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The Collaborative Optimization of Order Batching and Sequencing for Online Supermarkets with Parallel Picking Strategy Consumption

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Abstract: In the face of the diversity and complexity of online orders, online supermarkets need to improve their sorting efficiency to meet increasing customer demands. Order batching and parallel picking are two key measures to improve the efficiency of order picking, which have been widely applied in practice. Order batching involves combining multiple orders into one batch for picking, inspection, and packaging. Parallel picking involves picking items simultaneously in multiple picking areas. This research investigates the collaborative optimization problem of batching and sequencing online supermarket orders under the parallel picking strategy, aiming to reduce the waiting time between processes and improve the overall sorting efficiency. The research provides an effective scientific method for large-scale online supermarket order picking problems, which can enhance customer satisfaction through the improvement of service efficiency and further strengthen the competitiveness of online supermarkets.

Keywords: Online supermarket, Parallel picking strategy, Batching and sequencing, Improved simulated annealing, Collaborative optimization.

1. Background of the Study

In 2022, The State Council of China promulgated the "14th Five-Year Plan for Digital Economy Development", which focuses on the deep integration of digital technology and the real economy, aiming to promote the collaboration and integration of online retail and traditional physical retail by enabling the transformation and upgrading of traditional industries, cultivating new industries, new formats and new models, and further promoting the development of online retail. At the same time, with the rapid development and wide application of mobile Internet, more and more consumers begin to buy goods through the Internet, and consumers' shopping habits are gradually shifting from offline to online. The rapid development of mobile e-commerce has led to an increase in consumer purchasing power and promoted a large number of transactions on China's B2C electronic trading platforms.

With the rapid development of B2C model, online retail has become a force that cannot be ignored in China's economy and society. Compared with ordinary online shopping, the orders of large online supermarkets have the following characteristics: (1) the number of orders is huge, with the average daily order volume in big cities reaching 60,000; (2) There is a large difference in the receiving time of the order, such as half-day delivery, scheduled delivery, and three-day delivery; (3) The variety of goods in a single order is rich. Compared with ordinary online stores, online supermarkets have millions of kinds of goods, and customers often choose to buy more goods at one time, resulting in an order containing many goods, the quantity and variety of which reach 8 to 10 times of the average online shopping. In addition, the cost of online supermarkets is 3% to 5% cheaper than traditional supermarkets [1], and it also has a huge advantage in terms of operating costs. Online supermarket shopping has gradually become a popular online retail model.

At present, the rapid development of online supermarkets has increased the complexity of order fulfillment business [2]. Hundreds of millions of orders are manually sorted and packaged in warehouses every day, and the resulting complexity of order picking solutions has also increased significantly. For example, Jingdong Supermarket has about 20 distribution centers and more than 200 delivery stations in Beijing, and can handle 4 million orders per day. If a day's delivery plan is divided into four times, the number of theoretically feasible distribution related sorting plans would reach nearly one billion.

As a result, large online supermarkets not only compete with general retailers in terms of product categories, quality and price, but also need to complete complex sorting plans within delivery times to improve efficiency. According to the survey, the order sorting cost accounts for more than 55% of the operating cost of the distribution center, and the sorting time accounts for 30% to 40% of the total operating time consumed by the distribution center [3]. Therefore, the optimization of the order sorting process plays a very important role in the entire order fulfillment process. For the daily fast food products with the highest sales frequency in online supermarkets, the general B2C e-commerce enterprises adopt the whole-waret-based order-to-order sorting or serial picking strategies [4], which are far from meeting the needs of large online supermarkets to select a large number of personalized orders in bulk commodities, resulting in new order picking strategies, such as parallel picking strategy. Using this strategy can speed up the fulfillment of orders and improve customer satisfaction. The parallel picking strategy requires pickers in different regions to pick a pick list at the same time, until the last item is selected, and finally combine the goods in each region to enter the subsequent process.

In large online supermarkets, goods need to be classified and stored according to the type and degree of correlation of goods to form multiple independent commodity storage areas, also known as picking areas. By placing fixed pickers in charge of picking the goods in the area, the allocation area for picking is reduced, which reduces congestion and improves efficiency in the picking area. Considering the diversity of commodity types and the uncertainty of customer demand, supermarkets need to combine commodity orders and divide them into multiple batches to improve the efficiency of picking.

Therefore, in order to reduce the cost of sorting and continue the e-commerce business model that provides great convenience for People's Daily life, how to batch and sort tens of thousands of orders under the new sorting strategy and carry out efficient and accurate selection of commodities is a key issue related to the survival and development of online supermarkets [5].

2. Order Batching and Sequencing Study

2.1. Order sorting system study

Order sorting is the process of extracting products from the warehouse according to the specific requirements of customers. In the entire distribution operation, order sorting is the most time-consuming and costly work. Coyle et al. [6] found through investigation that order sorting cost accounts for more than 60% of the entire distribution cost. Due to the greater flexibility of manual sorting, which is used in 80% of warehouses [7], picking is the most labor-intensive operation in warehouses using manual systems and a very capital-intensive operation in warehouses using automated systems. For these reasons, Goe et al. [8] believe that order picking is a warehouse operation that must be repeated for each order, which has a great impact on the service efficiency of the distribution center and is a priority area that can improve productivity the most. Because order picking is an important object of order sorting system optimization, order picking is further studied to improve the service efficiency of distribution center.

Studies of sorting systems consider different optimization objectives. The most common optimization goal for order sorting systems is to maximize service levels within resource constraints such as labor, machinery, and cost. Service levels are made up of a variety of factors, such as average and variation in order delivery times, order completeness and accuracy. Graves et al. [9] believe that response time is the primary optimization goal for service warehouses containing small orders with digital information. For the sorting system with pre-sent information for small orders, the primary optimization objective is cost; For large orders with pre-sent information, the optimization goal is to focus on the accuracy of sorting. In addition, a key link between order sorting and service level is that the faster an order can be retrieved, the faster it can be sent to the customer, leading to the conclusion that minimizing order sorting time is an optimization goal for all order sorting systems. Iwasaki et al. [10] proposed to treat the order sorting problem as an assembly line problem, regard the order as the work in the flow operation, determine the sorting path and shelf priority relationship, establish a model to minimize the sorting time as the objective function, and study the crowding problem of sorting personnel on the same shelf in the logistics center. For the manual sorting system, Jarvis et al. [11] pointed out that the travel time in the order sorting system is an increasing function of the travel distance, and the picking journey takes a large proportion in the whole sorting process, so the picking journey can be regarded as an important goal for design and optimization. Other goals often considered in the design and optimization of sorting systems are: minimizing order throughput time, minimizing total throughput time, maximizing space use, maximizing equipment use, maximizing labor use, and maximizing the use of all items. For the realization of these goals, the decisions that enterprises need to make in the order sorting system are mostly divided into the following types [12] : layout and scale of the storage system, location allocation, order batching and partitioning, path allocation of order picking, ordering of order sorting process units, and order accumulation. Petersen[13] studied the influence of factors such as the shape of the partition, the number of shelves and the layout of the warehouse on the travel distance of the partition picking; Le Duc et al. [14] studied the influence between the number of partitions in the parallel partition and the total picking time; Brynz[15] combined the order merging strategy and the serial picking strategy to carry out numerical experiments. It is found that the distribution equilibrium can improve the sorting efficiency. Tappie et al. [16] studied the relationship between the size of the picking buffer and the sorting efficiency of the sorting system. Li et al. [17], aiming at the order batching problem under e-commerce, preprocessed the order by association rule mining algorithm, and proved the feasibility of the algorithm through simulation experiments. Leung et al. [18] developed an order system in which the strategy of order batching is to select the shortest moving distance. Mellema[19] combined the order consolidation strategy and the parallel picking strategy to improve the picking efficiency, and found the factors affecting the average walk time through simulation experiments. Wang Xuehui [20] considered the total order delay time, default rate and total performance cost to jointly optimize order selection and delivery. The above decisions are highly interdependent; for example, certain layouts or storage allocations may work well for some routing policies and poorly for others.

2.2. Order batch study

Order batching is the process of combining or splitting customer orders to the picker. When the customer order is large enough, a customer order can be picked up separately or the customer order can be split, that is, only one order or part of an order is picked up per pick trip. When orders are fairly small, multiple customer orders can be regrouped in batches into one set of pick orders to reduce travel time, order batch is a method of dividing a set of orders into multiple subsets, each subset can be retrieved through the process of picking. In order to avoid delivery delays, orders need to be sorted within a certain time range, that is, there is a completion time period. Batch processing standards are important for order batching. Some scholars use the closeness of the time window as the batch processing standard [21]. The unified time window batches orders by time segmentation, while the variable time window mostly fixes the order quantity of each batch. Order batch processing is a NP-hard problem, and many researches use heuristic algorithms to batch. The earliest algorithm is priority rule algorithm, which gives priority to orders and then batches according to the priority rule of batches to generate batch results. Daniel et al. [22] scored in batches according to the indicators to measure whether the characteristics of transport vehicles meet the material handling requirements, and calculated the scores through the weighted evaluation method and the expected value criterion of risk decision-making. Lam et al. [23] proposed an order sorting operating system to help make order batch plans, which integrated mathematical models and fuzzy logic techniques. In the study of batch algorithms, the seed algorithm and the saving algorithm are the most used algorithms. The seed algorithm constructs batches through two stages: seed selection and sequence rules, whose sequence rules include: Random order, the number of items ordered, the time period of sorting, the distance of items ordered, etc., add seeds to the batch in turn by order rules [24]. Elsayed et al. [25] adopted the seed algorithm for single-channel pickers in the Automated Storage and Retrieval System (AS/RS), while De Koster et al. [24] adopted the seed algorithm for multi-channel systems. The idea of the saving algorithm is based on the classical heuristic method in the vehicle routing problem. Some scholars have improved the saving algorithm: every time the merging step of an order is completed, the saving value sequence of the entire open order set is recalculated. Tang[26] took into account the batch strategy with a fixed order volume and manually sorted randomly arrived orders to fill a fixed number of order batches. They determined the batch size by estimating the first time point and the second time point of the service time. The results of simulation experiments showed that this method provided high accuracy. This kind of research usually aims at the minimum delay time cost or the sum of pick time and delay time cost, and uses heuristic algorithm or meta-heuristic algorithm to solve. Sarah et al. [27] considered the dynamic time window in the batching problem and solved the problem of workload balance. Zhu et al. [28] proposed a heuristic clustering algorithm to optimize the assignment of tasks among multiple warehouses. Based on the assignment of orders, the number of order batches should be reduced to minimize the total number of order divisions. Chen et al. [29] adopted the clustering method, built an order batch model, and solved it by association algorithm. Li Shizhen [30] concluded through the study of commodity characteristics and picking strategies that a reasonable partitioning strategy can effectively reduce the picking path and picking time, and introduced the concept of equipment utilization rate for the first time, analyzed the order batch picking model and algorithm, and considered the research of multi-system synchronous picking. Qin Xin et al. [31] optimized the order batching strategy through genetic algorithm and improved the sorting efficiency of the logistics center.

On the other hand, the order batching strategy implements batching [34] based on objectives: time window for order arrival [32], proximity of warehouse storage locations, total time to complete sorting [33], and delay time. In the study of the optimization goal of order batch, some scholars believe that response time is the primary optimization goal of service enterprise warehouse. Koster[35] believes that the optimization objectives of sorting systems with different attributes are also different. Tsai et al. [36] constructed an order batch optimization model aiming at minimizing the sum of distance cost and penalty cost for early or late completion, and adopted multi-stage genetic algorithm to solve it. Azadnia et al. [37] considered the completion time of orders, constructed an association rule algorithm with weights to calculate the correlation degree among orders, built an order batch optimization model with maximum correlation degree among orders, and used the genetic algorithm to solve the traveling salesman problem to solve the optimal selection path of the combined batches. Some scholars have studied the order batching problem considering workload balance under parallel partition selection. Li Zhenping et al. [38] built an order batching model with the minimum shelf handling times as the most objective based on the clustering idea. Some scholars also studied dynamic partition and established a parallel partition order batching model [39].

3. Batch Order Sequencing Study

Batch order ordering is an important problem in order sorting system, which is to minimize the total picking time by allocating batches reasonably. Henn[40] processed orders according to the order order and the start date of the batches to avoid the delay in sorting customer orders. He used tabu search [41] to study order ordering, and further optimized it by mountain climbing algorithm based on this, and adopted variable domain search algorithm in subsequent research [42]. The order ordering problem further improves the efficiency of distribution. Zhang Yigong and Wu Yaohua [43] used ant colony algorithm to solve the order ordering problem, and found that the quality of solving time and settlement is better than genetic algorithm and simulated annealing algorithm. Mattews[44] studied the order ordering problem in single selection system with integer programming method. Tsai et al. [45] believe that the order ordering problem must minimize lead time and delay time, and adopt multiple genetic algorithms to solve it, so as to generate the optimal batch order ordering plan. Hong et al. [46] proposed an integrated batch and sorting process called an indexed batch model for a precisely controlled mixed-integer programming solution, and designed a simulated annealing program to solve large practical problems. The results showed that the proposed method reduced the total process time by 5-15% by reducing the blocking between the picking processes.

4. Cooperative Optimization of Batch and Sorting of Order Sorting System Study

In 1993, Elsayed et al. [47] studied the problem of order batching and ordering, aiming to minimize order delay and early arrival penalty cost, and adopted effective simulation methods to realize immediate order sorting. Azadnia et al. [37] built an order batch optimization model with maximum correlation degree among orders. After solving the optimal selection path of the combined batch using the genetic algorithm for solving the traveling salesman problem, the sorting order of the generated batch is sorted using the genetic algorithm to minimize the delay time. Aiming at minimizing the total order delay time, Henn et al. [48] studied the joint optimization problem of batching and ordering considering the order completion time period and constructed two different meta-heuristic algorithms: local iterative search and mountain climbing algorithm based on commodity attributes. Bustillo et al. [49], aiming at minimizing the order delay time, studied the order batching and ordering problem considering the order completion period, and adopted the variable neighborhood search algorithm to solve it. In 2015, some scholars carried out collaborative optimization of order batch and batch ordering of customer orders. Chen et al. [50] built a joint optimization model of order batch ordering and picking path to minimize order delay cost, and proposed an effective hybrid heuristic algorithm to solve the problem. Secondly, ant colony algorithm is used to plan the picking path. Wu Yingying et al. [51] put forward the concept of order coupling factor in the sorting system and established a mathematical model. Through multiple iterations of the improved K-Means clustering algorithm, the order ranking results were optimized. On this basis, Le Duc [52] expanded the picking area to minimize the sorting time and estimated the batch size of the order batch through the throughput time. Huang et al. [53] studied the order batch optimization problem considering order batch ranking and order completion time, and proposed an improved grouping genetic algorithm. She established an optimization model and solution method for order group sorting in large online supermarkets [54]. Based on the calculation model of operation time of each process in the order sorting process, she established a joint optimization model for order batching and ordering, and proposed a two-stage heuristic optimization method based on the idea of reducing the solution space. The effectiveness of the algorithm was proved through application case analysis and sensitivity analysis, and in 2018, a mathematical optimization model was established and solved by dual-objective genetic algorithm [55]. Secondly, a batch order sequencing model was established and a solution algorithm based on pseudo-Boolean optimization was developed. However, there was a lack of research on the practical problem of multiple facilities and operators in the process. Peng [56] proposed the optimization model of order batch for various warehousing systems, and developed the distance algorithm, path algorithm and order batch processing algorithm. The algorithm package of planning algorithm and order batch processing algorithm can be used to solve this problem. The research progress of this problem can learn from the assembly line balance and sequencing problem. For example, Faccio et al. [57] combined the employee assignment problem with the rhythmic mixed-flow assembly line balance and sequencing problem, and used a hierarchical method to solve it. Li et al. [58] co-optimized the order balance and ordering problem and applied the simulated annealing algorithm to solve it. Compared with the symbiotic genetic algorithm proposed by Kim, Li et al. [58] obtained a better result, indicating the good adaptability of the simulated annealing algorithm. Scholz et al. [59] took the total order delay time as the objective function and established a collaborative optimization mathematical model based on order batching, sorting and personnel selection paths for solving small-scale problems. Defersha et al. [60] proposed a hybrid genetic algorithm to solve the balancing and sorting problem and the workstation planning problem. Lopes et al. [61] combined the buffer allocation problem and the balancing and sorting problem for co-optimization, proposed a combinatorial cooperative optimization model for such problems, and proposed an iterative decomposition framework to solve such cooperative optimization problems. Yang et al. [62] proposed a formula to measure order similarity, which further improved the picking efficiency. Feng Ailan et al. [63] considered the retention time of the order and designed a genetic algorithm with the goal of minimizing the retention time of the order to solve the batting and sequencing of the order. Constraint programming method has achieved great success in solving combinatorial optimization problems [64-65], and IBM developed constraint programming module for its widely used solver CPLEX. Ozturk et al. [66] included the production sequencing problem into the research scope, optimized the task assignment problem and production sequencing problem at the same time, and established a constraint programming model for the unilateral assembly line balance and sequencing cooperative optimization problem aiming at the minimum completion time.

5. Literature Review Summary

To sum up, in terms of order sorting system, relevant scholars have considered the batch process of order and order batch ranking in the order fulfillment process of online supermarket, and the research on order picking system of online supermarket needs comprehensive consideration. At present, most of the researches on order batching and ordering are based on hierarchical optimization, and most of the researches on collaborative optimization of the two focus on horizontal transfer between single or multiple warehouses, and there is a lack of further research on the parallel picking strategy in the coordination problem.

There are a lot of unfinished work in order system batching and ordering problems, which need to be further studied by future researchers. Specifically, based on the current issues, the direction of future work can include the following aspects.

(1) Try to use more algorithms to solve and optimize the model. In this paper, improved simulated annealing algorithm and improved genetic algorithm are used to solve the collaborative optimization problem of order batching and sorting. Other heuristic algorithms such as ant colony algorithm, tabu search algorithm and enhanced machine learning algorithm can also be tried. The advantages and disadvantages of different algorithms for solving this problem are analyzed.

(2) In the actual picking process, there may be a certain probability of failure in the audit, so as to roll back the order to re-pick, it is necessary to design an efficient order rollback strategy to ensure that the returned orders are re-batched or individually batched, as well as to formulate how to sort the orders after the rollback, optimize the model, and make the order system more realistic.

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