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DELIVERY TOUR-BASED ORDER BATCHING METHOD FOR ONLINE SUPERMARKETS

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Abstract. *Due to the distinguished complexity of order fulfillment of online supermarket, its order picking problem is particularly difficult. General order batching methods only aim at decreasing the total travel distance of pickers by reducing the number of trips and by shortening each length of trips. In this paper, a new order batching model is built not only considering minimizing the travel distance between locations in the warehouses, but also incorporating picking sequence, due time of orders and traveling cost of first stage delivery in the two-tier distribution network of online supermarkets. For the solution to the problem, this paper introduces a grouping genetic algorithm. Different from a standard genetic algorithm with item-oriented encoding, the grouping genetic algorithm with group-oriented encoding can accommodate a large-scale order batching problem of online supermarkets. Numerical experiments indicate that the proposed solution procedure outperforms current wave picking method from the aspects of the tardiness of order due time.*

Keywords: Online supermarket, Order batching, Large-scale optimization

1. **Introduction.** This research is inspired by the warehouse management of online supermarkets with respect to the method for order picking operation, which has urgent need for promptness of order response. Online supermarkets sell the mostly used fast moving consumer good (FMCG). It shows several distinguished features, selling millions of goods, with large amount of daily orders (up to 60,000 in one big city), orders averagely containing 16.7 items, and the diversity of delivery time windows. The building of multi warehouse stock network is required in one city to stock millions of goods. Each warehouse stores at least 40,000 SKUs. These result in great complexity and difficulty of good picking in order fulfillment of online supermarket. How to pick ordered items from millions of goods with high efficiency and accuracy has become a key problem for improving the performance of order fulfillment of online supermarket.

Traditional single order picking policy of operation is suitable for orders with a large amount of single good and should be picked individually. It results in significant trips and high operational cost. Batching order picking can greatly save picking time and improve picking efficiency. However, with the consideration of the distinguished features of online supermarkets, that is, orders are small and with multiple types of items, warehouses with a large amount of SKUs, existing order batching methods still could not satisfy order picking work in terms of efficiency or scale. Currently, one typical online supermarket in China has adopted an order batching strategy of wave picking in which orders arriving within a certain duration of time (e.g., 15 minutes) will be a batch for picking. Wave picking is a simple time-constrained batching method. It somehow decreases the travel cost and improves the productivity of order picking. For the rapid growth of orders of online supermarkets, the strategy is insufficient for handling large amount of daily orders. More and more pickers need to be recruited which finally adds high cost to online supermarkets.

Order batching problem (OBP) falls into the category of NP-hard problems [1]. As the number of batches increases, the solving difficulty of OBP will increase greatly. According to Choe and Sharp [2], there are basically two criteria for batching: time windows and the proximity of pick locations. Proximity batching assigns each order to a batch based on proximity of its storage location to those of other orders. Its key issue is how to measure the proximities among orders. Several typical criteria for similarity measurement are: maximizing the amount of similar items in one batch of orders; minimizing the distance of storage locations of items in orders; maximizing the travel time or distance savings; minimizing the maximum lead-time of any batch. As order batching is an NP-hard problem, many studies have been focused on developing heuristic methods for solving it, e.g., seed algorithm [3], simulated annealing method [4], genetic algorithms [5], ant colony optimization [6], tabu search [7], constructed heuristics [8] and neighborhood search [9]. Time window batching strategy refers to batching customer orders into picking orders in accordance with the arrival time of orders [10]. It is suitable for orders evenly arriving with fixed or variable length of time interval. It can be further divided to fixed time window batching (refer to [11]) or variable time window batching (refer to [12]). Besides these, Ma and Wen [13] present time postponement-based dynamic time windows of order batching strategies. Wang et al. [14] present a mixed-integer programming model considering orders' due time for on-line retailer's order batching method incorporating urgent degree and similar degree as order batching rules. For both proximity batching and time window batching, the existing batching strategies and solution procedures aim at reducing picking tours and length, mitigating traffic block while picking, eliminating the phenomenon of waiting time and block demand. They seldom consider the sequence of order batch picking and order due date, which are two key factors for quick response of online E-commerce orders. With the development of E-commerce, there are several results focusing on the tardiness for online orders. Chen et al. [15] study order batching, batch sequencing, and picker's routing under the consideration of the minimum total tardiness of customer orders. Henn and Schmid [16] present how metaheuristics can be used in order to minimize the total tardiness for a given set of customer orders. In summary, most of them only can deal with less than 2,000 kinds of commodities, a limited order scale (less than 3,000) and each order only containing 1 or 2 items. [12] improves the scale of stocks and orders, which can solve up to 10,000 SKUs and the average of items in orders is even up to 25. However, it can merely batch 60 orders. Due to several distinguished features of online supermarket, existing results are not suitable for solving its OBP.

This paper makes the following contributions. First of all, we build a new order batching model with an objective of minimizing the total order tardiness time, and with the constraints of order due time and delivery cost of the first stage of two-level transportation systems of online supermarkets. Second, we present a large-scale order batching procedure based on grouping genetic algorithm for picking system of online supermarket. In this procedure, both batching results and picking sequence of batches are achieved. Finally, the proposed algorithm is compared with current operating strategy of online supermarket using s-shape routing method in terms of the total tardiness of orders.

The remainder of this paper is organized as follows. Section 2 describes the characteristics of OBP faced by online supermarket and builds a new order batching model, providing a foundation for developing our solution procedure. Section 3 presents our grouping genetic algorithm-based solution procedure. Then a numerical sensitivity analysis is given in Section 4. Finally, concluding remarks and future research directions are summarized in Section 5.

2. **Problem Description and Mathematical Model.**

2.1. **Problem description.**

Classical order batching problem includes order batch identification and route selection. Considering the computational difficulty is mainly due to the combinatorial number of potential batches and the route selection problem is typically computationally easy, we just focus on order batching optimization and assume s-shape routing strategy is applied to picking items. Besides some fundamental assumptions in [12], we further make the following assumptions to simplify the analysis: the warehouse has one block. The orders in one satellite station should be delivered by one vehicle. For the supermarket with specific delivery policy, e.g., three deliveries a day, it begins to deal with orders at 8 AM, 12 PM and 4 PM each day. We assume that all customer orders are available at the beginning of the planning period.

2.2. **Mathematical model.**

For the OBP of online supermarkets, we propose the following mathematical optimization model with an objective of minimizing the total picking distance and order tardiness time, in which the tardiness of customer orders is referred to Henn and Schmid [16]. We assume the following notations.

n number of customer orders;

J set of customer orders, where $J = \{1, 2, \dots, n\}$;

I set of all feasible batches, where $I = \{1, 2, \dots, b\}$;

S set of satellite stations, $S = \{1, 2, \dots, a\}$;

K set of positions at which a batch can be scheduled, where $K = \{1, 2, \dots, \overline{m}\}$;

T set of order due time, $T = \{1, 2, \dots, c\}$;

L the length of tour each worker can afford in one batch;

C capacity of the picking device;

W maximal number of items which can be included in a batch;

D the maximum of the total picking distance;

m upper bound on the number of batches that have to be scheduled. This results in at most $\overline{m}$ positions at which the order picker can start a batch;

M a sufficiently large positive number;

w_j number of items of customer order j $(j \in J)$;

d_{ik} time of picking duration in which all orders of batch i $(i \in I)$ scheduled at position k $(k \in K)$ are collected;

c_j the capacity utilization required by order j $(j \in J)$;

pt_i processing time of the batch i $(i \in I)$;

ct_k completion time of the batch scheduled at position k $(k \in K)$;

O_{js} order j belonging to satellite station s $(s \in S)$;

a_{ij} binary entry; $a_{ij} = 1$, if order j $(j \in J)$ is included in batch i $(i \in I)$ or $a_{ij} = 0$, otherwise;

td_{jk} delivery duration of customer order j $(j \in J)$ if included in the batch scheduled at position k $(k \in K)$;

ta_{jk} tardiness of customer order j $(j \in J)$ if included in the batch scheduled at position k $(k \in K)$;

x_{ik} binary decision variable; $x_{ik} = 1$, if batch i $(i \in I)$ is scheduled at position k $(k \in K)$, or $x_{ik} = 0$, otherwise;

y_{jk} binary decision variable; which is equal to 1 if and only if order j $(j \in J)$ is assigned to the batch which is scheduled at position k $(k \in K)$;

T_j the due time of order j $(j \in J)$;

St_{st} the order amount of satellite station s $(s \in S)$ with respective due time t $(t \in T)$.

The optimization model can then be formulated as follows:

$$\min \sum_{j\in J}\sum_{k\in K} ta_{jk} \tag{1}$$

$$\sum_{j\in J} d_{ik}a_{ij} \le L, \ \ \forall i \in I, \ \ \forall k \in K; \tag{2}$$

$$\sum_{j\in J} c_j a_{ij} \le C, \quad \forall i \in I; \tag{3}$$

$$\sum_{j\in J} w_j a_{ij} \le W, \quad \forall i \in I; \tag{4}$$

$$\sum_{k\in K}\sum_{i\in I} a_{ij}x_{ik} = 1, \quad \forall j \in J; \tag{5}$$

$$\sum_{i\in I} a_{ij}x_{ik} = y_{jk}, \quad \forall j \in J, \quad \forall k \in K; \tag{6}$$

$$ct_{k-1} - \sum_{i\in I} pt_i x_{ik} \le ct_k, \quad \forall k \in K\backslash\{1\}; \tag{7}$$

$$\sum_{i\in I} pt_i x_{i1} \le ct_1; \tag{8}$$

$$ct_{k-1} + td_{jk} - ta_{jk} \le T_j + M(1 - y_{jk}), \quad \forall j \in J, \quad \forall k \in K; \tag{9}$$

$$\sum_{i\in I}\sum_{k\in K} d_{ik}x_{ik} \le D; \tag{10}$$

$$ta_{jk} \ge 0, \quad x_{ik} \in \{0,1\}, \quad y_{jk} \in \{0,1\}, \quad \forall i \in I, \quad \forall j \in J, \quad \forall k \in K \tag{11}$$

The objective function (1) represents the tardiness of all customer orders. It is guaranteed by Conditions (2) that travel distance of each batch does not exceed the length of tour each worker can afford. Constraints (3) and Constraints (4) separately ensure the total volume and the total capacity of one batch do not exceed the capacity of picking device. Constraints (5) ensure one order is included in exactly one batch. Constraints (6) ensure consistency among batches and orders scheduled at any particular position. Conditions (7) ensure feasibility with respect to time and guarantee that two batches do not overlap. Condition (8) determines the completion time of the batch at position 1. Constraints (9) restrict the tardiness of each customer order, which is defined by the number of time units between its due date and the resulting completion time. Constraint (10) ensures the total picking distance does not exceed the maximum. Constraints (11) impose non-negativity on all decision variables modeling tardiness.

3. Grouping Genetic Algorithm-Based Solution Procedure.

Figure 1 depicts a flowchart of the solution procedure in the paper. The design of such a procedure requires three structural decisions, namely concerning pre-clustering of customer order, delivery scheme generation, and grouping genetic algorithm. They are further explained in the following sections.

3.1. Pre-clustering of customer order.

First of all, according to c order due time points, we classify all the customer orders into c types. And according to the amounts of each type of orders in a satellite station, c types of orders can be further subdivided into $c * a$ groups. For each type of orders, we sort satellite stations in a descending sequence by their amounts of type orders.

3.2. Delivery tour generation.

For each type of orders divided by due time, we arrange a vehicle to deliver them to the satellite stations by one tour decided by the descending sequence of satellite stations. The satellite station which has the fewest customer orders

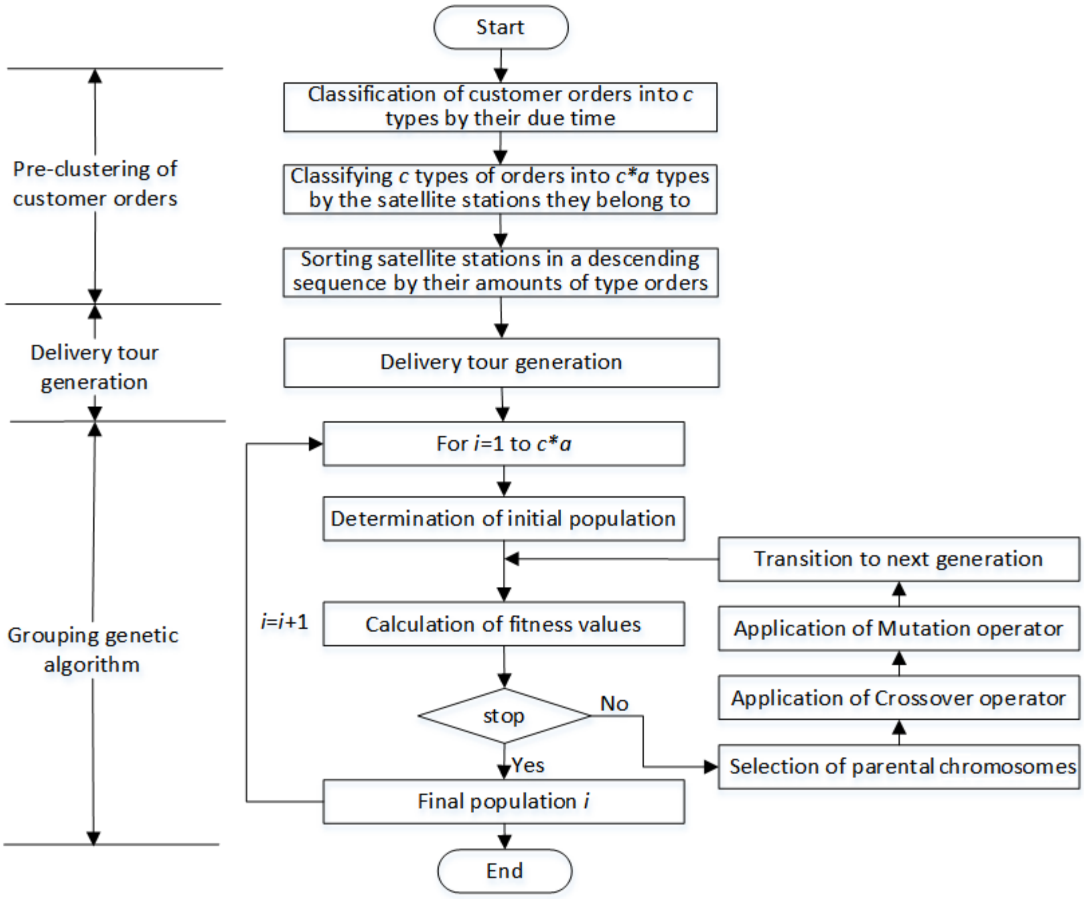

Figure 1. General structure of grouping genetic algorithm-based solution procedure

will be first picked and loaded, but last delivered. Furthermore, the more urgent the due time is, the earlier it will be picked and delivered. As a result, we get the picking sequence of each group of orders. For each group, grouping genetic algorithm will be utilized to further batch it.

3.3. **Grouping genetic algorithm.** The grouping genetic algorithm includes 7 steps: encoding, fitness value calculation, selection operation, crossing operation, mutation operator, checking, and local search procedure. Its principle also can refer to [5]. To solve the problem in the paper, the processes of grouping genetic algorithm have been improved. For the process of encoding, each gene of a chromosome represents a feasible order batch scheme. That is, the lengths of chromosomes could be variable. And the first chromosomes and batches are randomly generated by the computer, which should conform to the constraints. For example, an initial encoding scheme for a batch scheme of 20 orders is demonstrated as follows.

Customer orders:	1,3	7,8	10,11	9,13,20	2,4,9	5,6,12	14,17	15,16,18,19
Chromosome:	A	B	C	D	E	F	G	H

The objective is the total order tardiness, which is decided by picking duration and delivery duration of each order. For the process of fitness value in the grouping genetic algorithm, it is defined as the opposite value of the objective. After generating the population of chromosomes, we will calculate the fitness value of each chromosome and then rank them in the ascending order. We appoint that 10% of the ranking population as top part, which can be copied to the next generation directly. Processes of selection operation, crossing operation, mutation operator, checking follow the fundamental rule of grouping genetic algorithm. After the algorithm has gone through all the processes of generations, it concludes with a local search procedure, which is applied to the individuals of the final population. The local search procedure consists of SWAP-operation and SHIFT-operation. SWAP-operation will improve the value of objective function by interchanging one customer order with an order from another batch. If SWAP-operation can obtain no further improvement, SHIFT-operation will be done by moving a customer order from one batch to another to improve the value of objective function. The procedure will end while no further improvements can be obtained by either SWAPs or SHIFTs.

4. Test Design.

Once grouping genetic algorithm-based solution procedure has been proved to be feasible, we begin to develop its application software by .Net program tool and the database technology of SQL Server2000. Numerical experiments are carried out in order to determine the performance of the suggested solution procedure. In these experiments, the layout of the warehouse and several parameters can be referred to [17] in which the data are derived from an online supermarket in China. The picking area consists of 53,078 storage locations, which are divided into 15 categories. Data of orders are generated randomly, including 500, 1,000, 1,500, 2,000, 3,000, 4,000, 5,000 orders, each order containing $6 \sim 7$ commodities and uniformly distributed from 10 to 17 items, and each commodity occupying $0 \sim 1$ m^3. The capacity of picking device is 1 m^3. It is assumed to have 10 pickers. The limitation of running distance of each picker in one batch is 1000 m. A popular operation of wave picking is adopted in online supermarket. The wave size is usually $12 \sim 15$ orders partitioned by order arrival time. The comparison study will be done between our solution procedure and the wave picking method.

With the help of the solution system, we achieve some comparison results shown in Table 1. Two indications are given by the comparison work. Due to no optimization of order tardiness time and simple consideration of batching by order arrival time, the order tardiness in wave picking method is serious which will greatly decrease the quality of customer service. Nevertheless, its computation time stays almost unchanged as the number of orders grows. By contrast, as incorporating complex optimization principle, the solution procedure in the paper can greatly decrease the order tardiness, whereas it consumes much more computation time, especially with the number of orders growing.

Table 1. Comparison on 7 OBPs from wave picking and our procedure

(Unit: min)

Number of orders	Our solution procedure		Wave picking		Improvement (%)
	Order tardiness	Computation time	Order tardiness	Computation time	Order tardiness
500	2861	0.3	2001	0.1	−43.8
1,000	3407	1.6	6315	0.1	46.0
1,500	3661	3.5	7195	0.1	49.1
2,000	5325	5.7	9646	0.1	44.8
3,000	8193	12.5	12007	0.2	31.8
4,000	9378	13.5	20204	0.2	53.6
5,000	10532	18.2	29703	0.2	64.5

Note: Improvement (%) = 100 ∗ (results of wave picking – results of solution procedure in the paper)/results from wave picking

5. Conclusions.

The order batching method in the paper can improve promptness of online order fulfillment and reduce labor costs for picking. Order batching and sequencing of picking in the warehouse are both considered in this paper. Specifically, vehicle routing schemes of first stage delivery in the two-tier distribution network of online supermarkets are utilized as rules for determining the batches of order. It will promote the practicability and generality of order picking methods. The results will have better instructional significance and be beneficial to enrich and complete the theories of E-commerce logistics management.

Future research directions include: (1) improve the efficiency of solution procedure for large-scale orders by taking more complicated order attributes into considerations; (2) integrate the order batching procedure into the order streamline processing, which includes order grouping and splitting, item picking, collecting and packing, and order delivery.

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