Decision-Making for Packaging Consolidation of Fast-Moving Consumer Goods Orders with Multi-Warehouse in One Location

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Abstract. In a large-scale online retail environment, "Multi-warehouse in one location" often leads to the splitting of a single order into multiple sub-orders. To meet order demands, retailers stock fast-moving consumer goods in all warehouses, leading to more packaging options and mixed orders. This complicates the online generation of reasonable packaging consolidation schemes. With the objective of minimizing order fulfilment costs, a bin packing conflict model and a multi-warehouse transhipment model are constructed. These models were used to generate initial package consolidation schemes for non-fast-moving consumer goods and order package consolidation schemes, respectively. A two-stage algorithm was designed to solve the models. In stage one, FFD determines the initial packing and package count for non-fast-moving consumer goods. In the second stage, an improved breadth-first search algorithm is employed, with warehouses serving as the search nodes to optimize packing consolidation and identify the fulfilment warehouse for fast-moving consumer goods. Numerical experiments have shown that, compared to order splitting fulfilment, this method achieves an average cost reduction of 30.25% and a reduction in the number of packages by 28.18%.

Keywords: Multiple warehouses in one location, Packaging consolidation, Order splitting

1 INTRODUCTION

Online supermarkets, as the main force of online retail, primarily sell fast-moving consumer goods (FMCG) or mass-market products (non-FMCG)[1]. Product sales often obey the 80/20 rule: 20% of FMCGs generate 80% of sales. To achieve a reasonable layout and efficiently serve customers, Retailers typically arrange for fast-moving consumer goods to be stocked repeatedly across all warehouses, non-fast-moving consumer goods are stored in different warehouses according to their SKU categories. With the rapid development of technology, the e-commerce industry has expanded quickly. The "multi-warehouse in one region" system represented by JD.com is facing more

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severe challenges. The "Multi-warehouse" layout splits multi-item orders into sub-orders, each fulfilled by a different warehouse. Meanwhile, the establishment of certain delivery thresholds and discount services for reaching a minimum purchase amount has led to larger order sizes, which exacerbates the phenomenon of order splitting[2]. This splitting results in multiple packages being delivered separately, not only does it increase order fulfilment costs, but it also adds environmental pressure. JD.com's Yihaodian splits 13%-18% of its daily millions of orders, adding $1.9 cost per split sub-order[3].

package consolidation is now widely studied by scholars globally. Wagner L et al. proposed delivery consolidation can enhance customer satisfaction[4]. Zhang et al. introduced a new order fulfilment process with a packaging consolidation strategy, transferring SKUs from sub-orders to a central warehouse for consolidation via lateral transhipment.[2] Zhang et al. introduced the PCF method for multi-warehouse packaging consolidation, from various warehouses can be merged via transhipment before delivery[3]. Zhu et al. introduced a k-linkage heuristic algorithm to optimize product allocation in warehouses and reduce order splits[1]. These research findings aid large online retailers in consolidating split orders. Online retailers serve many customers with millions of SKUs. Retailers often store fast-moving consumer goods repeatedly across all warehouses. This leads to a significant increase in the number of consolidation options for split sub-orders.

Current related research is still insufficient in this specific scenario, so the generality of this approach needs to be improved. To address these limitations, from the perspective of minimizing fulfilment costs, a multi-warehouse transhipment model and a packing conflict model are constructed. Using the rapid generation of initial schemes and order packaging fulfilment schemes as a breakthrough point. A two-stage intelligent optimisation algorithm is designed to solve the model. The algorithm's effectiveness is proven via data comparison.

2 PROBLEM DESCRIPTION AND MODELING

2.1 Problem Description

As shown in Figure 1, taking into account that an online retailer has multiple warehouses in a region, each of which can fulfil orders and can serve as a consolidation warehouse. In this scenario, fast-moving consumer goods (FMCG) are stored in all warehouses while non-FMCG items are distributed and stored in different warehouses based on their respective categories, multi-item orders will be split into several sub-orders based on the availability of SKUs in the warehouses.

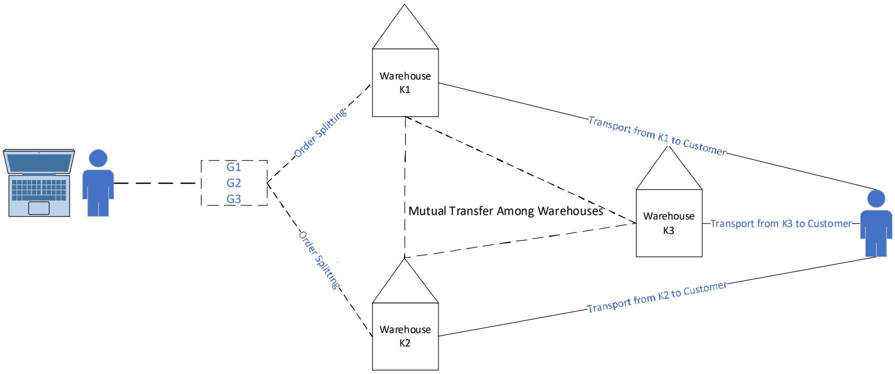

Fig. 1. Packaging consolidation fulfilment process. (Drawn by the author)

Assuming an order includes fast-moving consumer goods G1 and non-fast-moving consumer goods G2, G3. Fast-moving consumer goods are in all warehouses, G2 only in K1, G3 only in K2. No product conflicts, In this case, the order will be allocated to warehouse K1 and warehouse K2. With fast-moving consumer goods G1, the consideration of multi-warehouse transfers and consolidation after allocation leads to a multiplication of feasible consolidation options.

2.2 Model Building

Based on the common assumptions about order fulfilment in existing literature, the problem is formulated as a bin packing conflict model and a multi-warehouse transfer model. No warehouse holds all items. Commodities are divided into fast-moving consumer goods (FMCG) and non-FMCG, where FMCG are stored in all warehouses, while non-FMCG is stored according to their respective categories. For each sub-order, it can either be transferred and consolidated between warehouses or directly shipped to the customer.

$G = (Z, A)$ is a directed graph, where Z is the set of vertices.A A represents the set of transportation arcs (A_1) and transfer arcs (A_2).In the arc, the starting point is warehouse k, and the endpoint is customer m. Define A_1 as the transfer arc set $A_1 = \{(k_1, k_2), (k_2, k_3)......(k_x, k_{|k|})\}$, A_2 as the transportation arc set. $A_2 = \{(k_1, m), (k_1, m)......(k_{|k|}, m)\}$, B as the SKU conflict set.$\{(s_1, s_2)......|s_1, s_2 \epsilon S\}$。$K = \{k_1,......k_{|k|}\}$，$Z = K \cup \{m\}$，$S = \{s_1, s_2......s_{|S|}\}$ as the SKU set$S_f = \{s_x......s_{|y|}\}$ represents FMCG set, while S_n represents non-FMCG set, O represents the set of orders。$P = \{p_1, p_2...p_n\}$ is a set of packages，w_s and V_s represent SKU weights and volumes, while W and V represent package weight and volume limits.

The Packaging Conflict Model. The packaging conflict model provides the minimum number of packages and the initial packaging scheme for non-FMCG products in orders, based on SKU conflict situations, package volume, and weight restrictions, for the multi-warehouse transfer model.

Define two binary variables:r_{sp}、z_p,z_p=1 indicates that the package is in use,r_{sp}=1 indicates that SKU s is assigned to package p, otherwise ,z_p、$r_{sp} = 0$。The bin packing model minimises packages and schemes initial packaging for non-fast goods, considering SKU conflicts, volume, and weight limits.

$$\mathrm{Min} \sum_{p=1}^{\mathrm{n}} Z_p \tag{1}$$

$$r_{p_1} + \mathrm{r}_{\mathrm{p}_2} \le \mathrm{z}_{\mathrm{pk_xm}}, \forall(\mathrm{s}_1, \mathrm{s}_2) \in \mathrm{E} \tag{2}$$

$$\sum_{s \in \mathcal{S}} \mathrm{r}_{\mathrm{sp}} \mathrm{w}_{\mathrm{s}} \le \mathrm{z}_{\mathrm{p}} \mathrm{W}, (\mathrm{k}_{\mathrm{x}}, \mathrm{k}_{\mathrm{y}}) \in \mathrm{A}_2, 1 \le \mathrm{r} \le \mathrm{n} \tag{3}$$

$$\sum_{\mathrm{s} \in \mathcal{S}} \mathrm{r}_{\mathrm{sp}} \mathrm{V}_{\mathrm{s}} \le \mathrm{z}_{\mathrm{p}} \mathrm{V}, (\mathrm{k}_{\mathrm{x}}, \mathrm{k}_{\mathrm{y}}) \in \mathrm{A}_2, 1 \le \mathrm{r} \le \mathrm{n} \tag{4}$$

$$Z_p, r_{sp} \in \{0,1\},\ \forall s \in S_n, 1 \le p \le \mathrm{n} \tag{5}$$

(1) Minimize package count. (2) No conflicting SKUs in one package. (3)/(4) Merged SKUs within weight and volume limits. Constraints (5) define variable values.

Multi-Warehouse Transfer Model. The multi-warehouse transfer model adjusts the initial scheme based on cost, including warehouse merging and SKU fulfilment decisions.

f_{k_xm} representing the fixed cost from warehouse x to the customer.$c_{k_xk_y}$ representing the transfer cost from warehouse x to warehouse y.t_{k_xm} represents the unit transportation cost from warehouse k_x to customer m.$x_{sk_xk_y}$=1. Representing the transfer of SKU S from warehouse x to warehouse y.y_{k_xm}=1 Indicating at least one package from x to m.

$$\mathrm{Min} \sum_{s \in S} \sum_{(k_x,k_y) \in A_2} c_{k_xk_y} x_{sk_xk_y} + \sum_{(k_x,m) \in A_1} f_{k_xm}((1-\alpha) y_{k_xm} + \alpha \sum_{r=1}^{n} z_{pk_xm}) + \sum_{s \in S} \sum_{(k_x,m) \in A_1} t_{k_xm} y_{k_xm} \tag{6}$$

$$x_{sk_xk_y} \le 1, \forall s \in S, (k_x, k_y) \in A_2 \tag{7}$$

$$\sum_{(k_x,k_y) \in A_2} x_{sk_xk_y} - \sum_{(k_y,k_x) \in A_2} x_{sk_yk_x} = 0, \forall s \in S, \mathrm{k}_{\mathrm{y}}, \mathrm{k}_{\mathrm{x}} \in K \tag{8}$$

$$\mathrm{x}_{\mathrm{sk_xk_y}} \in \{0,1\}, \forall \mathrm{s} \in \mathrm{S}(\mathrm{k}_{\mathrm{x}}, \mathrm{k}_{\mathrm{y}}) \in \mathrm{K} \tag{9}$$

$$\mathrm{y}_{\mathrm{k_xm}} \in \{0,1\}, \forall(\mathrm{k}_{\mathrm{x}}, \mathrm{m}) \in \mathrm{Z} \tag{10}$$

The objective function (6) covers transfer, fixed, and variable transportation costs. Constraint (7): SKUs must be transferred from their respective warehouses. Constraint (8): SKU inflow/outflow meets supply requirements. Constraints (9-10) define variable values. Figure 2 illustrates the model process.

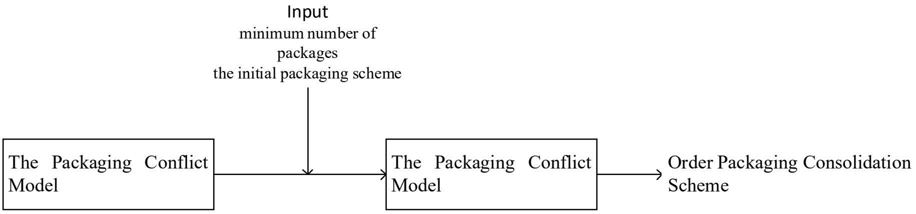

Fig. 2. Model Process

3 TWO-PHASE INTELLIGENT OPTIMISATION ALGORITHM

Given that solving the bin packing conflict model is fundamental to the multi-warehouse transhipment model, a two-stage intelligent optimization algorithm is proposed for both [5,6]. As shown in Figure 3 the first stage solves the bin packing conflict model to generate the initial packing scheme for non-fast-moving consumer goods. The second stage solves the multi-warehouse transhipment model, optimizing the initial scheme for non-fast-moving consumer goods based on cost, and determining the executing warehouses for fast-moving consumer goods.

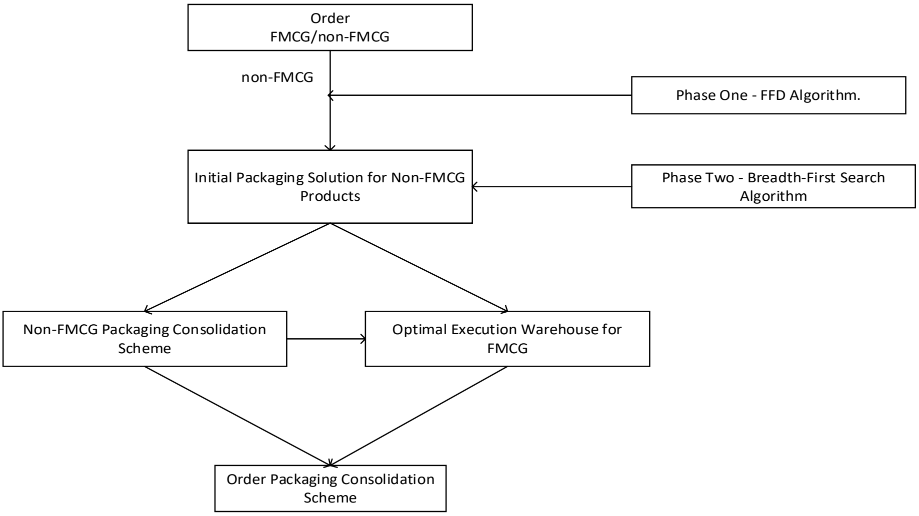

Fig. 3. Algorithm Flowchart

3.1 First Phase - Initial Order Scheme

Solve the packaging model in the first phase using the FFD algorithm.

Step 1： Initialize and sort orders, excluding any fast-moving consumer goods SKUs.

Step 2：Traverse orders, assigning each to a suitable, conflict-free package with enough capacity, then removing it from the list.

Step 3：Repeat Step 2 until the order list is empty, then proceed to Step 4.

Step 4: Use bin shuffling: pick the least utilized container, empty and re-pack its items with First Fit. Update the scheme if successful.

Step 5：Output the final packaging scheme.

The FFD algorithm yields a packaging scheme that minimizes the number of packages per order.

3.2 Second Phase - Order Transfer and Consolidation Scheme

BFS is used in the second phase to optimize the initial FFD-derived package quantity and consolidation scheme. The warehouse where each sub-order in the order is located is considered a state point, and the starting point of the search is the warehouse with the highest number of SKUs in the sub-order. The end goal is to find the last warehouse that saves costs. After determining the packaging scheme for non-fast-moving goods, we will compare the additional costs incurred by executing FMCG orders in each warehouse and select the warehouse with the lowest cost increase as the execution warehouse for FMCG. Adopt strategies to speed up calculations: **Consolidation Strategy**: For orders with ≥4 non-fast SKU types, consolidate at the warehouse with the most SKUs. **Cost Strategy**： Cost savings as a node selection metric narrow the solution space, saving time. Figure 4 shows BFS for four sub-orders in different warehouses (1-1, 1-2, 2, 3, 4), with warehouse 1 having two SKUs. Start at K1 and search for 2, 3, and 4 to maximise cost savings.

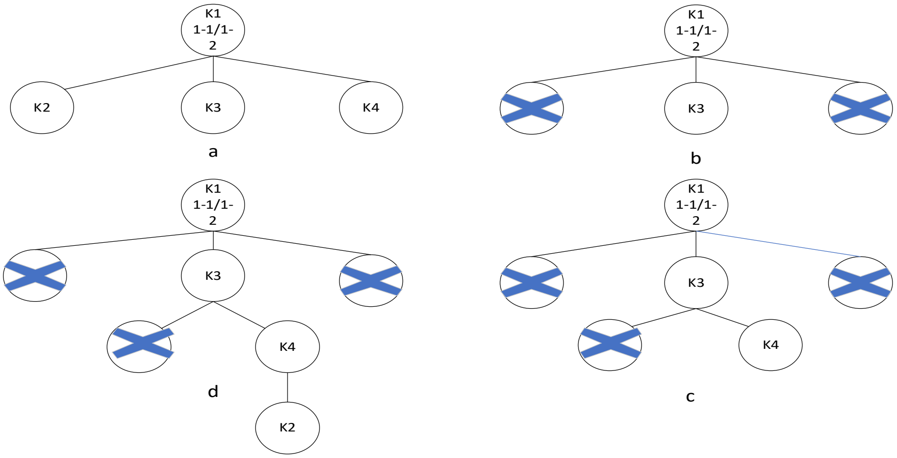

Fig 4. The process of breadth-first search(Drawn by the author)

4 EXPERIMENT AND ANALYSIS

In this section, numerical examples demonstrate the efficiency of the model and algorithm. Based on the actual sales of commodities and the warehouse layout of a large online supermarket in China, relevant small-scale research examples are constructed. The dataset was generated with K=10, totalling 1000 SKUs. Table 1 shows 100 orders per dataset, with the top 2% of SKUs in sales as fast-moving consumer goods. Orders are split into 2-12 sub-orders, each with 2-15 SKUs. SKU quantities follow U(1,4). Commodity weight and volume are randomly generated from U(0.1, 2) and U(0.1, 0.5). Intra-warehouse SKU conflict: 0.2; inter-warehouse conflict: 0.4. Transfer costs between warehouses range from 0-4.

Table 1. Parameters of the example(Produced by the author)

Example	Categories	Sub-orders	quantities
1	2~4	2	2~4
2	4~6	4	4~8
3	6~8	6	10~12
4	8-12	8	12-15

Compare PCF(Package consolidation fulfilment) and OCF(Order splitting fulfilment) in terms of the total cost, package count, average cost and package savings rates. In OCF, fast-moving consumer goods are the lowest-cost warehouse. As shown in Table 2, this advantage is particularly evident when the number of sub-orders ranges from 6 to 8, where the cost savings rate can reach up to 38.73%.

Table 2. Comparison Results(Produced by the author)

Example	PCF		OCF		Cost Savings	Package Savings
	coat	package	coat	package		
1	1550.34	165	2042.47	194	24.09%	14.95%
2	1944.54	205	2474.70	248	21.42%	17.33%
3	6255.92	584	10210.64	1034	38.73%	43.52%
4	7534.85	620	11915.84	983	36.78%	36.92%

Given the close correlation between unit transportation cost and transportation consolidation scheme, based on dataset 2, we analyse whether PCF can save costs under different transportation costs. As shown in figure5, the cost savings decline with the increase in transportation costs, and the total cost of PCF gradually approaches the total cost of OCF.

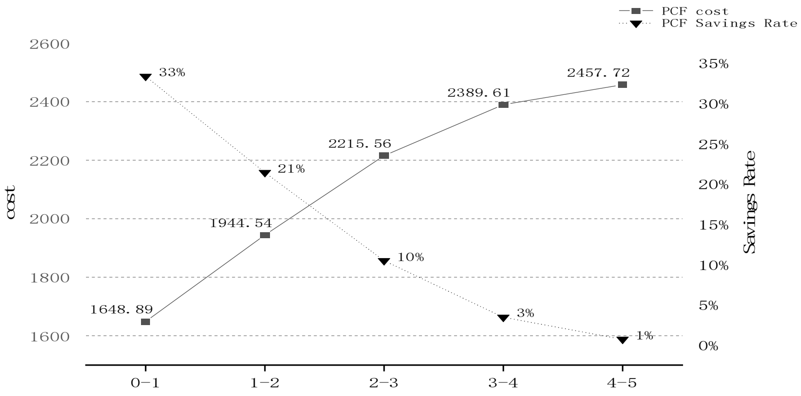

Fig. 5. The relationship between transfer expenses and costs

5 CONCLUSION AND OUTLOOK

Addressing characteristics such as multiple warehouse layouts in a single location, duplicate storage of fast-moving consumer goods, and a vast number of orders, propose a two-stage online algorithm to minimize fulfilment costs. Results indicate that, compared to traditional order splitting, multi-warehouse packaging consolidation significantly cuts the package count, especially with a moderate number of sub-orders per order. Construct a two-stage online intelligent optimization decision algorithm, Leverage the storage characteristics of non-fast-moving consumer goods and obtain a consolidation and packaging scheme in a short timeframe. Provide a basis for the execution warehouse of fast-moving consumer goods. Improve the breadth-first search algorithm by using physical warehouses as search nodes, Quickly generate packaging consolidation schemes for multi-item orders using cost and consolidation strategies. In practical applications, situations may arise where there are a large number of sub-orders within an order or a high quantity of FMCG products. In such scenarios, the algorithm may find it difficult to quickly generate a reasonable solution, necessitating a specialized search strategy for FMCG products. the model fails to take into account the limitations of warehouse capacity, which could potentially have an impact on packaging integration strategies. Furthermore, explore multi-warehouse transfers as a coordination network[7]. Explore the impact of warehouse transfers during order surges on efficiency.

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