Order Batching Optimization Model Considering Batch Quantity and Product Suitability

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Abstract. With respect to the order-batching problem in online supermarkets, this paper proposes a multi-objective optimization-based method. First, the basic assumptions and notations of the order batching optimization problem are described. Then, with the consideration of goods-batch, order-batch, weight limit, and volume limit, a multi-objective optimization model for order batching optimization is built with the objectives of maximizing the fitness degrees among different goods in the same batch and minimizing the number of order batches. Furthermore, based on the property of the built model, an improved genetic algorithm is designed. Finally, a numerical example in the context of "one order, multiple products" in an online supermarket is given to illustrate the feasibility of the proposed order batching optimization method. Meanwhile, to illustrate the effectiveness of the proposed order batching optimization method, the proposed order batching optimization method is compared with the existing order batching methods. The comparison results show that the proposed order batching method can significantly improve the suitability of the same batch of products with a better batch quantity.

Keywords: order batching · product suitability · number of batches · multi-objective optimization · genetic algorithm

1 Introduction

In recent years, online supermarkets have become an important part of the rapid development of e-commerce in China. Large online supermarkets have become one of the mainstream merchandise retail channels, such as Jingdong Supermarket, Tmall Supermarket, Suning Tesco, etc. Compared with the traditional B2C online retailing model, the orders received by online supermarkets are characterized by large quantities and a wide variety of products. Due to the limited inventory capacity and the different storage conditions for various types of goods, online supermarkets establish multiple warehouses in major cities to handle the warehousing of goods. Therefore, in the face of multiple orders from customers, order splitting has become the preferred strategy of online supermarkets, i.e., a single multiple-item order is split into multiple sub-orders according to

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quantity or category, and then an order is split into two or more batches for order picking, merchandise packing, and parcel delivery.

Order processing is the primary aspect faced by online supermarkets receiving customer orders, and the order processing results determine the cost of subsequent order fulfillment. In order splitting optimization processing, scholars at home and abroad mainly consider time window splitting, single product aggregate quantity splitting, fixed order quantity splitting, intelligent splitting, etc. Zhu et al. [4] Consider to reduce the order splitting to reduce the cost, established the optimization model to minimize the number of order splitting as the total goal, the model is based on the multiple category orders to optimize the product category allocation between multiple warehouses, and proposed a K-links heuristic clustering algorithm, to minimize the total number of order split. Zhang et al. [5] proposed a multi-commodity network flow model to determine the combination of warehouses for each order, and decomposed the model into a general multi-commodity network flow master problem and a set of conflicting commodity packing problems with a logic-enhanced Benders decomposition algorithm to minimize the total logistics cost of the order fulfillment process. Wang et al. [3] considered the shortest travel distance of pickers as the goal for optimization, and propose a data allocation mechanism (DBA) based approach to improve order picking operations by assigning goods to appropriate storage locations, thereby reducing the travel distance of pickers in the order picking process and improving picking efficiency. Zhang et al. [6] considered the joint objective of minimum order completion time and minimum picking cost, introduce the learning effect of pickers on the joint objective, and propose an online algorithm A with a competition ratio of 2. By this algorithm, it is concluded that the learning effect of pickers has a positive impact on the joint objective.

In addition, scholars have already designed algorithms for solving the order batching model. For example, Archetti et al. [1] only allowed the partitioning of commodity types, not the quantity, i.e., different vehicles to the same customer point to deliver different commodities, and build a C-SDVRP model to solve it by branch-price-cut method. Zhou et al. [7] constructed an order decision optimization model and combined the Pareto dual-objective optimization idea to design an ant colony optimization algorithm (ACO) to solve the model with reference to the hierarchical method order batching idea. Ardjmand et al. [2] proposed a hybrid column generation algorithm (CG), genetic algorithm (GA) and artificial neural network (ANN) heuristic algorithm for solving the minimization of manual picking completion time in order fulfillment.

Although the research perspectives and solution models of order batching optimization problems have been studied by scholars, which enrich the realistic background and solution methods of order batching optimization problems, there are still some limitations, mainly in: (1) the existing research lacks the consideration of weight and volume constraints on batches, because in realistic logistics distribution problems, different batches of goods are often distributed by distribution vehicles, and distribution vehicles usually have volume and weight constraints. Therefore, if the weight and volume of batches are not constrained, the picking operation and distribution efficiency will be seriously affected. (2) The suitability of different commodities into the same batch is not considered in the existing studies. Due to the differences in storage conditions of different types of commodities and the diverse needs of customers, some commodities (e.g. fresh fruits and toiletries) are not suitable to enter into one batch at the same time. (3) Most scholars who have studied only consider the similarity between orders under the similarity rule and do not split the orders. This will lead to lower utilization of batch capacity and reduce order picking efficiency.

To address the above limitations, this paper proposes a new order batching optimization method. First, with the objectives of maximum average fitness and minimum batch usage after order batching, a dual-objective order batching optimization model is constructed by considering constraints such as commodity-batch, order-batch, weight limit, and volume limit; then, based on the model characteristics and complexity, an improved genetic algorithm optimization algorithm is designed to solve the model; further, Through numerical examples and comparative analysis, the proposed order batching optimization method is validated The effectiveness of the proposed order batching optimization method is verified through numerical examples and comparative analysis.

2 Problem Description

In this section, first, we briefly introduce the "order batching optimization problem considering batch size and product suitability", and on this basis, we give the main assumptions and notation of the optimization problem.

The "order batching optimization problem considering batch size and product suitability" is described as follows: An online supermarket receives multiple orders from consumers at a certain time, each of which may contain multiple products. In order to fulfill the orders quickly and reduce logistics costs, the multiple orders need to be batched. When batching, it is necessary to take into account not only the weight and volume limits of the batch, but also the average degree of suitability between goods, i.e., the situation where goods are stored separately by category due to different storage conditions; under the condition of storage by product type, the higher the degree of suitability between goods in the same batch, the lower the subsequent picking time and transfer cost of the batch. To facilitate the description and understanding, the following Fig. 1 is given to show the process of dividing an order into batches, taking into account the number of batches and the degree of suitability of items.

Then, based on the proposed order batching optimization problem considering the splitting strategy, the research hypotheses considered in this paper are listed as follows.

Assumption 1. That the same goods of the same order shall enter the same batch.

Assumption 2. Assuming that the e-commerce company has enough goods and there is no quantitative shortage of goods.

Further, the notation of the mathematical variables and sets considered in this paper for "order batching optimization considering batch quantity and commodity suitability" is as follows.

$O = \{o_1, o_2, o_3, \cdots, o_m\}$, o_i stands for the i th order, $i = 1, 2, \cdots, m$.

$Q = \left\{q_1, q_2, q_3, \cdots, q_{q_{\max}}\right\}$, s_a stands for the a th product, $a = 1, 2, \cdots, f$. $j = 1, 2, \cdots, q_{\max}$. $q_{\max}$ denotes the maximum number of batches that may result from

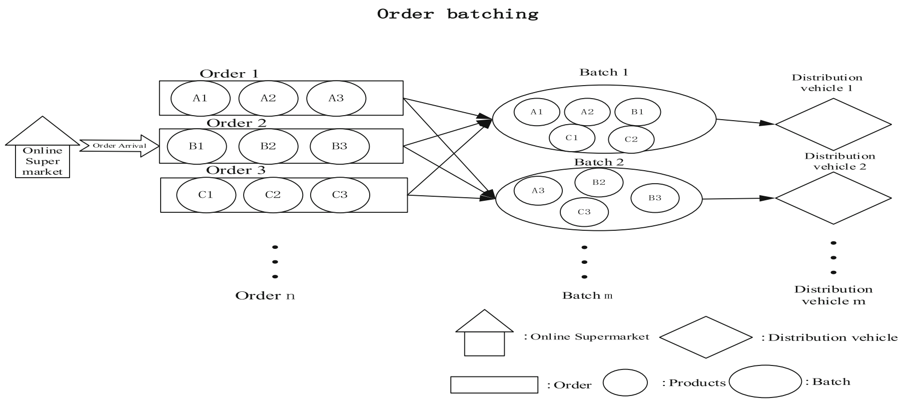

Fig. 1. Schematic diagram of the order batching optimization problem considering batch size and product suitability

processing orders ordered and accepted in a given time period by order splitting under the single batch rule of this paper.

W: The maximum weight each batch; V: The maximum volume that each batch can accept;

w_i^a: The weight of item a in order i. v_i^a: The volume of item a in order i;

$P = (p_{ij})_{f\times f}$:The fitness degree matrix of different types of goods entering into the same batch, The matrix $p_{ij}(p_{ij} \in [0, 1])$ indicates the degree of fit of product i and product j into the same batch. The larger the p_{ij}, the more suitable product i and product j are indicated.

The problem addressed in this paper is how to implement order batching based on a given set of orders O, taking into account the degree of fit between commodity types and the minimum batch size.

3 Model Construction and Solving

In this section, an order batch optimization model is built, designed to split different orders into different batches. Furthermore, the improved genetic algorithm is designed to solve the characteristics of the established order batch optimization model.

3.1 Optimal Modeling of the Order Batching Problem

The order batching optimization model constructed in this paper considers two main objectives: (1) maximizing the degree of fitness of goods in the same batch. In a realistic order batching problem, the limitations of storage conditions, commodity nature and distribution time limit make the degree of suitability of two or two commodities placed in the same batch vary. (2) Minimize the number of order batches. The number of batches of orders means the cost of distribution. In a realistic logistics distribution problem, a smaller number of order batches means that fewer distribution vehicles can be used for distribution, and thus less distribution costs.

Specifically, the order batching optimization model developed in this paper is as follows:

$$\max Z_1 = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{a,b=1,a\neq b}^{f} p_{ab}x_{ija}x_{ijb} \tag{1}$$

$$\min Z_2 = \sum_{j=1}^{n} x_j \tag{2}$$

$$\sum_{j=1}^{n} x_{ija} = 1, \forall i, a \tag{3}$$

$$1 - (1 - x_{ij})M \le \sum_{a=1}^{f} x_{ija}, \forall i, j \tag{4}$$

$$x_{ij}M \ge \sum_{a=1}^{f} x_{ija}, \forall i, j \tag{5}$$

$$\sum_{i=1}^{m}\sum_{a=1}^{f} w_i^a x_{ija} \le W, \forall j \tag{6}$$

$$\sum_{i=1}^{m}\sum_{a=1}^{f} v_i^a x_{ija} \le V, \forall j \tag{7}$$

$$x_{ija} \in \{0, 1\}, \forall o_i \in O, q_j \in Q, s_a \in S \tag{8}$$

$$x_{ij} \in \{0, 1\}, \forall o_i \in O, q_j \in Q \tag{9}$$

There are two objective functions: (1) Maximize the fit of the same batch, $p_{ab} \in [0, 1]$ indicates the degree of suitability of commodity a and commodity b when placed in the same lot, with a larger p_{ab} indicating the greater suitability of commodity a and commodity b. (2) Minimizing the number of order batches, x_j is a 0–1 variable, $x_j = 1$ when batch j contains goods, otherwise $x_j = 0$.Constraint (3) ensures that only one type of item in an order can enter one lot. Constraint (4) and (5) shows that as long as any item of an order enters a batch, it means that the order enters the batch. Constraints (6) and (7) represent the weight and volume constraints of the batch. Further, the decision variables of the established order batch optimization model mainly include: (8) determines the entry of item a in order i into batch j. (9) determines the entry of order i into batch j.

3.2 The Algorithm Design and Solution Scheme of the Model

The order batching problem considered in this paper is a typical combinatorial optimization problem, which is an NP-hard problem, which leads to a huge solution space for the order batching model and makes it difficult to obtain an exact solution. Among them, in a realistic e-commerce operation environment, within a short time, online supermarkets need to process a large number of orders (today's delivery, next-day delivery, etc.), and thus how to design algorithms that can obtain a better solution in a short time is a realistic goal of the order batching problem. To achieve this goal, this paper designs the solution method of the model based on the idea of classical genetic algorithm.Based on the basic idea of classical genetic algorithm, the improved genetic algorithm is proposed.

4 Numerical Experiments

In this section, we first present an example to demonstrate the specific flow of the proposed order batching method, and then discuss the effectiveness of the proposed method by comparing it with existing order batching methods. The above algorithm is implemented and run uniformly using Matlab 2021a on Windows 10 platform.

M Online Supermarket is located in a province in southwest China, with eight main product categories: product category 1 to product category 8 in order of electronic products, books, alcoholic beverages, toiletries, health care drugs, snacks, fresh fruits, and cleaning paper products, and has established its own warehouse according to local conditions, and because of the speed and convenience of online shopping for local customers, M Online Supermarket has been favoured by local customers. However, M Online Supermarket is now facing the problem of order fulfillment, i.e., how to quickly process the orders received within a short period of time and carry out order batching, so as to better provide online shopping services for local customers and improve customer satisfaction with M Online Supermarket, thereby gaining more market share. Based on existing knowledge and historical experience, M Online Supermarket has determined the fitness matrix $P = (p_{ij})_{8\times 8}$ for putting two of eight items into the same lot as follows:

$P =$

product	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
S_1	1	0.8	0.4	0.2	0.3	0.2	0.1	0.5
S_2	0.8	1	0.3	0.6	0.5	0.2	0.1	0.7
S_3	0.4	0.3	1	0.2	0.4	0.8	0.3	0.6
S_4	0.2	0.6	0.2	1	0.2	0.3	0.1	0.9
S_5	0.3	0.5	0.4	0.2	1	0.2	0.1	0.8
S_6	0.2	0.2	0.8	0.3	0.2	1	0.5	0.2
S_7	0.1	0.1	0.3	0.1	0.1	0.5	1	0.2
S_8	0.5	0.7	0.6	0.9	0.8	0.2	0.2	1

Without loss of generality, assume that eight orders are received within three minutes for an M online supermarket, where each order contains the category of goods, as well as the corresponding weight and volume as shown in Table 1.

In the solution process, set the population size = 100, cross probability = 0.8, variation probability = 0.05, and the maximum number of iterations is 100, the satisfactory solution is obtained, and the order batch optimization results are obtained.

Finally, according on the arrangement results, the batch results of available orders are shown in Table 2:

To verify the effectiveness of the order batching model proposed in this paper, this paper compares it with other order batching methods. Specifically, the order batching

Table 1. Commodity composition of eight orders

Order 1			Order 2			Order 3		
Category	Weigh(kg)	Volume(L)	Category	Weigh(kg)	Volume(L)	Category	Weigh(kg)	Volume(L)
S_1	3	6	S_2	10	6	S_3	35	30
S_2	5	3	S_6	10	16	S_5	4	8
S_7	15	18	S_8	25	50	S_4	36	26
Order 4			**Order 5**			**Order 6**		
Category	Weigh(kg)	Volume(L)	Category	Weigh(kg)	Volume(L)	Category	Weigh(kg)	Volume(L)
S_2	10	6	S_3	7	6	S_2	20	12
S_3	14	12	S_7	30	36	S_5	1	2
S_6	10	16	S_6	5	8	S_7	60	72
S_8	50	100	S_4	18	13	S_8	20	40
Order 7			**Order 8**					
Category	Weigh(kg)	Volume(L)	Category	Weigh(kg)	Volume(L)			
S_1	6	12	S_2	20	12			
S_3	35	30	S_4	18	13			
S_5	3	6	S_5	2	4			
S_6	25	40	S_7	60	72			
S_8	100	200	S_8	50	100			

Table 2. Batch optimization results of orders

Order batch results										
Batch 1	$S_6(O_7)$	$S_6(O_4)$	$S_7(O_1)$	$S_3(O_3)$	$S_3(O_4)$	$S_6(O_5)$	$S_7(O_5)$	$S_3(O_7)$	$S_3(O_5)$	$S_6(O_2)$
Batch 2	$S_2(O_4)$	$S_2(O_2)$	$S_1(O_1)$	$S_4(O_3)$	$S_2(O_6)$	$S_2(O_8)$	$S_4(O_8)$	$S_2(O_1)$	$S_4(O_5)$	$S_1(O_7)$
Batch 3	$S_5(O_3)$	$S_7(O_6)$	$S_8(O_6)$	$S_5(O_6)$	$S_5(O_8)$	$S_7(O_8)$	$S_8(O_4)$	$S_5(O_7)$		
Batch 4	$S_8(O_2)$	$S_8(O_7)$	$S_8(O_8)$							

methods compared in this paper are summarized into three scenarios through literature review as follows.

1) Scenario 1 Minimizing the number of order batches batching method. In this method, the objective of solving the order batching problem is to minimize the number of batches, thus taking into account the volume and weight constraints of the batches and the fact that orders can be split by commodity type.
2) Scenario 2 First-come, first-served order batching method. In this method, the goal of the order batching problem is to process the orders in the order of their arrival time, and then consider the volume and weight constraints of the batches for batching,

which is a classical order batching method widely used in real-life scenarios due to its simplicity and speed.

3) Scenario 3 The method proposed in this paper takes into account both the degree of suitability of the goods and the number of order batches. In this method, the joint objective is to maximize the degree of suitability of goods in the same batch and minimize the number of order batches, which in turn takes into account the volume and weight limits of the batches, and then considers the splitting of orders by the number of goods types, without splitting the quantity.

For the convenience of description, the order batching methods corresponding to scenarios 1–3 are denoted as Methods A, B, and C. Also, due to space limitations, the details of the three methods will not be repeated in this section. Then, in the process of comparative analysis, this paper considers the degree of suitability of goods into the same batch Z_1 and the number of order batches Z_2 as indicators for comparative analysis. In other words, if a method obtains a higher degree of suitability of goods into the same batch and a smaller number of order batches, the better is the batching method.

Further, to illustrate the robustness of the proposed results, this paper considers different number of orders and number of commodities and calculates the values of A and B. Specifically, this paper sets three groups of order quantity sizes with the quantities of 10, 15, and 20, respectively, and then the number of commodity types under each order is a random integer between [1, 2, …, 10], and each commodity under each order The maximum allowable load and volume of a single batch are 200 kg and 700 L, respectively, and each batch can accommodate a maximum of 30 product types.

Based on the numerical results of the experiments, the optimization rate metrics of method C compared with method A and method B are calculated in this paper, respectively. Specifically, let $Opt1(x/y)$ and $Opt2(x/y)$ denote the optimization rates of method x compared to method y in terms of fitness and batch size, respectively, as expressed in Eqs. (10) and (11). Let $OptF(x/y)$ denote the optimization rate of method x compared to method y in terms of overall fitness (considering both Z_1 and Z_2), expressed in Eq. (12).

$$Opt1(x/y) = [(Z_1(x) - Z_1(y))/Z_1(y)] \times 100\% \tag{10}$$

$$Opt2(x/y) = [(Z_2(x) - Z_2(y))/Z_2(y)] \times 100\% \tag{11}$$

$$OptF(x/y) = [(FitnessT(x) - FitnessT(y))/FitnessT(y)] \times 100\% \tag{12}$$

The results of the optimization rate indexes obtained in this paper are shown in Table 3.

Table 3. Optimization rate of each index under different order scale and commodity type and quantity

Order quantity	Total number of commodity types	$Opt1(C/A)$	$Opt1(C/B)$	$Opt2(C/A)$	$Opt2(C/B)$	$OptF(C/A)$	$OptF(C/B)$
10	45	11.11%	12.26%	0.00%	0.00%	60.05%	69.44%
10	60	12.08%	11.14%	0.00%	0.00%	37.42%	33.92%
10	78	19.50%	16.43%	−33.33%	−33.33%	27.83%	20.34%
15	84	26.65%	22.92%	−33.33%	0.00%	33.99%	54.17%
15	92	10.63%	5.13%	0.00%	0.00%	21.20%	9.76%
15	102	22.87%	12.25%	0.00%	16.67%	64.44%	44.87%
20	107	9.75%	9.28%	0.00%	0.00%	22.42%	21.22%
20	115	8.01%	8.47%	0.00%	0.00%	21.75%	23.17%
20	133	5.18%	17.17%	0.00%	0.00%	15.71%	67.76%

Using Table 3, the following conclusions can be obtained.

1) In terms of maximizing the degree of same-lot fitness, the average optimization rates of method C compared with methods A and B are 13.97% and 12.78%, respectively. This indicates that the order batching method proposed in this paper can significantly improve the degree of fit between same-lot items and reduce the cases of conflicting same-lot items compared with the existing order batching methods.
2) In terms of minimizing the number of order batches, the average optimization rates of method C compared with methods A and B are -7.41% and -1.85%, respectively. This indicates that the order batching method proposed in this paper is slightly inferior to the existing order batching methods in minimizing the number of order batches, which is due to the fact that more batches may be required after the commodities have been re-batched and combined to improve the suitability between the same batch of commodities, and thus it is not guaranteed to use the minimum number of batches for each order processing.
3) The average optimization rate of method C compared with methods A and B is 33.87% and 38.29%, respectively, in terms of maximizing the degree of same-lot fitness and minimizing the number of order batches considered simultaneously. This indicates that the order batching method proposed in this paper significantly outperforms the existing order batching methods. Therefore, it is concluded that the order batching method proposed in this paper can also significantly improve the degree of suitability between goods in the same batch and reduce the additional logistics cost caused by the conflicting types of goods in the same batch, while ensuring a better batching quantity.

5 Conclusions

In this paper, a new order batching optimization model is proposed for online supermarkets with a large number of orders and many items included in the orders. Compared with the existing studies on order batching, this paper also considers the suitability of different products into the same batch, while taking into account the number of batches of orders, and constructs a corresponding order batching model and designs a solution algorithm for the model. In addition, in order to illustrate the effectiveness of the proposed order batching optimization model, a comparative analysis is carried out in this paper, and the results show that the order batching algorithm in this paper has better results in terms of the degree of suitability of goods in the same batch and the number of batches of orders compared with the traditional first-come, first-served order batching method and the order batching method with the objective of minimizing the number of batches of orders. The method in this paper provides a reference for order batching processing of online supermarkets, which helps to improve the order processing speed of online supermarkets, reduce the adverse effects of product conflicts in orders, improve the order fulfillment efficiency as a whole, save distribution costs, further improve the service quality and competitiveness of online supermarkets, and promote the improvement and development of the business quality of online supermarkets as an e-commerce model.

Since the real order batching problem may occur when orders are out of stock or urgent orders exist, and the real order fulfillment chain also includes warehouse-distribution center-distribution station-customer, etc., in future research, we will further analyze the above problems based on the proposed order batching optimization model.

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