Research on AGV Scheduling Optimization Based on Hungarian Algorithm

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Abstract. Aiming at some problems in the mode of intelligent warehouse multi-selection and order outbound, this paper proposes to optimize the picking station assignment order task and order task assignment AGV in a "serial" or "parallel" manner to realize the synchronous scheduling of order tasks and AGV. The improved Hungarian algorithm is used to solve the optimal assignment solution. Simulation proves that this strategy can effectively improve the order picking efficiency and avoid buffer blockage, thereby improving the efficiency of the dispatching system.

1. Introduction

In intelligent warehousing, e-commerce companies use AGV (Automatic Guided Vehicle) to realize the order picking mode of "cargo to person"[1], which significantly improves the order picking efficiency. Whether the warehouse AGV can function effectively depends heavily on the AGV dispatching system. Scholars at home and abroad mainly use mathematical planning[2-3], strategic methods[4-5], ant colony algorithm[6], particle swarm algorithm[7-8], and genetic algorithm[9] to solve AGV scheduling problems. Toshiyuki[3] described AGV scheduling for conflict-free path planning as a mathematical programming problem to solve. Xiao[4] proposed a heuristic scheduling rule for avoiding system deadlock, online real-time, and multi-attribute tasks to implement AGV task scheduling. Mohammad[6] proposed a two-stage ant colony algorithm for solving job shop scheduling and conflict-free AGV path planning problems that minimized completion time. Bian[7] proposed the AGV dynamic scheduling strategy based on particle swarm algorithm to solve the problem of AGV resource allocation and task sequencing, so that the tasks of each AGV reached the overall optimum evenly. Zhu[9] proposed an improved genetic algorithm to optimize AGV task allocation and task sequencing, which solved the problem of multiple AGV scheduling for material transportation in the batching area.

In summary, most scholars optimize the scheduling system from the synchronous scheduling of tasks and AGVs and the AGV conflict-free path planning, so that the efficiency of the scheduling system is improved to a certain extent. Aiming at the problem of effective AGV resource waste in e-commerce intelligent storage, this paper proposes a "Tandem" or "parallel" method to realize the synchronous scheduling method of ordering table assignment order task and order task assignment AGV. The scheduling rule is used to transform the large-scale AGV scheduling problem into Obtaining a Better Solution to a Mathematical Programming Problem.

2. Warehouse AGV scheduling

E-commerce smart warehouses usually use grid maps, which are mainly composed of cargo storage area, cargo picking area, buffer area and AGV queue area, as shown in figure 1. An order picking process can
be broken down into a series of order tasks. Each order task corresponds to a shelf and a picking table. AGV completes the handling of the rack between the cargo storage area and the picking table.

Figure 1. Schematic diagram of e-commerce intelligent warehouse.

2.1. Overview of the assignment problem and the Hungarian algorithm
In the mode of simultaneous picking out of multiple picking tables, all picking tables share all AGVs[1]. The traditional scheduling method assigns an order task to the picking station one by one, and at the same time assigns the closest AGV to the order task one by one. This is a locally optimal assignment method. Different orders have different quantities of goods, different picking table operators take different time to pick the same goods, and the distance from the shelf to the picking table is also different. This has led to a number of picking stations in the warehouse waiting for the AGV to transport the shelves to the picking table. There are multiple AGV queues in the queuing area, which wastes effective AGV resources. This article optimizes the assignment problem from the perspective of the order task and the goods that make up the order task. Although the distance between the shelf of the order task and its corresponding picking station is determined, the distance between the shelf of different order tasks and different AGVs is different. The optimal assignment of batch order tasks and batch AGVs is obtained to optimize the order task assignment. AGV. Splitting the order task on the picking table under the limitation of the limited number of bins on the picking table, on the one hand, the order task is limited to a small scale, and the Hungarian algorithm can be effectively used to obtain the optimal solution, on the other hand, the results take the efficiency of different picking stations into account.

The Hungarian algorithm is a more common method for solving assignment problems. The theoretical basis of this method is: any row or column of the cost matrix (benefit matrix) plus or minus a constant optimal allocation scheme will not change[10]. The cost matrix is modified by adding or subtracting the same constant for each row or column until the benefit matrix has at least one zero element in different rows and columns, and the zero element corresponds to an optimal allocation scheme with the smallest total cost.
2.2. Order task and AGV assignment method

The time required for all assigned order tasks of the picking station $s$ to complete the picking is defined as the number of connections of the picking station $s$, which is recorded as $c_s$.

$$c_s = \sum_{i} \sum_{j} n_{ij} \cdot t_{\text{pick}}$$

Among them, $n_{ij}$ is the quantity of j-type goods in the i-th order task, and $t_{\text{pick}}$ is the average picking time of the operator.

The average time for the AGV to move from the goods storage area to the picking station is defined as $t_s$.

$$t_s = \frac{d}{v_{\text{avg}}} + \alpha$$

Among them, $d$ is the average distance between the AGV and the shelf, $v_{\text{avg}}$ is the average running speed of the AGV, and $\alpha$ is the adjustment factor.

When $c_s < t_s$, there may be a phenomenon that the operator waits for the AGV to transport the shelves at the picking station $s$, which is defined as "no-load warning of the picking station". When the number of AGVs in the queuing area reaches the maximum capacity of the queuing area, buffer traffic congestion may occur and is defined as "full load in the queuing area AGV"; when the number of AGVs in the queuing area is close to the maximum capacity of the queuing area, it is defined as "alarm full load in the queue". When "queue area AGV is fully loaded" and "picking station empty load warning" does not occur, it is defined as "picking station load balancing".

When the "queuing area AGV full load warning" or "queue area AGV full load" phenomenon occurs, traffic congestion may occur in the buffer area, thereby reducing the efficiency of the dispatching system and wasting limited AGV resources. This paper proposes a "bucket model" for ordering tasks assigned by the picking station. By limiting the number of AGVs that can be queued by the picking station, local buffer blockages can be avoided. The capacity of the bucket is $c_{\text{bucket}}$.

2.2.1. "Tandem" Assignment of Order Tasks and AGVs. When the "no-load warning of the picking station" occurs, the "tandem" assignment method is used to complete the order task and AGV assignment, so as to increase the number of connections to the picking station as soon as possible. The "tandem" assignment method is defined as follows: first, the picking station assigns order tasks; second, the order task assigned by the picking station assigns AGVs. Through the "Minimum Number of Connections" model of the picking table order task, the ordering task is assigned to the picking table poll to increase the picking time of the goods to be picked until the picking station releases the no-load warning or the picking table has no assignable order tasks. After the picking station assigns order tasks, the picking station may also change from "no load warning" to "full load", and the number of order tasks assigned by the picking station will also be limited by the bucket capacity. In order to complete the picking of certain orders as soon as possible, polling assigns the order tasks with the highest priority to the picking stations with the least number of connections. Due to limited AGV resources, polling assigns order tasks to the picking station with the most serious "picking station empty load warning" and updates the number of connections; in order to ensure the validity of order task assignments, the total number of assigned order tasks cannot exceed the total number of available AGVs. After the order task assignment of the picking station is completed, the assignment between the order task and the AGV is realized by the assignment algorithm. The number of order tasks is equal to the AGV, so the assignment process is a balanced assignment, and a standard Hungarian algorithm can be used to obtain the optimal assignment result.

2.2.2. "Parallel" Assignment of Order Tasks and AGVs. When "picking table load balancing" occurs, all the picking stations have a certain number of picking tasks. Whether or not an order task is assigned to one of the picking tables immediately does not immediately result in "picking table empty". In this scenario, the order task and AGV "Parallel" Assignment appears. The "parallel" assignment method is
defined as the use of an assignment algorithm to complete the assignment of all order tasks and all AGVs, and the order task in the assignment result is the result of the order task assigned by the picking station. All AGVs are assigned through all order tasks, and the current total benefit assignment scheme is obtained, but the blockage of the buffer will seriously reduce the efficiency of the scheduling system. Therefore, when ordering tasks and AGV assignments are completed by the assignment method, the number of order tasks that can be retained at each picking station is calculated based on the capacity of the bucket. The results of ordering tasks assigned to the picking station are tailored in consideration of task priorities. Put the excess, lower priority order tasks in the picking table back into the order task pool. In order to complete the picking of the order as soon as possible, it is necessary to ensure that the priority order task is assigned first when assigning. In the "parallel" assignment process, when the assignment result of the order task assignment AGV was obtained through the assignment method, the work of assigning order tasks to the picking table was also completed. Generally, the number of order tasks is greater than the number of AGVs. The assignment process is an unbalanced assignment, which can be achieved by improving the Hungarian algorithm.

2.3. Improved Hungarian algorithm for order tasks assignment AGVs

This article specifies the rows of the benefit matrix represent the order task, the columns represent the AGV, and the element \( c_{ij} \) in the matrix represents the cost of the i-th order task completed by the j-th AGV. When the Hungarian algorithm completes the order assignment task AGV, there are usually three scenarios: "less tasks than AGV", "the number of tasks equal to the number of AGVs", and "more tasks than the number of AGVs". When "the number of tasks is equal to the number of AGVs", the standard Hungarian algorithm can complete the assignment, and each real task can be assigned to a real AGV. When "the number of tasks is less than the number of AGVs", the imbalance problem is converted into a balanced assignment problem by "adding zeros and adding edges". All real tasks can be assigned to the AGV, even if the virtual task is assigned the real AGV, which does not affect assignment policies. However, when "the number of tasks is greater than the number of AGVs", the "plus-zero" method does not guarantee the priority assignment of tasks with high priority. The possibility of virtual AGV assignments can be reduced by maximizing the cost of ordering tasks to assign virtual AGVs.

In the grid warehouse map, assuming that the rack of the i-th order task is at \((p_i, q_i)\), and the j-th AGV is at \((m_j, n_j)\), then the rack of the i-th order task is moved by the j-th AGV, whose basic cost can be defined as \( \text{base}_{ij} \).

\[
\text{base}_{ij} = |m_j - p_i| + |n_j - q_i|
\]

In order to meet the priority assignment requirements, the cost matrix needs to be restricted as follows: order tasks with the same priority need to have only the difference in the base cost \( \text{base}_{ij} \); when the same AGV is assigned; when order tasks with different priorities are assigned the same AGV, they differ. There is a significant difference in the cost \( c_{ij} \) between priority order tasks, and order tasks with higher priority can be assigned priority AGV. In order for some order tasks to be completed as quickly as possible, the priority of all order tasks can be dynamically modified, and the order task priority is defined to increase as the value increases. Therefore, the base cost matrix is tiered according to the order task priority.

\[
c_{ij} = (p_{\text{max}} - p_j) \times \alpha + \text{base}_{ij}
\]

Among them, \( \alpha \) is the Manhattan distance on the diagonal of the grid map, \( p_j \) is the priority of the j-th task, and \( p_{\text{max}} \) is the highest priority of all current tasks.

3. Experiment and simulation

In this paper, experiments are performed to verify the effectiveness of the improved Hungarian algorithm when the order task is assigned to the AGV, and the simulation is used to verify the effectiveness of the proposed method for improving the performance of the scheduling system. According to the map shown in Figure 1, the simulation environment of the storage scheduling system was used on a PC to conduct a simulation experiment. The size of the shelf area used for the simulation...
was 47 * 33. In order to complete the validation of the improved Hungarian algorithm, when initializing the environment, the initialization of the three scenarios is completed by setting different numbers of tasks and available AGVs. "The number of tasks is less than the number of AGVs". Assuming that three order tasks (T1, T2, T3) and four AGVs (A1, A2, A3, A4) with the same priority are added. Virtual task T4, which converts unbalanced assignments into balanced assignments, Examples of benefit matrix and transformation results are as follows.

\[
\begin{bmatrix}
14 & 22 & 13 & 45 \\
8 & 12 & 23 & 23 \\
19 & 24 & 14 & 12 \\
0 & 0 & 0 & 0
\end{bmatrix}
\rightarrow
\begin{bmatrix}
1 & 5 & (0) & 32 \\
(0) & 0 & 15 & 15 \\
7 & 8 & 2 & (0) \\
0 & (0) & 0 & 0
\end{bmatrix}
\]

The assignment results of the improved Hungarian algorithm are (T1, A3), (T2, A1), (T3, A4), (T4, A2). All order tasks are assigned AGV, and there is no need to care about the task priority strategy during the assignment process. Similarly, when the number of tasks is equal to the number of AGVs, the standard Hungarian method can be used to complete all order tasks and assign all AGVs, and there is no need to care about the priority strategy. In the case of "more tasks than AGVs", it is assumed that there are 5 order tasks (the priorities are 2, 0, 1, 2, 1) and 4 AGVs. The balanced assignment is converted to a balanced assignment. An example of the efficiency matrix and transformation results is as follows.

\[
\begin{bmatrix}
18 & 27 & 9 & 43 & 43 \\
36 & 25 & 28 & 16 & 36 \\
29 & 66 & 43 & 24 & 43 \\
33 & 15 & 26 & 44 & 44 \\
18 & 34 & 59 & 31 & 59
\end{bmatrix}
\rightarrow
\begin{bmatrix}
18 & 27 & 9 & 43 & 43 \\
196 & 185 & 188 & 176 & 196 \\
109 & 146 & 123 & 104 & 146 \\
33 & 15 & 26 & 44 & 44 \\
18 & (0) & 11 & 29 & 9
\end{bmatrix}
\rightarrow
\begin{bmatrix}
9 & 18 & (0) & 34 & 14 \\
20 & 9 & 12 & 0 & (0) \\
5 & 42 & 19 & (0) & 22 \\
18 & (0) & 11 & 29 & 9 \\
(0) & 16 & 41 & 13 & 21
\end{bmatrix}
\]

The results assigned by Hungary are (T1, A3), (T2, A5), (T3, A4), (T4, A2), (T5, A1). Higher priority order tasks are assigned to real AGVs, and lower priority tasks are assigned virtual AGVs.

In the AGV scheduling simulation environment, the number of warehouse picking stations $N_{\text{station}}$ is set to 7, and the maximum capacity $c_{\text{bucket}}$ of each picking station queuing area is 8. According to experience, the capacity of the bucket $c_{\text{bucket}}$ is set to $c_{\text{bucket}}$ when the "picking table load balancing" is performed. The "unloading warning of the picking station" and "full warning of the AGV of the queuing area" set the leaking bucket capacity $c_{\text{bucket}}$ to $c_{\text{bucket}} + m$, $(m = 0, 1, 2, \ldots)$, and the m experience value is set to 2, which reduces the picking station to a certain extent No-load and buffer jams occur.

The multi-picking platform synchronous operation mode scenario and the composition of the order goods are very complicated. The same order may be picked by different picking stations in multiple simulations, and different picking platforms have different picking efficiency for different goods, so it is difficult to compare the effectiveness of different scheduling methods from a single order perspective. In this experiment, for multiple sets of order tasks, the traditional scheduling method and the synchronous scheduling method using "Tandem" or "parallel" assignment methods are respectively used to measure the performance of different scheduling methods by the average time for the completion of the same batch of orders. In the simulation environment, different numbers of AGVs are used for different batches of order tasks. The traditional scheduling method and synchronous scheduling method are used to complete 10 order pickings respectively, and the average of the order picking time is obtained. Among them, the order task completion time of a group of order tasks with different scheduling methods is shown in figure 2.
Experimental results show that the synchronous scheduling method improves the order picking efficiency to a certain extent. When the number of AGVs is large, although the load saturation of the rack handling aisles in the cargo storage area makes local traffic jams prone to occur, it also improves the picking efficiency of operator orders to a certain extent.

4. Conclusion
The experimental simulation results show that the "sequential" or "parallel" synchronous scheduling method can effectively improve the order picking efficiency, reduce the occurrence of buffer traffic jams, and improve the utilization of limited AGV resources. In the assignment process, in order to ensure that the total cost of order tasks performed by AGV is minimum and the effectiveness of the order task priority assignment strategy is improved. The Hungarian algorithm is improved as follows: (1) Manhattan between order shelves and AGV is used Distance is used as the base cost of the cost matrix; (2) Unbalanced assignments of "Order task less than AGV quantity" and "Order task greater than AGV quantity" are respectively adopted by "adding zero and adding margin" and "maximizing by adding margin" The problem turns into a balanced assignment problem; (3) The staging of the base cost through task priorities.

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