Simulation based Design for Materials Delivery System of Engineering Machinery Assembly Line

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Abstract. This paper deals with problem of modelling, simulation and optimization for the material handling system of the assembly line. The influence of cycle time, materials stock and AGVs charging time are considered in the model, different dispatch strategies are compared in the simulation experiments. Through the analysis of the experiments result, an optimal strategy with the suitable set of vehicles and materials stocks is found, and the adaptive test is also tested with the best result. Finally, the paper also points out the direction for future research on assembly line’s logistic system design.

Introduction

In discrete manufacturing system, production logistics optimization receives more and more attention, and the cost of production logistics takes up 13%-30% of production cost[1]. Production logistics refers to logistic activities during production[2], from the books of raw materials, processes of products being produced, semi-finished products, finished products in warehouses, to delivery of finished products. The study of production logistics focuses on optimization of factory layout, process flows, and loading and unloading in workshops, to determine the location of machinery, warehouses and facilities, reasonably assign manufacturing tasks and allot resources, and rationalize loading and unloading operations in workshops and dispatch of materials[3,4]on the premise of smooth production. During a production cycle, the time spent in logistics activities is far more than the actual time of manufacturing; therefore, the research results of production logistics have greater potential in saving time and resources[5].

Researches on production logistics generally simplify problems into vehicle routing problem (VRP) or dispatch of automated guided vehicle (AGV). VRP problems were first raised in 1959 by G.Dantzig and J.Ramser, which have been extended to vehicle transport problems with many constraints[6]; and in the workshop production logistics, the distribution is often performed by AGV, thus the dispatch of AGV has been widely studied[7-11]. For example, Su found the AGV dynamic control and multipoint distribution method[12,13] by carrying out simulation experiments and defining various constraints under certain control procedures with simulation model for AGV. These researches in general aim at solving the vehicle dispatch problems, and the vehicles used are different from that used for tool distribution in a factory’s assembly lines; the researches also inadequately consider the vehicle dispatch for assembly lines.

This paper focuses on the issues of material delivery in assembly line workshop of engineering machinery, in the study of specific problems it concentrates on the effective control of inventory cost, transportation cost and transportation time in material delivery. Material delivery is defined as dispatching suitable quantity of materials to line stations by least vehicles and assigning the dispatched vehicles with time and routes that are most cost-effective in the condition of meeting the needs of line station. Therefore, the way to quickly formulate the optimal delivery schedules has been in demand in reality. It can reduce delivery cost and increase efficiency of delivery for a factory’s needs.
The main issues in assembly line’s material delivery include issues of assembly material stock and vehicle dispatch[14]. Assembly material stock exists to meet the needs of assembly cycle time in a assembly line, it supplies materials required for assembly line from the start of assembly and reduces inventory, cost and space occupied by the materials in the production lines as much as possible at the same time. The relatively ideal assembly material stock is JIT, that is, when an assembly line needs materials, the materials can be replenished in time before the materials run out[15]. Vehicle dispatch issue mainly is about how to satisfy the demand for assembly material stock. These two issues are closely related and constrained to each other. The problem of assembly material stock arises from the needs of assembly line, and the assembly material stock has dependence on vehicle dispatch.

**Literature Review**

There are researches on the three issues of material delivery in assembly lines. Choi proposed a dynamic material delivery system for automobile assembly lines that first dynamically assess types and quantity of parts to be used according to actual production schedules, then the material distributors finish the material delivery according to instructions and vehicle routes[16]. If there are several distributors able to finish the delivery of material, the delivery controller selects the most suitable distributor by calculating the delivery accuracy of time cost function. Andrea studied the performance assessment of assembly system management under LED display control strategies, used transit quantity from the LED display to control the flow of assembly parts, exerted queuing network model to calculate level of production such as pass rate of product, average delay time due to nonconforming products etc[17]. Wu et al solved the problems of single-loop material delivery in manufacturing system of semiconductor superfine fiber by using multiple-parameter adjustable and assignable algorithm. They also adopted emPlant simulation and achieved good results[18]. Simon Emde et al studied the mixed-model assembly lines[19]. They minimized delivery routes by setting up points of material supply and dynamic planning models to optimize the locations and number of the points, on the premise that the materials for an assembly line and punctuality can be assured. Kozan studied the processes in assembly lines of truck that production materials are sent out from warehouses then packed[20], and converted the issue of packing and distributing materials to issue of VRP, and built related mathematical models, used genetic algorithm to optimize the total material packing time. That article proposes 5 strategies for storing materials, and uses on-site data to perform simulation experiments for comparison. It analyzes from the preparation of material delivery, with emphasis on important issues that researchers of general logistics neglect.

This paper comprehensively takes production scheduling and material delivery in assembly lines into consideration, combines real situation of on-site production, builds simulation models, and uses optimization tools to design a suitable materials handling system.

**Problem Description**

There is an engineering machinery assembly line, which consists of two parts and a logistics passage in the middle (Figure 1a). On the two sides of the passage are stations of the assembly line. The products are produced and conveyed to next station according to the cycle time in the assembly line. The area by the assembly line near the passage is for material storage, most of the materials are stored in standard containers. Each station has two places for container, respectively storing materials currently in use and spare materials in containers (Figure 1b). The materials currently in use are the materials needed for assembly in the current cycle time. The spare materials are materials used in the succeeding cycle times, which prevent production halt due to lack of materials. If the production stops, great loss will be resulted.

In order to increase assembly efficiency and quality, materials in container are stored in sets, that is, each cycle time uses up one set of materials. Each storage place has 1 container at most, but each container can store multiple sets of materials. The materials in a container must be used up first then the container can be returned.
Automated guided vehicles (AGVs) are used to move materials. As an AGV receives an instruction, it first goes to warehouse to pick up the materials, sends them to the specified station and unloads them, retrieves the station’s container and returns it to warehouse then waits for next instruction. An AGV needs to move according to specified routes. Because the logistics passage is narrow, the AGVs moving in the same direction cannot overtake each other. After some time of operation, the AGVs have to recharge. Before the power runs out, it has to start emergency power supply to ensure it can return to the charging area. During an AGV’s idle time, it can stay at the charging area to recharge. An AGV only takes one container per time, the loading and unloading of container take some seconds. Suitable containers, number of vehicles and related dispatch methods are required to minimize logistics cost.

Assume the following conditions are true.
(1) The AGVs will not have malfunction during delivery.
(2) All materials are used up the last moment of cycle time.
(3) The warehouse can deliver materials fast enough, and respond to needs in the assembly line anytime.
(4) During operation, the assembly line has specified amount of materials stored next to it.
(5) The charging area can hold any number of AGV.
(6) The production schedules will not change, no order inserting will occur.

Logistic Control Processes

The logistics mechanism established for the above problems first solves the issue in time control of material delivery arising from the needs of cycle time; second, it needs to control the use of vehicle resource, and takes material requirement and cost factors into comprehensive consideration to establish optimal delivery plan.

Time Control of Material Delivery

There are part A, B and C in the material delivery system. Part A is a kind of materials with huge size. Each storage area can only hold 1 part A each time, which means than it will be distributed with JIT mode. Part C is a kind of material which is standard with small size, it can be supplied with lot size, when the inventory is lower than the safe level. In order to make the delivery time staggered, make full use of the vehicle; the safety stock setting should be optimized.

Assume that CT stands for cycle time in the production line, if starting from T0, the materials in storage area next to the assembly line will be used up. From T0+CT, the parts needed in a station must be all assembled, thus the materials required for assembly at each station in a cycle time are called a set of material, which is Part B. Ordinary containers can hold m sets of material, namely, the materials in a container need m cycles to be used up, and only empty containers will be returned.
The in-used pallets status (one table set)
The spare pallets status (one table set)
The in-used pallets status (two table sets)
The spare pallets status (two table sets)

Figure 2. Relation of Cycle Time, Set and Delivery Time

If the number of set is 1, from the moment of T0, the container No.1 in place of current use must have 1 set of material ready (status indicated in yellow), meanwhile, the place of spare may have container No.2 ready; during T0 and T0+CT, namely the duration of assembly cycle time, materials in container No.1 will not be used up (status indicated in green), simultaneously the place of spare may have container No.2 ready; at the moment of T0+CT, materials in container No.1 will be used up completely, meanwhile, container No.2 in place of spare must be ready, the empty container No.1 will be removed, which may be replaced by the container No.3 newly delivered, and the process repeats again. If the number of set is 2, then at the moment of T0+CT, container No.1 still has 1 set of material ready for use, which will not be used up until T0+2CT, the second cycle time, and the place of spare must have container No.2 ready. From the above process we can see as the number of set increases, the delivery quantity can be reduced during the same length of time. The number of transport can also be decreased and each container’s materials will increase and the flexibility of production will be affected, especially as product schedule changes or abnormality occurs.

Vehicle Dispatch and Material Delivery Control

The material delivery control process will start to deliver materials at reasonable time with a suitable dispatching strategy (Figure 3). The vehicle dispatch strategies used here are showed as in Table1.

Table 1. Dispatch Strategies

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRT</td>
<td>Minimum Remaining Time First</td>
</tr>
<tr>
<td>FCFS</td>
<td>First Come Fist Service</td>
</tr>
<tr>
<td>LDF</td>
<td>Longest Distance First</td>
</tr>
<tr>
<td>SDF</td>
<td>Shortest Distance First</td>
</tr>
<tr>
<td>LDF/MRT</td>
<td>Longest Distance/MRT First</td>
</tr>
</tbody>
</table>

The principle of most remaining time first is a strategic principle with multiple properties. First it needs to prioritize tasks; the priority of each task can be expressed in the following equation;

\[ P_i = TC - LT_i - \frac{d_i}{v} \]  

(1)

TC is the current time. The equation shows the time left for task \( i \), namely, the urgency. Put the smallest \( P_i \) first in the sequence. After sequencing the tasks, the actual start time of a task needs to be decided according to material requirement time. The start time of task \( i \) is \( ST_i \).

\[ ST_i = ET_i - \frac{d_i}{v} \]  

(2)

\[ TC - ST_i \leq 0 \]  

(3)

By the comparison of current time and start time (Eq. 3.), decide whether to trigger the task or not; if there’s a task triggered, the task is released.

When there’s a task being released, the vehicle dispatch logic is started (Figure 3). It first examines whether there’s idle vehicle available, if not, it will wait until a vehicle is free. The idle vehicle enters the standby area for recharging or maintenance. As there are several idle vehicles available, the
vehicle usage rate needs to be used to select the vehicle, which ensures equal use of each vehicle and reduces overuse or over-idleness of vehicle. The selected vehicle receives materials and moves to its destination.

\[ f = \min(c_1 n + \sum_{i=1}^{n} c_2 m + MN_L) \]  \hspace{1cm} (4)

\( c_1 \) stands for AGV cost, \( c_2 \) is inventory cost, \( n \) refers to number of vehicle, \( m \) denotes number of set, \( M \) is a large positive number, \( N_L \) indicts the real production time of each product.

**Simulation Optimization and Results**

This section elaborates on building model for delivery process and its optimization to find the optimal combination of assembly material stock and number of vehicle according to vehicle dispatch and material delivery control process.

<table>
<thead>
<tr>
<th>Total number of station (I)</th>
<th>7</th>
<th>Loading time (t_l)</th>
<th>50s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of passage (L)</td>
<td>200m</td>
<td>Operation cost (c_1)</td>
<td>10</td>
</tr>
<tr>
<td>Production cycle time (CT)</td>
<td>60min</td>
<td>Inventory cost (c_2)</td>
<td>7</td>
</tr>
<tr>
<td>Recharging time (tr)</td>
<td>10min</td>
<td>NO. of container in a set</td>
<td>8</td>
</tr>
<tr>
<td>Unloading time (t_u)</td>
<td>60s</td>
<td>AGV speed (v)</td>
<td>0.5m/s</td>
</tr>
</tbody>
</table>

**Tab. 3. Experiment Results**

<table>
<thead>
<tr>
<th>Stations</th>
<th>Part B</th>
<th>MRT</th>
<th>FIFO</th>
<th>LDF</th>
<th>SDF</th>
<th>LDF/MRT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part C</td>
<td>Part C</td>
<td>Part C</td>
<td>Part C</td>
<td>Part C</td>
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<td>40</td>
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<tr>
<td>vehicles</td>
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<tr>
<td>Object</td>
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<td>14700</td>
<td>14750</td>
<td>14700</td>
<td>14680</td>
<td></td>
</tr>
</tbody>
</table>

First, it set the initial number of set and vehicle and stocks. Second, the model carries out the material delivery control and vehicle dispatch according to production schedule; the specific strategies have been discussed in details in the preceding section. The simulation optimization is mainly about two cycles; the first is the examination after all the tasks on the task list have been finished. If there’s any
delayed task, need to reset the number of vehicle; the second cycle is finishing all the tasks in the specified time frame. It needs to be compared with the objective function, and resets the number of set to carry on the next simulation until the optimal value of the objective function is acquired. The values of parameter are listed on Table 2.

The module finds the optimal solution by setting controlled variables and reactive variables after experimenting and applying intelligent optimization algorithm, that is, the optimal result to the objective function. The experiment results are listed in Table 3. It is showed that the set of vehicle and part B have no differences among these dispatch strategies. We can figure that strategy LDF/MRT runs with the best result. Figure 4 has also show that vehicles have the highest usability with this strategy.

![Figure 4. Average AGV Usage Rate](image)

After getting the best result, an adaptive test is run by the simulation which can make the result more usable for the designers. The test gets that the cycle time will be reduced to 19 minutes with the best result; if we keep the vehicle number the same, set the stocks as many as possible, the cycle time will be reduce to 15 minutes at most, or we have to provide more vehicles.

**Conclusion and Future Work**

This paper finds the resource arrangement at the lowest cost and the dispatch control methods, the delivery and dispatch models of assembly line’s model is built first and simulation optimization methods is used to get best result. 5 dispatch strategies for materials delivery sequence is compared in the experiments of simulation. It provides important guidance for design of materials handling system using with AGVs. The delivery and dispatch models established in this paper is for one of the typical scenarios of real production system. These models can be extended through several different considerations to form complex model series for real production problems.

1. When the materials are from different warehouses, how to dispatch vehicles and avoid collision etc.;
2. When the assembly line has multiple types of vehicle and fluctuation of production time, how to schedule the delivery time and decide the number of set;
3. If the layout has to be designed again, how to design a layout that suitable for the aforesaid delivery of logistics passage;
4. As the warehouse has limited capacity, how to determine the delivery time.

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**References**


