Research on Order Batching Strategy Based on (Q,T) Time Window

Jingjing Duan *, Jinbo Liu, Yahui Wu, Yan Yan, Naifa Gong

Radar Nco School of Air Force Early Warning Academy, Wuhan, Hubei, 430019, China
*duan_jingjing9510@qq.com

Abstract. Intelligent warehouse picking is to first receive and integrate customer orders, and then carry out task assignment and picking according to order information. When the number of orders received in a certain period of time is large, and the number of items in a single order is large, picking one by one will seriously reduce work efficiency. In order to improve efficiency, the warehouse system can carry out order batch, that is, multiple orders are summarized, the goods with the same attributes are integrated and selected in batches, and then handed over to the finishing desk staff for processing and packaging. This paper studies common order batching strategies, and proposes (Q,T) time window batching strategies on the basis of static and dynamic time window strategies. This strategy ensures that each order is selected in time, the amount of single batch picking does not exceed the maximum load of batch picking, and the sorting is balanced in each time period, which has obvious advantages.

Keywords: Order batch; Time window; (Q,T) Time window

1 INTRODUCTION

In the environment of rapid development of e-commerce, logistics activities need to meet the personalized, real-time and efficient needs of customers. Large logistics centers are receiving a large number of orders at all times, and the orders are small batches, multiple batches and other characteristics, intelligent warehouses need to improve their service capabilities with a shorter response cycle and a more accurate feedback process. According to statistics [1], the picking operation time is about 30%-40% of the total storage operation time, and the cost of the picking operation is about 60% of the total storage cost. It can be seen that the improvement of the efficiency of the picking operation has become a key bottleneck for the optimization of the intelligent storage system. To this end, the sorting efficiency of the intelligent warehousing system can be improved by integrating orders with the same item and time attributes, that is, order batches.

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2 SUMMARY OF ORDER BATCH STRATEGY

The existing order batching is mainly studied from two perspectives: order batching based on similarity and order batching based on time window.

2.1 Order Batch Research Based on Similarity

Similarity-based order batch research refers to the classification of orders according to the main characteristics of the order, which can be concentrated to improve the efficiency of picking. The main algorithms are seed algorithm, saving algorithm and clustering algorithm. The seed algorithm is divided into two stages. The first stage, select the seed order stage. Select an order from the order set as a seed order according to specific selection principles, such as random seed principle, maximum number of items principle, minimum storage-roadway ratio principle, etc. The second stage, the order consolidation stage. Select some orders from the remaining orders and combine them with seed orders to form a pick batch according to specific order consolidation principles, such as randomization, minimum additional storage, maximum number of identical laneways, etc. The saving algorithm was first used in vehicle routing problems [2] and later applied to order batch consolidation. It groups the two orders with the greatest savings after selecting the merge into the same batch, then treats them as a single order, and repeats the merge in the remaining orders until the maximum is increased. The saving algorithm can effectively reduce the length and time of picking.

2.2 Order Batch Research Based on Time Window

The study of order batch based on time window is suitable for the continuous dynamic arrival of orders, the high penalty cost of order time or the significant characteristics of order arrival time. The batching process needs to consider how to adopt the batching strategy for the dynamic orders of the warehouse, which can ensure that the intelligent storage system can make full use of the warehouse selection resources to complete the order task[3]. Henokh,Y.F et al. [4] proposed a dynamic index order batch processing model, which could smooth the transition between time Windows and balance the operation amount of pickers with different abilities. Finally, mixed integer programming was applied to solve the problem, and the effectiveness of the model was verified. According to whether the time window is fixed or not, it can be subdivided into static time window batch research and dynamic time window batch research. Wang Xuping et al. [5] constructed an online order batching algorithm that comprehensively considered the urgency and similarity factors, adopted a fixed time window method, and established a mixed integer programming model to solve it. Ek,P.C et al. [6] used probability distribution function to describe the arrival of orders, built a queuing system model for order batches, and discussed the influence of batch processing time and batch size in dynamic time window on order picking delay time. Compared with static time window batching, dynamic time window batching takes into account the randomness of order items, number and order arrival time, and adopts the variable time window length to adapt to the arrival of batch orders, which has more practical significance[7].

3 ORDER BATCH STRATEGY BASED ON TIME WINDOW

The intelligent warehouse belongs to the state of real-time operation, receives a steady stream of customer orders, and is in a dynamic state of change. The arrival time of the order task is uncertain, the category and quantity of the selected goods are unknown, and the integrated order batch processing and assignment of tasks can enable the intelligent warehousing system to make reasonable decisions, greatly increase the number of orders delivered, and ensure the completion efficiency of the order task [6]. Batch picking is suitable for a warehouse system with a large number of orders and a small number of items per order, and the smaller the number of times the picking process, the higher the efficiency of batch picking. The intelligent storage system should integrate the orders of a certain period of time in batches and determine the selection of the order object, that is, the time window division. The reasonable division of time window is conducive to the balance of work load and the continuous uniform and stable operation of the system. This is the premise and foundation of multi-robot task assignment and path planning.

3.1 Static Windows in Batches

The static time-window batching strategy is the re-consolidation of all orders that arrive within a fixed period of time. This method is simple and easy, and only needs to determine the size of the time window at the beginning, and then carry out batch sorting at fixed intervals. However, if a large number of orders arrive in a certain time window, so that the time required for picking exceeds the time of the time window, then the batch picking operation in the subsequent time window must be postponed; If there are only a few orders in a certain time window, there will be a lot of idle waiting time between the completion of the batch pick and the next time window pick, which also fails to achieve the purpose of shortening the pick travel path that bulk pick has. It can be seen that due to the uncertainty of the arrival of warehouse orders, the adoption of fixed time window picking during peak and trough periods leads to discontinuous picking work and unbalanced workload, which affects the overall efficiency.

3.2 Batch of Dynamic Time Windows

The dynamic time-window batch strategy means that the warehouse sets fixed pick orders, regardless of the length of the time window, as long as the number of warehouse orders accumulates to the specified standard, batch picking begins[8][9]. This method can ensure that a certain number of pickings can be reached each time, so that the utility of the picking equipment can be fully utilized each time. However, due to the uncertainty of the arrival order time and quantity, the dynamic time window ignores the time requirement of a single order. Urgent orders need to be picked as soon as possible, and general orders also need to be picked and shipped within a specified time[10]. Therefore, the dynamic time window will reduce the quality of customer service. In addition, the need to wait a long time to meet the pick quantity requirements during the order trough will also cause a large number of blank pick times, resulting in discontinuous storage operations.

4 ORDER BATCH STRATEGY BASED ON (Q, T) TIME WINDOW

Based on the above analysis, static time window picking is suitable for the situation where the order arrival order is relatively stable, and can make reasonable use of the sorting facilities and equipment in the warehouse, but it is not conducive to dealing with the frequent arrival time of orders or idle time. The dynamic time window focuses on the utilization efficiency of storage sorting facilities and equipment, but neglects customer service satisfaction and lags in order completion time. In order to promote the smooth operation of storage sorting and ensure the customer's satisfaction, a new batch strategy, namely (Q, T) batch strategy, is proposed by combining the advantages of static and dynamic batch strategies. On the one hand, this strategy sets the maximum picking quantity Q of a single batch to ensure the stable and efficient operation of the warehouse, and can quickly process the order volume in peak hours to balance the picking demand in various periods. On the other hand, set the latest pick time T for a single batch to ensure that each order can be picked before the deadline to improve the quality of service. The specific analysis is as follows:

In the intelligent warehouse system, customer order demand will be received one after another over time, and this new order demand is a constant stream, and the order arrival information is unknown in advance. When the warehouse receives orders one after another $O_1, O_2, O_3 \ldots\ldots$, the warehouse system needs to reasonably divide the time line into a single time window $\{T_1, T_2, \ldots\}$, and batch process all orders within the specified time window T_i. There are a total of P kinds of goods in the warehouse, and the order collection $B_i = \{O_{i1}, O_{i2}, \ldots, O_{in}\}$ is collected in a certain time window T_i, which contains n orders, among which order $O_{ij} = \{V_{ij}, t_{ij}, q_{ij}\}$.

Then, the total weight selected in the time window T_i is

$$Q_i = \sum_{j=1}^{n} q_{ij}$$

The time window is

$$T_i = [T_{i-1}, t_{in}]$$

The key problem of the research is how to divide the reasonable time window $\{T_1, T_2, \ldots\}$ and summarize the orders in the time window for batch processing, so as to ensure the balanced operation among each time window and improve the efficiency of the system.

(1) Based on the above analysis, the model assumes the following conditions:

1) The order information is unknown until the order arrives
2) Each time window contains at least one order
3) Each order contains at least one item
4) Orders cannot be split, and individual orders can only be picked within an independent time window
5) Sufficient quantity of goods, known and fixed storage
(2) Define the constants and variables in the model as follows:

$V_{ij} = \left\{ x_{ij1}, x_{ij2}, \ldots, x_{ijp} \right\}$ represents the item vector of the goods contained in order O_{ij};

T_g is a fixed time window;

Q_g is the fixed pick quantity;

t_{ij} is the arrival time of order O_{ij};

q_{ij} is the weight of order O_{ij};

B_i is the i-th order set;

T_i is the i-th time window, it is from the end of the i-1 time window to the end of the last order O_{in}.

(3) Algorithm design ideas

Combined with the introduction of static time window order batching and dynamic time window batch method, both have shortcomings. On this basis, combined with the minimum picking quantity of warehouse batch processing and the time limit of order delivery, a (Q,T) time window batching algorithm was proposed. Ensure that each batch picking can maximize the continuity of the system picking and improve customer service satisfaction.

The basic steps of the (Q, T) time window batching algorithm are as follows:

Step 1: Initialize parameters: Fixed time window T, fixed picking quantity Q, order batch B is empty（$i = 1$）, initial time node $T_0 = 0$.

Step 2: When the new order $O_k \left(k = 1, 2, \ldots \right)$ arrives at the warehouse and $T_i < T_{i-1} + T_g$, proceed to Step 3; If $T_i \geq T_{i-1} + T_g$,then $T_i = T_{i-1} + T_g$, proceed to Step 5.

Step 3: Add order O_k to batch B_i, so that $Q_i = Q_i + q_k$, $T_i = T_i + t_k$.

Step 4: Determine if $q_k + Q_i < Q_g$ in order O_k. If so, proceed to Step 2; If not, proceed to Step 5.

Step 5: Order batch B_i has been completed and entered the task allocation and picking stage.

Step6： $i = i + 1$, form a new order batch B_i, B_i is empty, proceed to Step 2.

5 COMPARATIVE ANALYSIS OF TIME WINDOW BATCH STRATEGY

At present, there are significant differences in the quantity and characteristics of orders from different warehouses, and there is no standard experimental data, making it difficult to use a unified standard for measurement. To verify the effectiveness of the (Q, T) time window batching algorithm, it is assumed that the weight of orders arriving per unit time follows a Poisson distribution of $\lambda=10$, and 100 random numbers are generated simultaneously. The specific values are shown in Table 1 and Figure 1; The fixed time window length T_g is 10; The fixed picking quantity Q_g is 100.

Table 1. Order weights arrived following a Poisson distribution of $\lambda=10$ in the time series

Arrival Time	Weight	Arrival Time	Weight	Arrival Time	Weight	Arrival Time	Weight
1	12	26	17	51	10	76	15
2	6	27	5	52	11	77	12
3	6	28	10	53	5	78	13
4	16	29	15	54	8	79	9
5	11	30	10	55	8	80	8
6	10	31	12	56	2	81	6
7	7	32	7	57	13	82	8
8	9	33	13	58	13	83	15
9	5	34	9	59	8	84	8
10	10	35	15	60	7	85	9
11	12	36	6	61	4	86	7
12	6	37	11	62	11	87	12
13	13	38	12	63	8	88	15
14	14	39	8	64	21	89	13
15	6	40	9	65	8	90	11
16	12	41	8	66	7	91	6
17	11	42	7	67	4	92	15
18	14	43	10	68	12	93	7
19	15	44	11	69	13	94	15
20	14	45	16	70	14	95	14
21	10	46	10	71	7	96	12
22	6	47	10	72	1	97	12
23	8	48	9	73	7	98	11
24	12	49	5	74	11	99	12
25	9	50	12	75	14	100	10

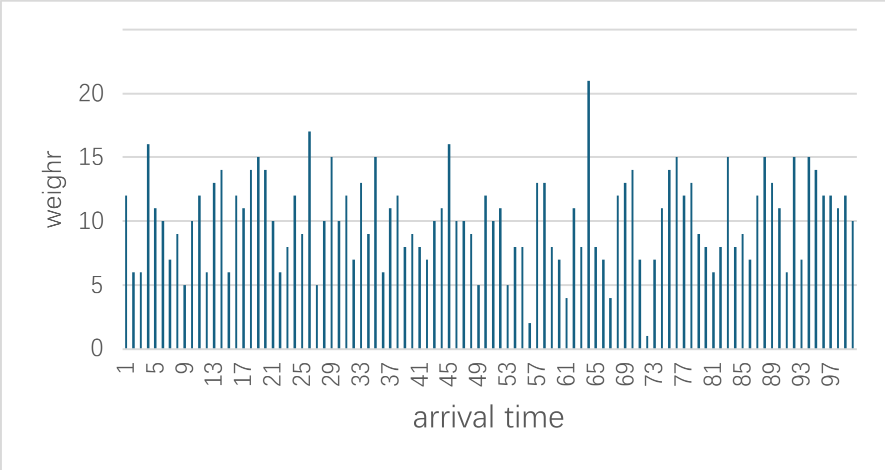

Fig. 1. Order weight arrived following a Poisson distribution of $\lambda=10$ in the time series

When using the static time window batching strategy for order batching, the batching result is（12，6，6，16，11，10，7，9，5，10），（12，6，13，14，6，12，11，14，15，14），（10，6，8，12，9，17，5，10，15，10），（12，7，13，9，15，6，11，12，8，9），（8，7，10，11，16，10，10，9，5，12），（10，11，5，8，8，2，13，13，8，7），（4，11，8，21，8，7，4，12，13，14），（7，1，7，11，14，15，12，13，9，8），（6，8，15，8，9，7，12，15，13，11），（6，15，7，15，14，12，12，11，12，10）.

Adopting a dynamic time window batching strategy for order batching, the batching results are（12，6，6，16，11，10，7，9，5，10，12）0，（6，13，14，6，12，11，14，15，14），（10，6，8，12，9，17，5，10，15，10），（12，7，13，9，15，6，11，12，8，9），（8，7，10，11，16，10，10，9，5，12，10），（11，5，8，8，2，13，13，8，7，4，11，8，21），（8，7，4，12，13，14，7，1，7，11，14，15），（12，13，9，8，6，8，15，8，9，7，12），（15，13，11，6，15，7，15，14，12）.

Using the (Q, T) time window batching strategy for order batching, the batching result is（12，6，6，16，11，10，7，9，5，10），（12，6，13，14，6，12，11，14，15），（14，10，6，8，12，9，17，5，10，15），（10，12，7，13，9，15，6，11，12，8），（9，8，7，10，11，16，10，10，9，5），（12，10，11，5，8，8，2，13，13，8），（7，4，11，8，21，8，7，4，12，13），（14，7，1，7，11，14，15，12，13，9），（8，6，8，15，8，9，7，12，15，13），（11，6，15，7，15，14，12，12，11）.

Based on the three different batch results mentioned above, the standard deviation of the weight of each batch in the static time window batch is 8.93, the standard deviation of the dynamic time window batch strategy is 5.19, and the standard deviation of the (Q, T) time window batch strategy is 5.28. Relatively speaking, the static time window batching strategy results in significant differences in the picking quantity between different time windows. The workload of the intelligent warehouse picking system is unbalanced in different time periods, and resources cannot be fully mobilized during low periods, leading to resource idleness and waste; The standard deviation of the dynamic time window batching strategy and the (Q, T) time window batching strategy are similar, both of which are relatively low, and can fully mobilize the picking equipment in the warehouse in the long term and maintain stable operation. However, compared to the (Q, T) time window batching strategy, the dynamic time window batching strategy resulted in time delays of 1, 0, 0, 1, 3, 2, and 1 unit, totaling 8 units of time delay, prolonging the waiting time for each batch of orders, especially affecting the later orders of that batch, reducing the warehouse's response speed, and affecting customer satisfaction.

Based on the above analysis, the advantages and disadvantages of different window batching strategies can be compared.

Static time window batching strategy When the length of the fixed time window is reached, the order begins to be batched. Its advantage is that it can be picked at a fixed time node, clear; Ensuring timely batch selection for each order improves customer service satisfaction. The disadvantage is that the number of orders in a single time window is unstable, which may be too small, or may exceed the unit time load; The adjacent time window may cause idle or delay.

Dynamic time window batching strategy When a fixed item weight is reached, the order begins to be batched. Its advantage is that each batch result can fully schedule the operation of the picking equipment, and improve the efficiency of single batch operation; The number of batches meets the minimum requirement, which facilitates subsequent task allocation and improves overall efficiency. The disadvantage is that it cannot ensure that orders in the low period are sorted in time; In the low period, the machine idle time is longer.

The (Q, T) time window batching strategy is that orders begin to be batched when a fixed time window or a fixed weight of goods is reached. Its advantage is to ensure that each order after arriving at the warehouse, timely batch selection; The amount of single batch picking does not exceed the maximum load of batch picking; Orders can be evenly distributed in different time periods for balanced sorting. The disadvantage is that the process is relatively complex and the combined influence of two factors needs to be considered at the same time.

It can be seen that (Q, T) time window batching strategy combines the advantages of the first two strategies, and comprehensively has more obvious advantages.

6 SUMMARY

On the basis of traditional warehouses, intelligent warehouses have added functions such as automated operation of storage equipment, informatization of business management, and intelligent decision-making assistance for business. For the intelligent warehouse receiving dynamic continuous customer orders, this paper proposes a (Q, T) time window batching strategy, which enables the system to pick smoothly and improve efficiency, laying the foundation for subsequent warehouse picking work. Due to the lack of time and energy, this paper only focuses on the time window factor to study the order allocation. In future research, it can be further studied or improved in the following aspects: (1) Combined with path planning research. Order batching strategy is closely related to sorting work. Considering the two factors comprehensively, it is beneficial to effectively improve the sorting efficiency of the warehouse. (2) Further refine the dynamic time window research. The existing research on time window is extensive and in-depth, and the subsequent research can be further expanded according to the characteristics of warehouse picking.

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