Simulation Optimization Design of Set Parts Supply System for Automobile Assembly Line

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Abstract. This article studies material distribution system of mixed-model assembly line. A new material distribution model, set parts supply (SPS) system, is applied to a practical automobile assembly line (S Company) with a takt time of 80s. Firstly, Plant Simulation is used to build the material assembly system simulation model. For the distribution area subsystem, to maximize picking efficiency, material layout and task allocation plan of distribution area are obtained through simulation combined with genetic algorithm with two-chromosome expansion coding mode. As for material transporting subsystem, Design of Experiment (DOE) method based on simulation model is used to achieve the optimization of system parameters such as number of AGVs, capacity of buffer and so on.

Keywords: Simulation optimization; Set parts supply system; Assembly line.

1. Introduction

The increasingly fierce competition in the automotive industry and the increase in customization have led to diversified product varieties and frequent process changes, which have led to complex assembly manufacturing processes, so improving the operation efficiency is a very concerned issue of automotive mixed-flow assembly line. This problem mainly involves three aspects. One is to optimize the assembly line design, reasonably allocate the content of the operation, and balance the workstation load. The second is to optimize the production sequence, make the production process more balanced and improve the production efficiency. The third is to optimize the material distribution system including procurement, inventory, distribution, logistics and other aspects of system design and parameter optimization to ensure efficient and smooth logistics.

Industrial and academic circles have conducted a lot of research on the material distribution system of mixed-flow assembly lines. Rockwell Automation has developed and successfully implemented a series of logistics solutions for the automobile manufacturing process. Cao et al. [1] analysed the logistics pulling system and Kanban operation process from the perspective of timely and accurate distribution of logistics. Zhou et al. [2] used Plant Simulation, combined with the emergency order processing strategy, to establish a material distribution system simulation model of the make-to-order (MTO) mixed flow assembly line. Li et al. [3] applied a new type of distribution operation mode in the material distribution system of the actual automobile assembly line, to reduce inventory and optimize internal logistics. Brynzer H. [4] emphasized the purpose of studying material placement is to reduce the picking time. Petersen [5] reduced the picking path problem to the shortest path problem. Ek Peng Chew et al. [6] combined the probability theory to establish the expected value objective function of
the picking path and used the optimization algorithm to plan the picking path. Semih Onut et al. [7] determined the number of shelves in the batching area by the particle swarm method, and the number of layers and columns of each shelf minimized the handling cost.

In this article, we combine simulation optimization and genetic algorithm to optimize the design of SPS, an efficient material distribution system. An optimization plan of storage allocation and picking station task allocation are obtained. The key parameters such as the number of AGVs (Automated Guided Vehicle) and material trucks are also optimized through the DOE method.

2. Brief View of Set Parts Supply System

Set parts supply (SPS) system is a new material distribution mode suitable for mixed-flow assembly production lines. It consists of material storage & picking area and automated transporting vehicle system (several material trucks dragged by AGV). In the material storage & picking area, all the parts required for each product to be assembled are picked and transported to the assembly line head via trucks dragged by AGV. The material trucks then flow along with the main parts along the assembly line. The assembly workstation takes the materials as needed until the assembly process is completed, the empty trucks return. In general, SPS is very suitable for assembly lines with diverse product types, numerous assembly workstations, and limited temporary storage area on the side of the line.

An automobile company (S Company) designs a mixed-flow assembly line to assemble three models: BZ3, B73 and T88. The production ratio is 45%, 24% and 31% respectively. The planned takt time is 80s. There are 205 part types, which can be divided into two groups: large parts (GV parts) and small parts (PC parts). The assembly line is 137.5m long and consists of 25 assembly stations. The automobile assembly system adopts the SPS distribution model, which consists of storage & picking area, AGV transportation system, and assembly line. Figure 1 shows a simulation model of the assembly system based on Siemens Plant Simulation.

According to the design requirements, the material storage & picking area needs to satisfy the material consumption for 2 hours of assembly. The parts are stored in packages in the GV or PC shelf area according to size. The five distributed picking stations are shown in Figure 1 (a). AGV dragged three empty material trucks into the distribution area and reached each picking station in turn. According to the scheduling instructions, the pickers at each station loaded the GV parts on the left and the PC parts on the right. The loaded AGV leaves the distribution area and goes to the assembly line head, as shown in Figure 1 (b). After arriving, the material trucks enter the temporary storage area of the line head and are pulled by the ground rail chain to complete the assembly operation. The empty material trucks enter the temporary storage area at the end of the production line, waiting for the arrival of AGV.

To prevent the material distribution system from mismatching, missing and unqualified parts, the following three measures are taken. One is to store a small number of important parts near the assembly line to respond in time when problems occur. The second is to establish the error-proof system. According to the picking instructions, an indication signal is generated, and the corresponding part indicator lights up. After the worker picks the part, the light is turned off. The third is the standardized design of the parts layout in the material truck, reducing the chance of error.
3. Simulation Optimization of Storage & Picking Station Task Allocation Plan

The optimization purpose of the SPS distribution area is to optimize the material storage allocation plan and the picking station task allocation plan, so that the distribution time of SPS area is less than the takt time of the assembly line (80s).

As shown in Figure 2, in the storage and picking area, the GV pieces are placed on a single-layer shelf in the GV area. According to the size of the packaged GV pieces, the shelf is divided into 2 compartments, and each compartment can store one package of GV pieces. PC pieces are stored on the shelves in the PC area. According to the size of the packaged PC pieces, each PC shelf is divided into upper, middle, and lower three layers of 9 PC compartments. Longer PC package can span multiple compartments on the same layer. It can be placed in a PC with a depth of 2400mm. It can also hold multiple PC packages.

There are 31 kinds of GV parts, each of which is stored in 2 packs. They are placed side by side on a GV shelf, and different types of GV parts are placed in sequence horizontally. Therefore, when the order of 31 GV pieces is arranged, and the storage allocation of the GV area is determined. There are 174 kinds of PC pieces, and each kind of storage varies from 1 to 18 packs. They are stored together. Therefore, if the sequence of 174 PC pieces is arranged, the corresponding PC area storage allocation plan can be obtained. The number and size constraints of packages should be considered. The storage allocation problem in the distribution area is finally reduced to a sequence optimization problem, which theoretically exists 31!*174! solutions. It is an NP-complete problem.

We combine genetic algorithm and simulation software to solve this optimization problem, the gene encoding process is as follows:

1) Using double chromosome sequential coding method, which respectively represents GV sequence and PC sequence, the original chromosome length is 31 and 174.
2) For each initial chromosome, insert m-1 (m is the number of picking stations) consecutive natural integers at the random position in the middle to indicate the position of the picking station.

Taking 31 GV pieces as an example, the original chromosome and the chromosome inserted into the picking stations are shown in Figure 3. 32-35 denote four separators. They divide the sequence into 5 segments, corresponding to 5 picking stations.

![Figure 2. Single GV shelf (left) and PC shelf (right).](image)

![Figure 3. The original chromosome (Upper) and the chromosome with 4 separators (Lower).](image)

The gene decoding process is explained as follows:

1) For GV parts, according to the genetic sequence, the material assignment of the GV area and the GV shelves responsible for each picking station can be directly obtained.
2) For PC parts, the decoding process of genes is more complicated. Most PC parts are small, and one compartment can hold one pack. A few parts need two compartments on the same level of the shelf to place them. Very few parts require three compartments, that is, one layer of the shelf. Due to the size constraint, an empty compartment will appear during gene decoding. In the task assignment of the picking station, since the station assign the tasks in units of shelves, and the PC parts do not seem to correspond one-to-one with the GV part numbers, the PC parts corresponding to the gene number after the integer separator in the sequence need to be placed on new PC shelves. For example, the right rear
seat belt buckle, 600mm long, 400mm wide, 148mm high, 18 stocks, one PC compartment can store 4 packages, a total of 5 PC compartments are required; air intake diversion box, 1200mm long, 1000mm wide, 380mm high, 2 bags in stock, single bag needs 3 compartments on the same layer of the shelf to be placed, because the shelf width is 2400mm, a layer of compartments can accommodate 2 bags. If the rear right seat belt buckle and the air intake diversion box are placed on the shelf in order, the PC compartments No. 1-5 will place the right rear seat belt buckle, No. 6 is empty. The air intake diversion box will be placed in the PC compartments No. 7-9. If there is an integer greater than 174 between the two accessory numbers in the sequence, the PC compartments No 6 to 9 are empty, and the air intake diversion box will be placed in the compartments 1 to 3 on the next shelf. The fitness function of the genetic algorithm is the takt time of the distribution process. Due to the complexity of the material distribution system and the randomness of the product types, the takt time is difficult to calculate directly. Therefore, the simulation method is used to obtain the fitness value. Decoding the gene sequence, dynamically setting the material layout and station task allocation of the simulation model, and setting other simulation parameters, and then running the simulation model, after a period of simulation, calculating the ratio of the simulation time to the total number of trucks, we get the material distribution takt time (seconds per truck).

The parameters of the genetic algorithm are set as follows: the population size is 20, the order crossover operator (OX) is used, the crossover rate is 0.8, and the mutation operation is realized by exchanging the position of the genetic element, the mutation rate is 0.1, and the genetic iteration ends at 20th generations.

The basic assumptions and settings of the simulation model are as follows: 1) The pickup position is the middle position of the corresponding storage compartment, ignoring the influence of the mobile AGV on the distribution process of the worker; 2) The material distribution plan is randomly generated (45% BZ3, 24% B73, 31% T88) to ensure that enough trucks enter the distribution area to maximize the distribution capacity. 3) Moving speed of the AGV is 0.416m/s; moving speed of worker is 0.9m/s. The pickup speed of the PC part in the upper, middle, and lower is 1s/piece, 0.7s/piece, 1s/piece, respectively. The speed of placing the PC piece into the truck is 0.5s/piece. The speed of taking GV parts is 1.4s/piece. The speed of putting GV parts into the truck is 0.6s/piece; 4) Three times of simulation for each scheme, the average value of fitness is taken, and the simulation running time is 10 days.

The iterative process of genetic algorithm is shown in Figure 4. After the iteration is terminated, the optimal material distribution takt time is 68.20s, which is less than that of the assembly line (80s), so the distribution capacity of the SPS area is sufficient. The best solution is shown in Table 1, which is divided into 5 groups, corresponding to 5 picking stations. The separators of picking station are 32-35 for GV parts and 175-178 for PC parts.

![Figure 4. The iterative process of genetic algorithm.](image-url)
Table 1. Optimization result.

| Best Solutions |
|----------------|
| The Sequence of GV parts | 31,7,2,12,17,15,32,5,30,6,16,24,1,29,35,21,4,20,9,14,26,33,25,18,3,13,8,19,34,27,11,23,28,10,22 |
| The Sequence of PC parts | 145,124,167,77,74,8,6,125,138,10,49,33,127,118,113,90,51,135,43,84,64,131,71,117,97,75,31,162,95,19,20,149,144,159,176,70,21,156,153,2,99,3,161,143,42,102,114,58,78,96,103,52,34,160,13,109,130,72,151,134,123,46,37,119,12,56,28,166,85,177,154,67,170,87,22,164,80,29,100,68,105,49,94,128,82,116,41,132,54,32,16,35,44,7,93,76,107,111,171,139,60,146,140,178,165,81,169,122,66,25,104,91,11,79,108,55,1,86,47,129,142,115,110,98,73,133,40,14,23,57,30,150,59,148,172,5,158,157,39,175,88,83,163,4,174,36,136,152,168,27,65,61,101,106,9,120,121,45,69,92,53,38,62,89,50,24,112,63,18,155,173,147,126,17,137 |

4. Simulation Optimization of Other Parameters

After determining the storage allocation plan of the distribution area, other important parameters of the entire distribution system need to be optimized, including the number of AGVs, the number of material trucks, the capacity of the temporary storage area of the material at the beginning of the assembly line, and the temporary storage of the material at the end of the assembly line, the optimization goal is to meet the requirements of the assembly line 80s production cycle with the least cost.

Use the Experiment Manager provided by the Plant Simulation to optimize the parameters. The number of AGVs is between 6-15 and the increment is 1. The number of trucks is between 30-60 and the increment is 5. Assuming that the temporary storage area of in the line head and tail is large enough, we obtain the test results after two sets of simulation tests.

The first group of experiments determined the optimal number of AGVs, a total of 70 simulations. The results are shown in Figure 5. When the number of AGVs is the same, the assembly line takt show a downward trend with the increase of the number of feeders. When increasing from 45 units to 50 units (increment of 5), the takt is reduced from 83.62s to 78.89s (less than 80s), so the optimal number of AGVs is 9.

The second group of experiments determined the optimal number of trucks, set the number of AGVs to 9 and conducted a test in which the number of trucks was increased from 45 to 50 in turn, a total of 6 simulations. The simulation results are shown in Figure 6, when the number of trucks is 48, the takt is reduced to 79.35s. Therefore, the optimal number of trucks is 48.

Figure 5. Simulation test results of AGV quantity.
After determining the optimal number of AGVs and trucks, through simulation, observe the change of the number of trucks in the temporary storage area of the line head and tail of the assembly line. The results show that when the temporary storage capacity is 6 (number of trucks) for the line head and 1-2 for the line tail, it can meet the requirements. At this time, the utilization rate of the workers of each picking station in the distribution area is in the range of 60-70%, and the tasks are balanced and reasonable.

5. Conclusion
This article takes the automobile assembly line as an application example and conducts simulation and optimization research on the set parts supply model for mixed flow assembly line. Through the combination of simulation technology and genetic algorithm, the design scheme of the material distribution system is optimized, including the parts layout, distribution task allocation, resource configuration and so on. Simulation results show that the optimized solution can meet the requirements of assembly takt time and reduce the logistics cost as much as possible. In the future, it is valuable to take the scheduling of AGVs into account.

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