding, Painting and Final Assembly" Corridor. in the Painting Workshop, It Needs to Undergo a Series of Processing Treatments Such as Electrophoresis, Sealing, Drying, Base

  DOI: 10.25236/ISMHI.2019.042

Coating, Finishing Coating, Spot Repair, as Well as Repair and Wax Injection, and Then Enters the Final Assembly Workshop. the Painting Workshop of the y Enterprise Has 4-Layers, with the Heights of 0 m, 9.3 m, 14.8 m and 17.55 m for Each Layer. All Layers Are Connected by Elevators. the Car Bodies and Skids Are Transported between Each Layer Repeatedly, Forming an Assembly Line Operation. the 5-Lane Three-Dimensional Warehouse in the Workshop Serves as the Conventional Storage Area Behind the Drying Line; Each Lane Has a Stacker to Perform the in and out Operation.

The painting production line of Y enterprise is 3C2B, namely the “wet touch wet” line. The car body is painted with three layers of baked twice; and the base coating layer and floating coating layer are dried together. The process includes the pre-treatment line, the electrophoresis line, the floating coating line, the finishing coating line and so on. The brief process flow is shown in Figure 1. Processing lines 1, 2, 4 and 5 are located at the 9.3m layer; processing lines 3, 6, 7 and 8 are located at the 0m layer. The processing line 9 is located at 14.8m layer. There is no processing line at 17.55m layer.

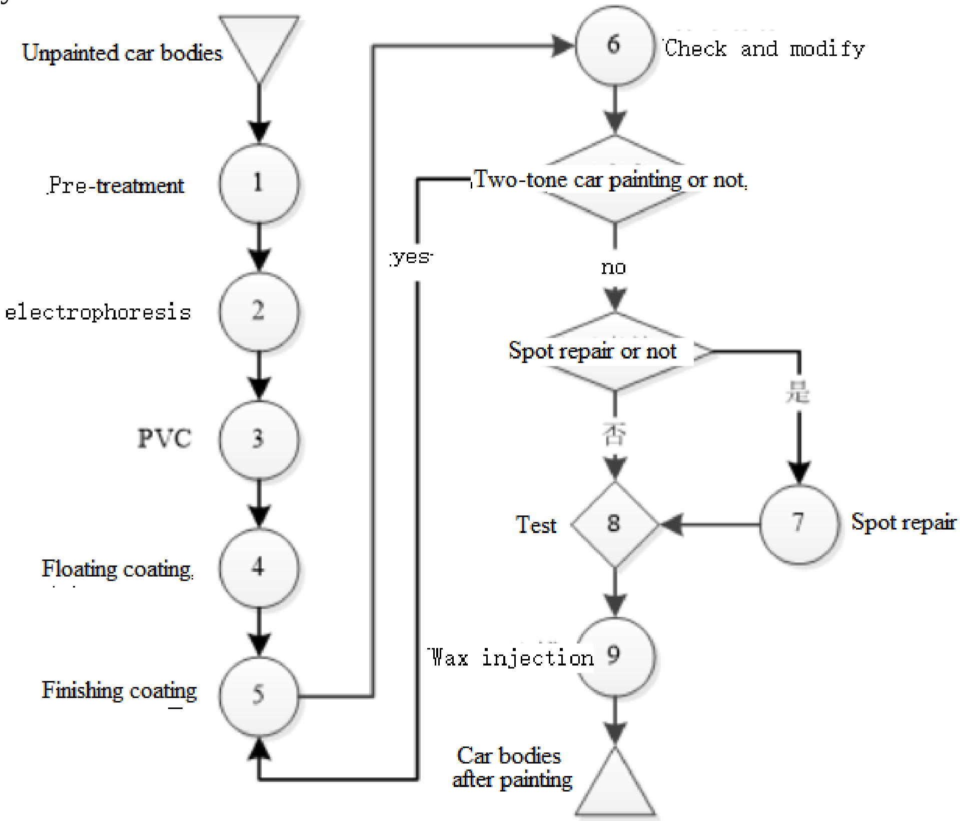


Fig.1 Process Flow Diagram.

3. Establishment of the Painting Production Line Simulation Model

The painting production line of the Y enterprise is similar to that of other assembly line workshops, except for the storage area of three-dimensional warehouses instead of the common roller beds. The modeling and simulation of the painting production line are mainly carried out from the following perspectives.

3.1 Data Collection and Sorting

According to historical data of the Y enterprise, the hourly production capacities of the HE welding workshop and the H welding workshop are 18 JPH and 9 JPH respectively. The coating production line works 250 days a year, 16 hours a day, and the planned annual output is 100,000 qualified vehicles. Specific parameters of the coating process are shown in Table 1.

Table 1 Table of Process Parameters.

Process	Name	Takt /min	Pitch /m	Speed of transportation	Operation rate/%
F_9m3.PTRoDipM	Pre-treatment device	2.28	6.75	2.97	95.0
F_9m3.ECRoDipM	Electrophoresis device	2.28	6.75	2.97	95.0
F_9m3.EC_Holding	Electrophoresis drying	2.28	5.5	2.42	95.0
F_9m3.EC_Colding	Strong cooling with electrophoresis	2.28	5.5	2.42	93.0
F_0m.EC_Sanding	Electrophoresis polishing	2.28	5.5	2.42	93.0
F_0m.PVC	Primer spraying	2.23	6.6	2.96	93.0
F_0m.Coarse_sealing	Coarse sealing	2.23	6.6	2.96	93.0
F_0m.Damping	Liquid damping spraying	2.23	6.6	2.96	93.0
F_0m.Fine_sealing	Fine sealing	2.23	6.6	2.96	93.0
F_14m8_16m5.WAX	Wax spraying	2.02	6.6	3.28	93.0

The three-dimensional warehouse in the painting workshop is composed of five double deep racks with four rows and seven layers. Each rack has 56 storage spaces (the size is 6 * 2.9 * 2.75 for each unit). The vehicle body needs to enter and exit the three-dimensional warehouse through the roller bed; the access positions are different. Therefore, normally, each rack can store less than 56 vehicles; the specific numbers are different. Parameters of the rack are shown in Table 2. There are two values of the vertical speed and vertical acceleration of the rack; No. 4 and No. 2 racks take the larger values; No. 5, No. 3 and No.1 racks take the smaller values. Other parameters are the same.

Table 2 Parameters of Racks.

rack	capacity	Stock - in position	Stock - out position	Storage content
No.5	51	(21,9.8)	(3,15.3)	Painted car body; two-tone car
No.4	52	(9,9.3)	(9,0.9)	Finishing coating car body; Painted car body
No.3	49	(9,9.8)	(9,0.9)	Floating coating car body
No.2	45	(9,0.9)	(21,18.05)	Electrophoresis car body
No.1	50	(3,9.8)	(9,0.9)	Electrophoresis car body

Table 3 Parameters of The Stacker.

Parameters	value
Horizontal and vertical speeds	120; 35 or 60m/min
Horizontal and vertical acceleration	0.5; 0.3 or 0.5m/s2
Fork expansion speed (no load, full load)	120; 60m/min
Pick and delivery time	11.79s

3.2 System Simplification and Assumption

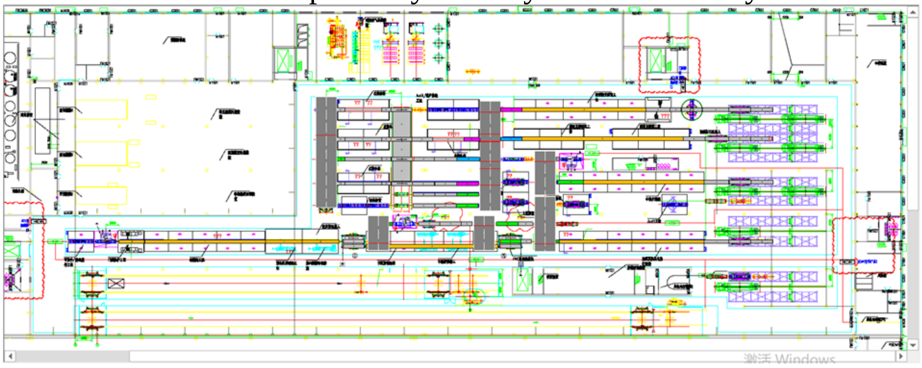
The welding and assembly plants are not the research objects. We only carried out the simplified modeling through Source, Assembly, Buffer, Drain and other objects; the secondary use of the welding skid was not considered.

3.3 Construction of Objects and Modules

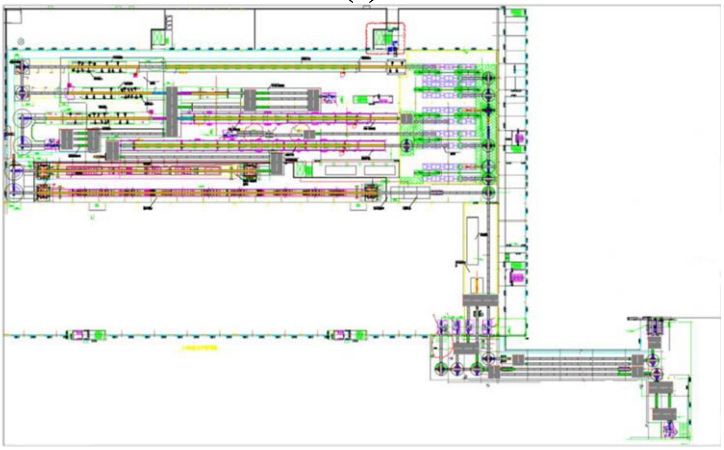
Objects needed for modelling, including the unpainted car bodies, skids, trays, roller beds (ordinary roller beds and process section roller beds), turntable and others, were added into the new folder of the object library. Areas near the bidirectional roller bed could be occupied by relative logistic objects at the same time. In order to avoid congestion, it is necessary to follow the principle of “first in, first out” in the establishment of the control module. According to the actual operation situation, the equipment and operations such as the transitional machine, the elevator, the stacking and de-stacking, as well as the skid changing should be constructed as separate modules, which are convenient for direct use in the modelling and can improve the accuracy and flexibility of modeling.

3.4 Modelling of the Production Line

Taking the layout of the painting production line as the background of two-dimensional modeling and according to the sequence of process flow, the simplified model with four sub models of the painting production line, two welding workshops and one general assembly workshop were established in the Plant Simulation respectively. The layout of the 4-story structure is as follows.



(a)



(b)

Fig.2 Layout of the Painting Production Line.

3.5 Modelling of the Three-Dimensional Warehouse

The ASRS module was constructed; the input parameters of the three dimensional storehouse were diversified and miscellaneous. In order to facilitate the assignment of parameters and the statistics of results, the Dialog operation interface in Figure 3 was set, and the SimTalk language programming was used to realize the stock in strategy, the stock out strategy, the storage strategy, as well as the stackers' operation process and scheduling strategy. The interface can operate and directly control them. At the same time, in order to strengthen the visual effect, the three-dimensional model of the three-dimensional storehouse was built by programming. The 3D simulation model of the three dimensional storehouse is shown in Figure 4.

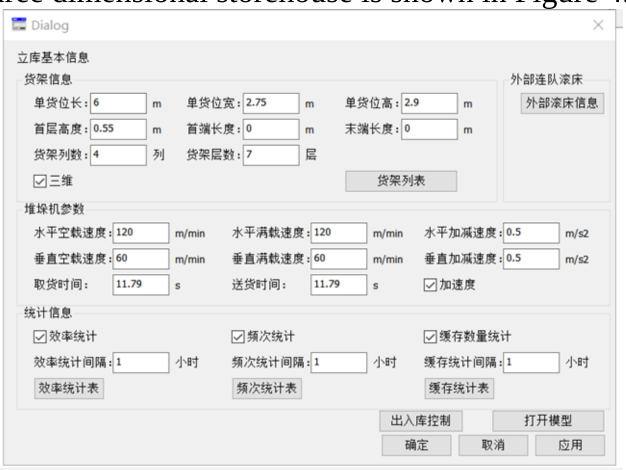


Fig.3 The Operation Window of Asrs Module.

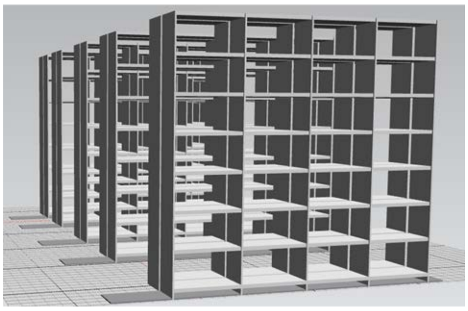


Fig.4 Interface of the 3d Simulation Model of the Three Dimensional Storehouse.

When the stacker is searching for the storage location, the car body shall be stored according to the following storage strategies. Firstly, the search range is the 1-7 layers of the rack. Secondly, in the vertical direction, electrophoresis, floating coating and finishing coat car bodies shall be kept clean during the storage, so it is preferred to search from the 7th layer; car bodies after painting should be searched from the 1st layer. Thirdly, in the horizontal direction, after painting, the car bodies move in from the left side and move out from the right side; car bodies after electrophoresis, floating coating and finishing coating move in and out from the left side. In order to reduce the walking distance of the stacker, the nearest warehouse exits shall be preferred when finding the storage location.

In order to improve the universal property of the model, and better manage input parameters such as production takt, equipment failure, working shift and the number of buffer in the delivery port, the DataBase module was built.

3.6 Model Debugging and Verification

In the top-level model, “Interface” was used to connect the interrelated sub models to form a complete simulation model. After the model was built, it needed to be improved and revised in the process of debugging, so that the simulation model and the real system were consistent in process and operation logic. The interface of the two-dimensional simulation model is shown in Figure 5.

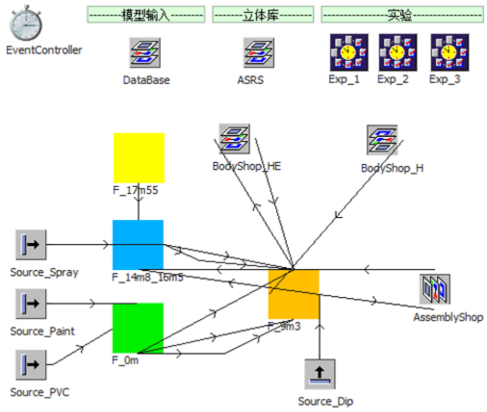


Fig.5 Interface of the 2d Simulation Model of the Painting Production Line.

4. Operation of the Simulation Model and Analysis

The time unit of the model is minute. In consideration of the equipment operation rate and working shift, the simulation time of the event controller was set as 31 days, in which the first day was the preheating of the model. Model running and data collection began from the second day. The statistical information of the object AssemblyShop.Drain_Car is shown in Figure 6. From the hourly throughput of 18.06, it can be calculated that the coating production line cannot meet the requirements of painting 100,000 qualified vehicles annually. This simulation result is the same as the actual production situation of the coating production line.

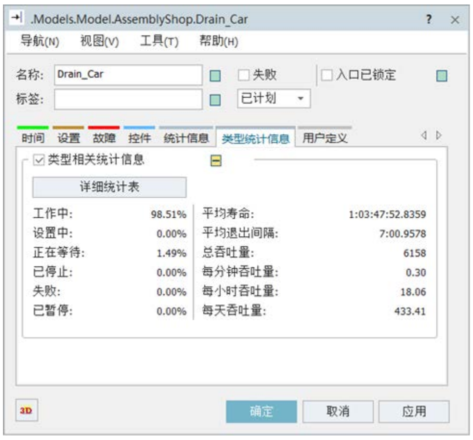


Fig.6 Simulation Results.

After verifying the production capacity of the coating line, the efficiency of the stacker and the number of sack buffers were further analyzed. The former reflects the busy degree of the stacker; the latter analyzes the inventory of the three-dimensional warehouse at different times. The stacker efficiency calculation formula is as follows, in which t_{pick} and $t_{delivery}$ represent the pick-up time and delivery time of stacker respectively, and $t_{avinterval}$ represents the time interval of efficiency statistics.

$$\text{availability} = \frac{\sum t_{pick} + \sum t_{delivery}}{T_{\text{AvInterval}}} * 100\% \tag{1}$$

The statistical time intervals of efficiency and cache quantity were set as 1H; the model also ran for 31 days. The trends are represented by line graphs.

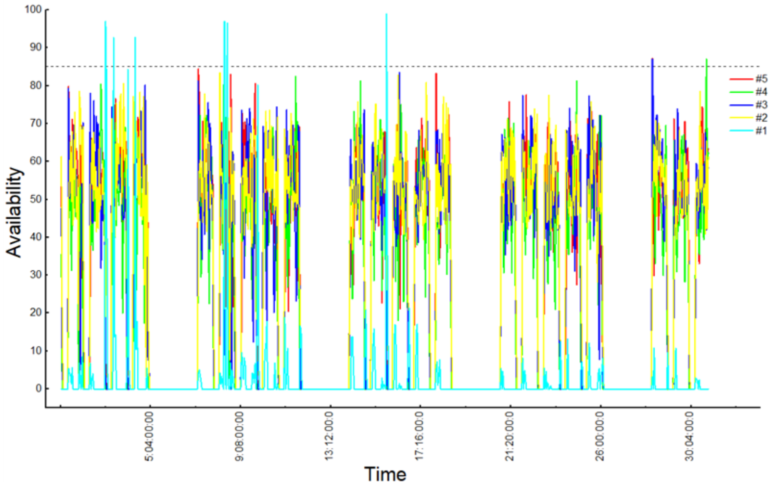


Fig.7 Efficiency of Stackers.

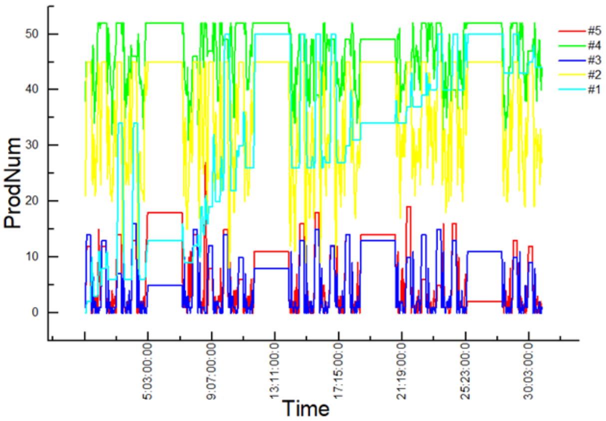


Fig.8 Average Caches.

It can be seen from Figure 7 that the average efficiencies of No. 4, No. 3 and No. 2 stackers fluctuated relatively slightly. The average value of the average efficiency is more than 50%, which is determined by the relatively single task performed by the stacker. Although No. 4 also undertakes the transfer of the finishing coating car bodies, its exit is at the 9.3m layer, rather than the highest layer. So No. 4 stacker has relatively short walking distance. The No. 5 and No. 1 fluctuate relatively greatly. The average efficiency of No. 5 is more than 80% when it is the highest, which is lower than the standard line of 85%. The reason is that both stackers undertake a special task: transferring finishing coating bodies and moving electrophoresis car bodies between the warehouses.

The Figure 8 records the changes in inventory for five sacks. The average buffers of No. 2 and No.1 sacks are high, close to the maximum buffer. It is caused by the condition that capacities of the pre-treatment process and the electrophoresis process are much higher than those of subsequent processes. No. 2 sack stores directly stock-in bodies after electrophoresis drying, as well as electrophoresis car bodies transferred from No.1, which is also the reason of high average buffer.

The above analysis results show following conclusions. First, the current number of storage locations can barely meet the needs of normal production. Once there is an abnormal situation, the requirements will not be satisfied. Second, the existing three-dimensional warehouse cannot achieve the function of color sequence adjustment, and the additional cost is needed to increase the storage area capacity. On the whole, the utilization rate of the three-dimensional warehouse is high; there is basically no vacant location under normal conditions. But the flexibility is low. If some cars are stopped for a long time, the storage locations will be insufficient. The problem needs to be solved by working overtime. It indicates that the three-dimensional warehouse has certain defects.

5. Simulation Optimization Design and Analysis

JPH refers to hourly workload, and the calculation formula is "JPH = total workload / total working hours". Therefore, the improvement of JPH can be carried out from improving the total workload and reducing the total working time. Specific measures include improving the production capacity through improving the line speed and reducing bottlenecks, as well as reducing the time of failure or shutting down from the equipment, process, quality and other aspects. Based on the capacity verification and analysis of the three-dimensional warehouse, and combining with the characteristics and limitations of the painting production line itself, the following adjustments and optimizations are made.

The first measure is to reduce the production takt of the process section and improve the equipment operation rate; the repair rate is reduced from 10% to 5%.

The second measure is to extend the length of the "inspection and decoration" station by about 16m, expand the floating coating drying room by 11m and expand the finish coating drying room by 16m. The floating and finishing coating strong cooling rooms are changed to the horizontal position. The first row of the storage places on the left side of No. 5 sack is cancelled.

The third measure is to add roller beds as the buffer area in the part connecting the process section and the three-dimensional warehouse to reduce the pressure of the stacker and the three-dimensional warehouse. Accordingly, the storage roller beds, storage positions and maximum capacities of the three-dimensional warehouse should also be modified.

The fourth measure is to unify all parameters of stackers. The vertical speed and vertical acceleration of No. 5, No. 3 and No. 1 stackers also take the larger values.

According to above optimization measures, the simulation model is modified and operates for 31 days under the same conditions. The simulation results in Figure 9 show that the hourly production capacity of the coating production line can be increased to 25 JPH, 41.58% higher than that before optimization. The optimization measures are effective.

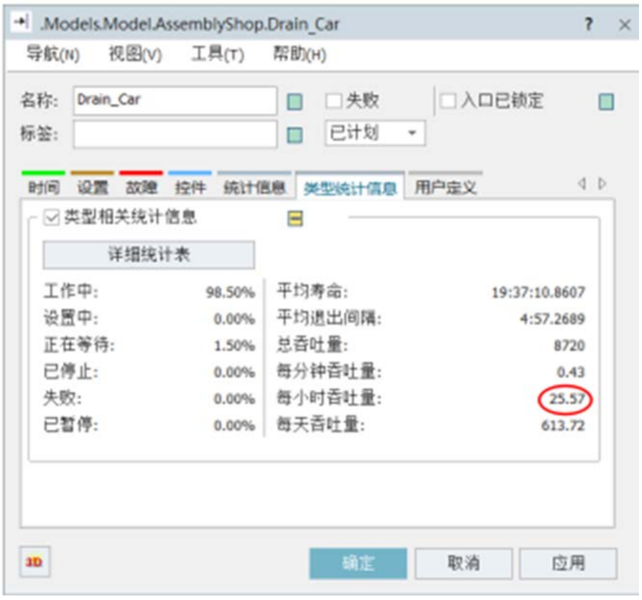


Fig.9 Simulation Results after Optimization.

On the basis of verifying the feasibility and effectiveness of the optimization scheme, the optimal number of vehicles is calculated by the experimental manager of Plant Simulation. Carries in the coating production line of Y enterprise include 3 kinds of skids and 1 kind of tray, among which the recovery routes of PVC tray and wax spray skid are relatively short, so they are not considered as dependent variables of this experiment. The study only considers the influence of the number of base coating skid and finishing coat skid on the coating output. The quantity range is as follows.

Table 4 Skid Classification.

Object	Name	Rang of number	Cost (ten thousand yuan)
Skid_Dip	Base coating skid	80~90	9100
Skid_Paint	Finishing coat skid	140~150	7900

In order to reduce the influence of randomness on the experimental results, each group was observed for three times. The statistical information of the experiment output is as follows.

Table 5 Summary of Optimal Results of the Experiment.

group	Base coating skid	Finishing coat skid	Coating JPH	Cost (ten thousand yuan)
one	90	140	25.098	192.50
two	90	140	25.098	192.50
three	82	148	25.098	191.54

Before the simulation, the number of primer skids and finishing coat skids in the painting production line is (100160); the cost is 100 × 9100 + 160 × 7900 = 2.174 million yuan. The cost of the optimal solution (82,148) of the experimental results is 1.9154 million yuan. Therefore, the decision-making provided by the simulation results can save 30 skids and 258,600 yuan for the Y enterprise.

6. Conclusion

In the actual production process, there are many factors that affect the painting capacity and the operation of the three-dimensional warehouse. The diversity and complexity of factors and as well as the randomness of the coating production line itself make the research more complex. With the help of the Plant Simulation software, the simulation model of coating production line of Y enterprise is established. Through the analysis of simulation output and combining with existing resources and production conditions, the optimization direction and specific measures are put forward. The feasibility and effectiveness of the optimization scheme are verified by comparing the production capacity of the production line before and after the optimization. Problems such as insufficient production capacity and blocking in the buffer area are solved. The research provides a good model and guidance for automobile manufacturing enterprises to make full use of existing resources on the coating production line, in order to improve production efficiency and capacity, and reduce production costs.

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