Research on Simulation Based Dynamic Scheduling Strategy of the Logistics Distribution System for Assembly Lines in Engineering Machinery

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Abstract. The objective of designing a logistics system for assembly production planning should be accurate, efficient distribution, and low cost. It is difficult to use mathematical methods to solve the design of logistics distribution route planning for a given layout of assembly lines which often be restricted. We take the logistics distribution system for actual assembly lines of engineering machinery as the research object, and analyze its current status. And we build a 3D simulation model of the corresponding scene, and use a variety of logistics scheduling methods to optimize the logistics distribution system. Considering the congestion strategy characteristics of some distribution channels, adjustment strategy of time window is proposed, and a dynamic scheduling strategy of congestion is designed. Combined with the simulation tests, we analyze and optimize the solution suitable for the actual assembly lines. The results show that our strategy had better performance than other common scheduling strategies. And the proposed strategy could optimize the material distribution system of assembly lines, reduced the number of vehicles and the cost of the enterprise.

Keywords. Material distribution, adjustment strategy, dynamic scheduling strategy, simulation.

1. Introduction

With the increasing demand of custom customization, the research of flexible assembly lines is paid more attention. The assembly lines could produce many similar products, but each product required different material parts. The efficient, timely, and accurate delivery of suitable material parts to each station is very important for assembly production. The line space beside the assembly lines is limited, so it needed to supplement material parts in time and frequently to ensure the normal assembly. If not, there will often be low inventories, low capacity utilization, and failure to deliver orders on schedule.

We study an assembly lines workshop with fixed channels layout for engineering machinery. The workshop contains a number of logistics channels with different widths. Due to the constraints of material distribution Channel 1 and 2 width, different types of AGVs and forklifts needed to be scheduled to avoid vehicle collisions in the logistics channel, as shown in figure 1. The material parts of the workshop are distributed in kits. Johnson et al. [1] studied the kits and production line inventory system. The demand time windows of stations are overlapped, it is necessary to design adjustment strategy of time window to reduce conflicts by comprehensively considering the factors of channel congestion and vehicles.

It is difficult to establish an accurate mathematical model for this problem [2], because there are many factors involved in the actual consideration of assembly lines workshop. For the complexity of such problems, simulation analysis and optimization is a better choice than mathematical method to
solve the current problem. In recent years, considering different constraints, researches on the distribution logistics system for assembly lines are transformed into queuing theories [3], traveling salesman problem (TSP) [4], vehicle routing problem (VRP) [5].

Aiming at the AGV scheduling in flexible manufacturing system (FMS), Kim et al. [6] introduced hierarchical rules according to load balancing. Montoy et al. [7] compared and analyzed the impact of various vehicle scheduling strategies on vehicle scheduling for the automatic material delivery system. Chan et al. [8] designed a vehicle dynamic selection strategy, adopting normalized dynamic selection of the optimal strategy, and updating the selected strategy at different decision points. Le-anh [9] proposed a multi-attribute mixed scheduling strategy for material supply, and carried out simulation experiments in the distribution of different scenarios. Wang Cj et al. [10] proposed a vehicle dynamic scheduling strategy based on the assembly line distribution congestion, analyzed the logistics distribution system based on simulation. Kluska K et al. [11] adopted the simulation modeling method to design and apply the Milk Run internal logistics system. Urru A et al. [12] proposed a new Milk Run transportation system planning method, which considers not only logistics but also information flow of current process.

Therefore, this paper establishes a simulation model for the logistics system. We design the time window adjustment strategy for different types of material parts and a new dynamic scheduling method in case of vehicle conflict which compared with various common scheduling strategies. Combined with simulation experiment analysis, the control strategy and decision-making parameters are dynamically adjusted to explore the formation of a perfect logistics distribution system.

This paper is organized as follows: section 1 presents the background and literature review about the distribution logistics system for assembly lines. Section 2 describes problems of the assembly lines. Section 3 presents the developed dynamic scheduling strategy based on simulation. Section 4 builds a simulation model of the corresponding scene, and section 5 discusses the results. Finally, section 6 presents some concluding recommendations for our research.

2. Problem Description
Assembly lines can be divided into fixed assembly and mobile assembly according to the form of assembly. Figure 1 is a simplified schematic diagram of a fixed layout assembly workshop, which shows the material distribution system and logistics route conflict of the mixed assembly line.

![Figure 1. The layout diagram of assembly lines and logistics routes.](image-url)
According to the different characteristics of components to be assembled on the current assembly line, they are divided into different types including very large parts (Class A), complete parts (Class B), and general parts (Class C). These different types of parts are stored in different places. They are individually packed in appropriate containers and pre-shipped exactly to the line warehouse on each workstation. When the material parts are exhausted, the line side issue the material requirement instruction. The manual forklift distributed Class A parts are stored in warehouse 3 along the black line route in channels 1 and 2, and they couldn't retrace. Class B and Class C would be distributed by AGVs along the blue lines. The AGVs could turn in the direction of the channel.

The current problem is forklifts and AGVs might collide in the distribution channels because different channel widths. The distances between each workstation and the warehouse are also different, so the delivery times of the material parts are different. The distribution of material parts are very frequent, so the time windows required for each workstation are multiple overlapping. In order to complete the distribution of parts in time, we analyze the conflicts that may occur during the driving of the vehicle to optimize. We design dynamic scheduling strategies to avoid conflicts.

3. Dynamic Vehicle Scheduling Strategy Based on Simulation

The assembly plan determines the order of production and the bill of materials required for production, which include the quantity of required materials and the time required for workstations. The delivery sequence is obtained by sorting the requirements according to BOM. Then the task lists for vehicle scheduling are obtained with the appropriate vehicle to each task.

3.1. Delivery Sequence of Required Materials

The materials needed for a specific station should be distributed one container cycle in advance, because it consumes and distributes several kits of material parts in the cycle time unit. When the container in the line position became empty, a feed signal is sent to replenish the line warehouse.

If the assembly line starts working from \( T_0 \), the assembly cycle time is \( CT \). If the container of station \( i \) could store \( M_i \) kits of materials, and the \( n \)th the timing of the signal that need material is \( S_i^n \), then the length of the response time window for the next container equel to \( RT_i = M_i \times CT \). There are multiple non-overlapping time windows for the same workstation, so the time window for the material needed by workstation \( i \) for the nth time is \([ET_i^n, LT_i^n] \), we know \( ET_i^n \leftarrow S_i^n \) and \( LT_i^n \leftarrow S_i^n + RT_i \). Late arrival of components to workstations is likely to lead to shutdown, resulting in workstation out-of-stock costs and even shutdown losses.

The task attribute of material parts is \( R_i = \{i, M_i, RT_i, ET_i^n, LT_i^n, d_{ij}, P_i\} \), which \( d_{ij} \) is the nearest distance between workstation \( i \) and warehouse \( j \), and \( P_i \) is the priority of component. In the simulation model, the temporary entity model is established according to the attributes. With the updating of the simulation clock, each workstation generated signals of materials in need, and distribution tasks are generated in the warehouse. After the distribution tasks are sorted, they are transmitted to warehouses and vehicles for vehicle scheduling procedures.

Chan et al. [8] listed some common dynamic scheduling strategies, as shown in table 1. Based on the attribute of material parts, they are referenced and compared in the simulation model.

| Strategy | Meaning | Description |
|----------|---------|-------------|
| FCFS     | First come first served | Sort tasks according to time |
| MRT      | Minimum remaining time first | Sort tasks according to the task urgency principle |
| LDF      | Longest priority | Sort tasks according to the distance between the pick-up point and the distribution point |
| SDF      | Shortest priority | Sort tasks according to the distance between the pick-up point and the distribution point |

Table 1. Common dynamic scheduling strategies.
3.2. Adjustment Strategy of Time Window
During the production cycle, the multiple time Windows of different workstations are overlap. In channel 1 and 2, forklifts and AGVs of different sizes are distributed, which made them extremely prone to congestion. Therefore the time window adjustment strategy of forklifts and AGV is designed. For a certain period of time, the forklifts are driving in one direction. In other time periods, the AGVs could travel in both directions.

The time window for a single kit of material parts is \([ET_i^n, LT_i^n]\). The time window for multiple kits of material parts is composed of a single kit, expressed as \([ET_i^{n1}, LT_i^{n1}], [ET_i^{n2}, LT_i^{n2}] \ldots [ET_i^{nm_i}, LT_i^{nm_i}]\). Distribution could be made at any one of the time Windows. The formula shows that \(IT_i^n\) is the piecewise time of the time windows. \(w\) is the parameter that controls the time period of forklifts and AGVs. Too long or too short might not meet the task distribution.

\[
IT_i^n = \frac{ET_i^{nm_i} + LT_i^{nm_i}}{w}
\]

Considering the characteristics of material parts, AGVs have higher priority than forklifts. Therefore, the time windows are divided into two segments, which are unified as \([ET_i^n, LT_i^n]\). The AGVs time window: \([ET_i^n, IT_i^n]\); The forklifts time window: \(([IT_i^n, LT_i^n]\). Both are soft time Windows, which could avoid the failure of delivery tasks within the limited time windows due to the unreasonable \(w\). They are allowed to exceed, but not to exceed the original time window \([ET_i^n, LT_i^n]\).

\([ET_i^{n1}, IT_i^{n1}], (IT_i^{n2}, IT_i^{n2}] \ldots [ET_i^{nm_i}, IT_i^{nm_i}]\) are multiple demand time Windows for multiple kits of material parts, one of which could be selected for distribution.

According to the adjustment strategy, a corresponding task priority assessment method is designed, which could compare the task priority of material parts. It also could distinguish forklifts and AGVs, and respectively compare the priority of forklifts or AGVs in the channels. \(P_i\) is the priority of task \(i\) in distribution. Assign reasonable weights according to the remaining times and the distances of the task to obtain \(P_i\).

\[
P_i = \frac{1}{M_i \times (LT_i^n - ET_i^n)(LT_i^n - T_{now} - T_{ji})}
\]

3.3. Dynamic Scheduling Strategy for Channel Congestion
Time window adjustment strategy would not completely avoid the congestion. Therefore, according to the characteristics of the assembly line and the corresponding vehicles and logistics channels, dynamic scheduling strategy for channel congestion is designed, referring to dynamic dispatching strategies proposed by Wang CJ et al. [10], as shown in figure 2 and figure 3.

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**Figure 2.** Scheduling strategy for AGVs those could travel in both directions.
Figure 3. Scheduling strategy for the forklifts that could travel in one direction.

4. Simulation Model

Due to the uncertainty and complexity of the assembly system, it is difficult to establish a mathematical model [13]. Therefore, we introduce an optimization method based on simulation to solve the existing problems. The material distribution process model based on simulation is built by Flexsim platform, and then the logistics distribution system is simulated modeling and testing. Based on the simulation model, the dynamic analysis is carried out, and the rationality of the strategy is verified, so as to provide a reasonable basis for the design of the logistics system.

4.1. Data Input

The actual system is too complex, and the amount of data is huge. In order to run the simulation model efficiently and accurately, the assembly system is simplified in this paper. According to the production plan and BOM, the logistics system on-line plan and stocking lists are determined. Combined with the rules, the data table entered by the simulation model is obtained. The number of forklifts and AGVs is an integer, and the number of vehicles is limited by the enterprise budget.

4.2. Static Simulation Model

After simplifying the system, based on its layout and basic data, static simulation model is established. As shown in figure 1, the simulation model consists of three warehouses and an assembly shop. Each warehouse has a shipping port, and a garage for storing and charging vehicles. The assembly shop contains multiple assembly lines, workstations, and line side warehouse.

4.3. Material Consumption Logic

Each station produces according to the cycle. For large material parts, containers are released only after consuming materials at the start of the cycle. For small material parts, containers are released after consuming materials completely, due to the number of kits of a single container needed to be considered after the start of the cycle.

4.4. Material Call and AGV Scheduling Logic

The feed logic is carried out according to the message in the material consumption logic. After the logic is fired, an AGV is called based on the container used the type of AGV. The scheduling logic is as follow figure 4.
5. Case Study

The total length of a channel is about 100 m. The assembly line balance production with 20 minutes CT that could change depending on the type of product.

The parameters in the simulation model are set as follows: the average unloading time $t_u$ is set to 30 s, and the average loading time $t_l$ is 30 s. The speed $v_1$ of forklifts is 0.5 m/s, and the speed $v_2$ of different AGVs is 0.5 m/s. Since the vehicle delivered the containers to the workstations and then picked up the empty containers, the load speed is the whole process. The operating cost of forklifts $c_1$ is 150, the cost of big AGVs $c_2$ is 120, and the cost of small AGVs $c_3$ is 100. The penalty coefficient $M$ is set to 100. The number of container kits for class A is 1, the number of container kits for class B is up to 4, and the number of container kits for class C is up to 10. After many simulation tests, $w$ set to 2 is more appropriate, and basically don’t affect the forklift distribution tasks.

Referring to Egbelu [14], the formula is improved according to the characteristics of this paper, to calculated the number of AGVs and forklifts in the case and the corresponding logistics cost. The distribution number in the production cycle is $f_{ij}$. Compared with the simulation results of various strategies, $CT_{r}$ is the actual cycle. The calculation of big AGVs is the same as small AGVs.

$$N_1 = \frac{\left(\sum_{i=1}^{n_1} D_{ji} / v_2 + (\sum_{i=1}^{n_1} f_{ji}) * (t_u + t_l)\right)}{60T}$$  \hfill (3) 

$$N_2 = \frac{\left(\sum_{i=1}^{n_2} D_{ji} / v_2 + (\sum_{i=1}^{n_2} f_{ji}) * (t_u + t_l)\right)}{60T}$$  \hfill (4) 

$$f = \min(c_1 * n_1 + c_2 * n_2 + c_3 * n_3 + M * CTr)$$  \hfill (5) 

In the study, the model is run for 12 h each time when the new scheme is verified, and there is 4 h warm-up period (all counted in the simulation production time) before the model is run, and the number of replicates is set to 30.

The optimal results are obtained by simulating and optimizing with five scheduling strategies. Comparing the results, it can be seen from table 2 that the solution based on simulation is superior to the estimation method. The reasonably constructs simulation model consider many practical factors for accurately reflecting various situations in the logistics system. Compared with simulation, the mathematical method is a static method and couldn’t respond to the dynamic changes of the system. The estimation formula could only be used as a reference value in this study, because the differences of various strategies couldn’t be shown in the estimation formula, and the uncertainties in the actual scene.
are not taken into account. For example, the occurrence of congestion in the passage couldn’t be counted. Due to the simplification of the consideration factors, there is always an inevitable deviation between the planning results and the implementation results. In addition, for larger problems, the expected result deviation between the two methods would be larger.

Table 2. Comparison of simulation results and estimation results.

| STRATEGY | SIMULATION RESULTS | ESTIMATE RESULTS |
|----------|--------------------|-----------------|
|          | BAGV | SAGV | Forklift | Cost  | BAGV | SAGV | Forklift | cost  |
| FCFS     | 10   | 10   | 7   | 34006 | 11   | 14   | 9   | 33850 |
| MRT      | 10   | 12   | 9   | 33190 | 11   | 14   | 9   | 33850 |
| CT=20    |      |      |      |       |      |      |      |      |
| LDF      | 10   | 12   | 8   | 33540 | 11   | 14   | 9   | 33850 |
| SDF      | 9    | 11   | 7   | 33017 | 11   | 14   | 9   | 33850 |
| DSS      | 9    | 10   | 7   | 32980 | 11   | 14   | 9   | 33850 |

It could be seen from table 2 that, the results of DSS would be best and could achieve a better logistics system cost target. Based on the dynamic scheduling strategy of simulation, time window adjustment strategy could avoid some possible channel congestion. The dynamic scheduling strategy make a dynamic decision when the channel congestion might occur, which avoids situations such as locking, so as to avoid the unfeasible situation of logistics distribution.

We set the logic of statistical calculation to the statistics global table in the simulation model, including the proportion of unloading state, loading state, blocked state and idle state in the total running time, all of which are the average value.

The average vehicle utilization for this approach and other strategies are shown in figure 5. For all strategies, the vehicle utilization is in the 65-85% range. This means the utilization of all the strategies is closer to reality, indicating the importance of the proposed approach. The utilization range of DSS is comparable to other strategies. The above results indicated that this strategy is more suitable for the logistics distribution system for assembly lines.

6. Conclusion
This paper analyzed the present situation of the logistics system and improved the dynamic scheduling strategy. Simulation is introduced to construct the 3D simulation model of the distribution system for assembly lines in engineering machinery. For some distribution channels with limited width, designed the time window adjustment strategy and improved dynamic scheduling strategy to avoid congestion conflicts. Several simulation experiment results showed that the proposed scheduling strategy is suitable for the existing case factories and can provided an important basis for the design and simulation of the logistics system at the assembly workshop in the future.
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