Research on the Modeling and Balance of Satellite Assembly Line Based on Plant Simulation

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Abstract: In order to design satellite assembly line reasonably and make the rhythm of production line design meet the production demand, this paper based on Plant Simulation software, through a case study of satellite assembly line modeling analysis, found the shortcomings of the design process and satellite assembly line bottlenecks, and through the simulation analysis results of the production line balance analysis, put forward the satellite assembly line design optimization strategy, so as to further improve the pace of the satellite assembly line, to effectively improve the efficiency of the satellite assembly line.

1. Introduction

With the rapid development of aerospace field in recent years, the traditional single satellite production mode has gradually transited to the satellite mass production mode, so satellite assembly line is needed to meet the needs of future satellite batch production. In the process of satellite assembly line design and implementation, the evaluation index is mainly reflected in its beat index. Therefore, it is particularly important to combine the actual conditions with the actual demand, and to optimize and design the production line to make its beat meet the production demand.

This paper studies the modeling of satellite assembly line, analyzes the key links of production line operation, and provides theoretical support for site optimization, production line balance and other issues involved in the production process.

2. Station design of satellite assembly line

The whole production line consists of 13 general assembly test stations and general production support units. According to the layout design of production line and site calculation and analysis. Among them, the operation plan and time of the auxiliary line support unit are not included in the assembly time of the production line, and the production can only be carried out according to the production line capacity matching.

According to the survey, the current production line planning, the production line uses off-duty or weekend maintenance, to ensure the stable operation of the production line in the working day.

Effective working time of the whole year is D_S days (excluding weekends). Meanwhile reserve D_r days allowance as buffer (production line beat discontinuity or shutdown caused by product failure and other factors). The remaining effective working hours are about D_e days. According to the above table 1, the production line beat is B_e days.

$$D_e = D_S - D_r \quad (1)$$

$$B_e = Max\{\mathrm{T_i}, \mathrm{i} = 1,2,3...,13\} \quad (2)$$

Table. 1. Station Statistics of satellite assembly line

Name	Station	Workload
Assemble 1	S1	T_1
Test 1	S2	T_2
Assemble 2	S3	T_3
Test 2	S4	T_4
Assemble 3	S5	T_5
Test 3	S6	T_6
Assemble 4	S7	T_7
Test 4	S8	T_8
Assemble 5	S9	T_9
Assemble 6 Test 7	S10	T_{10}
Test 5	S11	T_{11}
Assemble 7	S12	T_{12}
Detection 1	S13	T_{13}

3. Satellite assembly line modeling based on Plant Simulation

3.1 Simulation modeling process

According to the operation logic and process of the production line, the plant simulation software is used to establish the simulation model of the production line. After the logic analysis and model simplification of the production line, in order to get the balance of the production line and extract the key elements of the production line, the plant simulation software is used to establish the production line simulation model.

According to the logic relation diagram of the production line, the logic diagram of the station between the production lines is established, and the modeling and simulation are carried out for the actual site in the production line. The process is as follows, which are:

(1) The original warehouse is replaced by the container model in the source source to represent the loading of raw materials;

(2) Station and buffer are used to replace the model in assembly station;

(3) Assembly station and buffer are used to replace the docking station;

(4) Parallel station and buffer should be used to replace the composite ability station;

(5) The whole satellite which has completed all the work on the line enters the warehouse and is replaced by the drawer model;

(6) The logical relationship of the model is established to form a complete operation process of the production line;

(7) Input the man hour and related input of each station, and set the time sequence of simulation module;

(8) Input and write simulation logic language;

(9) 3D processing of site layout, effect processing;

(10) Start the model simulation.

The logic diagram is as follows:

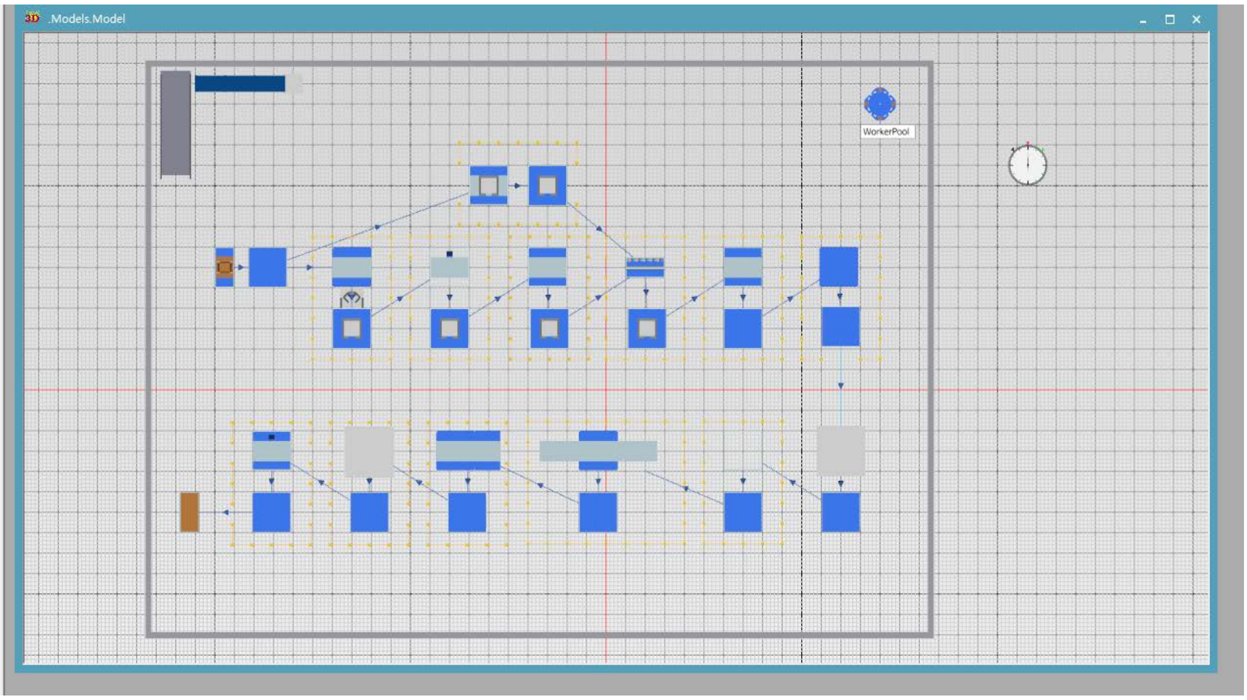

Figure 1. Plant Simulation Logic diagram of production line simulation model

The parameters of production line station work statistics are input into the production line model for simulation.

3.2 Analysis of simulation results

In the process of simulation, the fault situation, human resource allocation and order distribution are not considered temporarily. Only the working time and beat of the logistics operation process of the production line are simulated, and the simulation results are analyzed, the balance rate of the production line is compared, and the adaptive improvement suggestions are given.
The process is as follows.

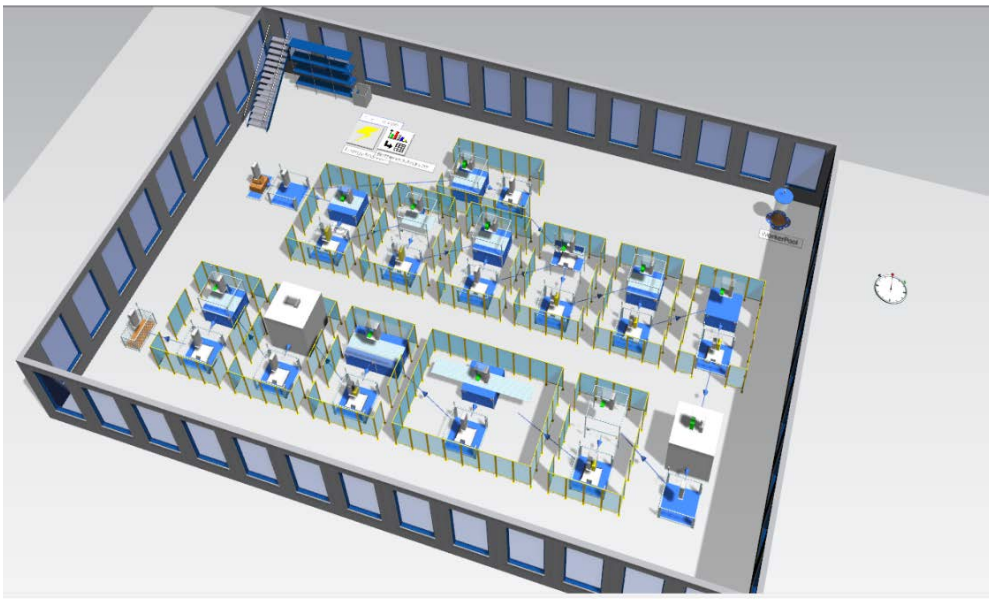

Figure 2. Plant Simulation production line simulation model process

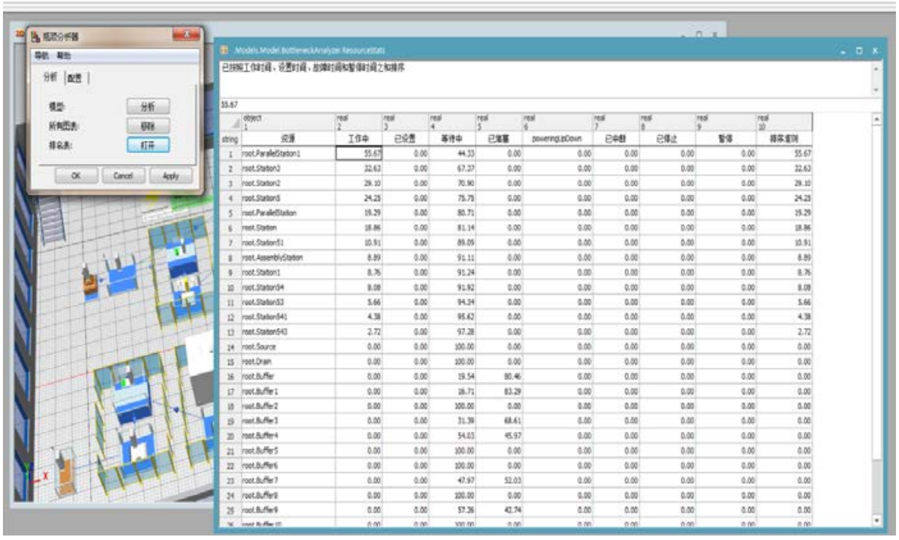

Figure 3. Plant Simulation production line simulation process data

The simulation results are analyzed as shown in the figure 4 and 5.

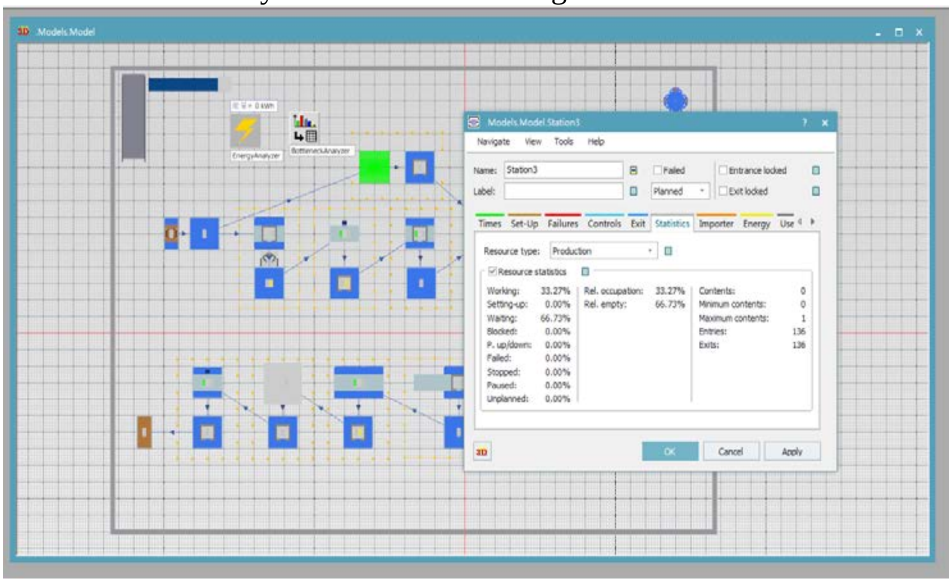

Figure 4. Plant Simulation production line simulation process result of Station 1

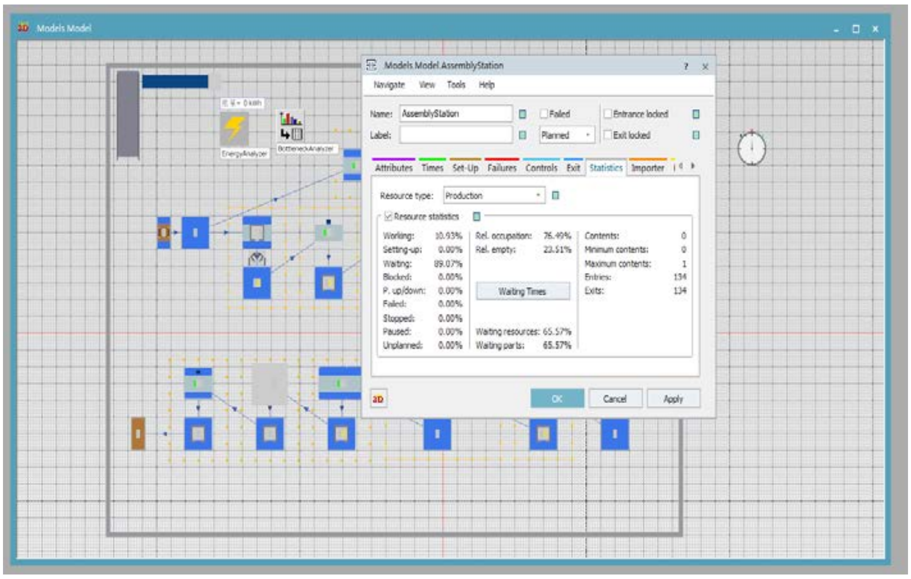

Figure 5. Plant Simulation production line simulation process result of Station 5

According to the simulation results, the working rate and idle rate of each site and the equipment utilization rate of the corresponding site can be displayed. The results are shown in the table below.

Table. 2. Data table of simulation results for each station

Station	Work rate	Vacancy rate	Utilization rate	Loss rate
S1	18.60%	81.40%	18.60%	81.40%
S2	33.27%	66.73%	33.27%	66.73%
S3	9.24%	90.76%	9.24%	90.76%
S4	32.90%	67.10%	32.90%	67.10%
S5	10.93%	89.07%	76.49%	23.51%
S6	32.41%	67.59%	32.41%	67.59%
S7	16.14%	83.86%	16.14%	83.86%
S8	95.53%	4.47%	23.88%	4.47%
S9	10.60%	89.40%	10.60%	89.40%
S10	17.51%	82.49%	17.51%	82.49%
S11	11.31%	88.69%	11.31%	88.69%
S12	61.77%	38.23%	15.44%	38.23%
S13	12.74%	87.26%	12.74%	87.26%
Average	27.92%	72.08%	23.89%	67.04%

4. Balance optimization of satellite assembly line

4.1 Balance evaluation index

There are many kinds of production line balancing objectives, and the corresponding evaluation indexes of balance effect can be set according to different needs [4].

(1) Minimum number of workstations

By using a certain method to predict and estimate the market demand and the corresponding equipment capacity at this stage or in a certain period of time, the minimum number of workstations can be obtained. In this case, the equipment and personnel are almost the least, so as to "reduce costs, optimize the production process, and improve production efficiency. This kind of problem is also called albp-1.

(2) Minimize beat

When the production line cannot be changed to a certain extent, because the corresponding resource allocation has been relatively fixed, if the output is increased, only through the production line balance to optimize the production rhythm. This kind of problem is usually called albp-2.

(3) Minimum smoothing index

When the number of workstations and beat are relatively fixed, it is necessary to consider further balancing the load of the production line, so as to make the man hour deviation between each station of the production line as small as possible. In other words, when the number of work stations m and the beat C_T are known, the objective is to minimize the smoothness index (SI). There are many Si representation methods, the most commonly used is:

$$\mathrm{SI} = \sqrt{\sum_{i=1}^{m}(C_T - T_j)^2 / m} \tag{3}$$

Where T_j is the working hours of the j th workplace (the values for each site are given in the previous section).

For the convenience of this paper, it is defined as the minimum index as follow.

$$\mathrm{SI}' = \sqrt{\frac{\sum_{i=1}^{m}(1-\frac{T_j}{C_T})^2}{m}} \tag{4}$$

The minimum smooth percentage SI', whose value range is:

$$0 \leq \mathrm{SI}' \leq 1 \tag{5}$$

The closer the value is to 0, it means that the smoother the production line is, the higher the utilization rate of the station is, the more balanced the production line is and the more reasonable the design is. The more the value tends to 1, the result is opposite.

(4) Maximize line efficiency

Line efficiency (LE) represents the balance and continuity of the whole or part of the production line

$$\mathrm{LE} = \frac{T}{m \times C_T} \times 100\% \tag{6}$$

In addition, this can be converted into the minimum equilibrium loss rate d, expressed as:

$$d = 1 - LE \tag{7}$$

Where T is the total working time of all sites.

In this paper, three indexes, namely, minimizing beat, minimizing smoothing index and maximizing production line efficiency, are used to evaluate the balance index of production line modeling and design.

4.2 Analysis and optimization strategy of balanced evaluation index

1. Analysis on evaluation index of production line balance

(1) Minimize beat

According to the results of current modeling and simulation, in this design, the beat is minimized as the total time of bottleneck site, namely S8 site.

According to the current beat, under the annual effective working hours, the capacity of the current design assembly line cannot meet the actual production demand without considering the normal operation of the fault, so it is necessary to further improve and optimize the production line design.

(2) Minimize smoothing percentage index

According to formula 2, the minimum smoothing percentage index of the production line under this model is 0.76.

The minimum smoothing percentage index of the production line is greater than 0 and close to 1, which shows that the bottleneck station of the production line seriously affects the work efficiency of other stations and the production line balance. Therefore, it is necessary to solve the problem that the bottleneck stations block the production line beat.

(3) Maximize line efficiency

According to formula 6, the maximum production line efficiency under this model is 29%;

According to formula 7, the minimum equilibrium loss rate of the production line under this model is 71%.

Similarly, it can be seen from this index that the balance of production line under this design needs to be adjusted to improve the balance of production line.

2. Production line balance optimization strategy

Due to the poor balance effect of the current production line, the reason is that the working time of bottleneck station is longer than that of other stations, which results in the beat and smoothing index being subject to the bottleneck site, and the impact is very serious.

According to the analysis in table 16, only the bottleneck site S8 and site S12 work more than 50% of the 13 sites. Therefore, improving the capacity of the two stations can reduce the beat of the production line and improve the efficiency of the production line.

After investigation, as the actual construction of the production line is affected by many factors, the most possible way to improve the balance effect of production line is considered. The equipment of S8 and S12 stations are added to improve the site capacity, that is, two stars can be allowed to work at the same time at the same site.

4.3 Evaluation of production line balance index after optimization

After modeling and simulation, the simulation results of the optimized production line are analyzed as the follow:

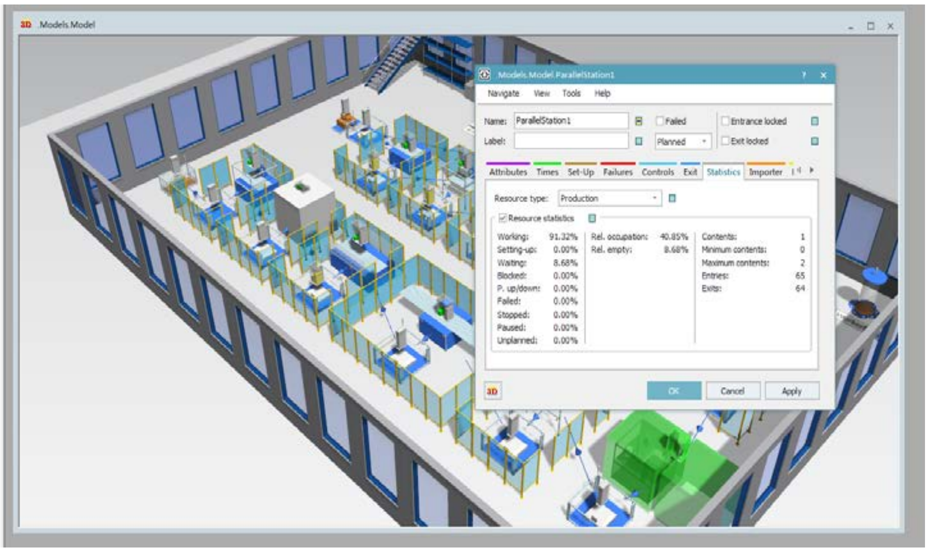

Figure 6. Simulation results of production line model in optimized plant simulation

Table. 3. Data table of optimized simulation results

Station	Work rate	Vacancy rate	Utilization rate	Loss rate
S1	33.42%	66.55%	33.45%	66.55%
S2	59.60%	40.40%	59.60%	40.40%
S3	16.50%	83.50%	16.50%	83.50%
S4	58.91%	41.09%	58.91%	41.09%
S5	19.56%	80.44%	19.56%	80.44%
S6	57.94%	42.06%	57.94%	42.06%
S7	28.77%	71.23%	28.77%	71.23%
S8	91.32%	8.68%	40.85%	8.68%
S9	18.78%	81.22%	18.78%	81.22%
S10	31.10%	68.90%	31.10%	68.90%
S11	20.15%	79.85%	20.15%	79.85%
S12	92.30%	7.70%	22.66%	7.70%
S13	28.98%	71.02%	28.98%	71.02%
Average	42.87%	57.13%	33.63%	57.13%

After analyzing the data, the optimized production line balance index is as follows.

(1) Minimize beat

Through the optimization proposal, the bottleneck site is backed up and two stars are allowed to work in the site at the same time, which greatly improves the bottleneck site time, so the production line beat is significantly improved after optimization

The current beat design leaves a certain amount of margin, because the bottleneck site may carry out other uncertain work, and there is a certain floating time, so a certain amount of beat margin is reserved to ensure the smooth and continuous operation of the production line

(2) Minimize smoothing percentage index

According to formula 4, the minimum smoothing percentage index of the production line under this model is 0.626, which is higher than that before optimization.

(3) Maximize line efficiency

According to formula 6, the maximum production line efficiency under this model is 52.3%;

According to formula 7, the minimum equilibrium loss rate of the production line under this model is 47.7%.

It can be seen from this index that after optimization, the efficiency of production line is obviously improved from 29% to 52.3%, which makes the improvement of production line balance more reasonable, and the production line operation is smoother from the simulation analysis.

5. Conclusion

Due to the constraints of the existing conditions, the production line cannot make other better optimization and improvement in the actual construction situation. In the future construction process, the site with less labor, such as S3 site, can be merged with other sites, and the long-time work site or bottleneck site can be decomposed into multiple serial sites or integration sites that allow multiple sub sites to be carried out in parallel. In the face of subsequent online production of satellites with different configurations, the site configuration of production line can be adjusted appropriately to make it more inclined to the final assembly process of main batch production satellites, so as to improve the production efficiency of the whole line.

In this paper, combined with the actual needs of satellite assembly line construction, the process design and layout design are carried out. Through modeling and simulation, the key links and bottleneck sites in the operation of the production line are analyzed, and the reasonable optimization strategy is proposed.

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