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Research Article

Integrated Optimization on Assortment Packing and Collaborative Shipping for Fashion Clothing

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With the diversification of customer's demand and the shortage of social resources, meeting diverse requirements of customers and reducing logistics costs have attracted great attention in logistics area. In this paper, we address an integrated optimization problem that combines fashion clothing assortment packing with collaborative shipping simultaneously. We formulate this problem as a mixed integer nonlinear programming model (MINLP) and then convert the proposed model into a simplified model. We use LINGO 11.0 to solve the transformed model. Numerical experiments have been conducted to verify the effectiveness and efficiency of the proposed model, and the numerical results show that the proposed model is beneficial to the fashion clothing assortment packing and collaborative shipping planning.

1. Introduction

Within a supply chain for fashion clothing, inefficient operation and irrational resource utilization are key considerations as they lead to high costs and low profits. The inefficient operation is mainly due to the redundant process of sorting and packing items in the supply chain, which is further coursed by the variety of both items and demand. The irrational resource utilization is mainly determined by the process of item distribution in the supply chain, which further depends on the plenty of stores located in different locations. As one of the largest fashion clothing industrial producing countries in the world, Chinese fashion clothing industry support ¥2,000 billion of domestic fashion consumer market [1], and the retail sales of the fashion clothing were at ¥1,035.64 billion in 2017; it is predicted that the retail sales will reach ¥1,095.8 billion in 2018 [2]. Though the fashion clothing industry has achieved certain results, the above two problems are still common in the fashion clothing supply chain. It is reported that most truck loads in the distribution process are usually only 57% of their maximum gross weight [3]. In addition, the proportion of social logistics costs to GDP is almost over two times that of developed countries [4]. Therefore, it is of great significance to improve the operational efficiency by assorting and packing items in the origin of the supply chain and improve the resource utilization through carrying out collaborative shipping in the end of the supply chain at the same time.

The problem of integration optimization on assortment packing and collaborative shipping has the following characteristics: (1) multiple types of demand but small single item demand and (2) large number of stores but geographically dispersed. For different characteristics, we propose the following countermeasures and possible challenges: for the former, we can introduce the box configurations to meet the diversified demand. However, if there are large number of box configurations, they will be able to meet the demand of each store in an exact manner, but with increased operating costs. If the number of box configurations is limited, the operating costs will be low, but some items will be overloaded or underloaded at the stores. For the latter, we can connect the large number of stores located in different locations through collaborative shipping under the constraints of truck capacity and geographical location.

The integration of assortment packing and collaborative shipping provides an effective way to improve the operational efficiency and reduce the waste of resources in the fashion clothing supply chain. The decision-making problem reveals

the assortment packing ways and the distribution routes according to the demand of stores, the types of box configurations, and shipping cost between different nodes and truck cost. In this paper, we aim to solve two questions: (1) how to determine the type and quantity of each box configuration allocated to each store and (2) how to realize collaborative shipping through vehicle scheduling.

The contributions in this study contain three aspects: (1) addressing an integrated optimization problem that combines fashion clothing assortment packing with collaborative shipping; (2) proposing a mixed integer nonlinear programming model to formulate the fashion clothing assortment packing and collaborative shipping problem; (3) converting the proposed model into a simplified model, applying LINGO 11.0 to solve the converted model, and carrying out numerical experiments and sensitive analysis to verify the efficiency and validity of the converted model.

The remainder of the paper is organized as follows. Section 2 presents the relevant literature; Section 3 formalizes the problem using mathematical models; Section 4 uses a small instance to test the effectiveness of the numerical experiment; Section 5 draws some conclusions and outlines future research directions.

2. Literature Review

Our study involves two major streams of research literature, that is, the assortment packing decision and the collaborative shipping optimization.

In the research stream of assortment packing decision, relevant literature basically combines optimization model with heuristic algorithm to study. Depending on research objectives, the existing literature can be divided into two categories: the minimization of entire supply chain costs and the minimization of mismatches between the supply and the demand.

For the minimization of entire supply chain costs, Chettri and Sharma [5] presented the entire decision-making process for the assortment packing problem and they proposed a method to balance the trade-offs between different points in supply chain based on data intensive models. For the minimization of mismatches between the supply and the demand, Sung et al. [6] considered a nonlinear programming model and applied it to Kolon Sport Company by converting the nonlinear programming model into a linear programming model and then they solved the problem with a heuristic algorithm. Based on the data set, the sales increased by approximately 8% in 2015. Other researchers in this field have proposed numbers of similar heuristic algorithms and programming models [7–10], and the optimal assortment packing decision can be found through iteratively solving the problem. Besides, two other papers that combine the above two objectives are Wang [11] and Pratti [12]. Both formulated the assortment packing decision with inner packs and outer packs, and they proposed various heuristic approaches that assume that the available pack configurations are given, which is more comprehensive and practical to solve the problem.

In the research stream on collaborative shipping optimization, many studies focus on the vehicle routing problems with truck capacity-constrained (CVRP). To our knowledge, Clarke and Wright [13] were the first to apply the liner optimization model to the problem, which is ordinarily encountered in the logistics and transportation field under the name of CVRP. They have numerically demonstrated that the utilization of the truck capacity improved by 17%. In addition, researchers [14–18] proposed various approaches to solve CVRP, such as the enhanced version of the artificial bee colony heuristic based on the bee swarming behavior model. On the basis of CVRP, some further studies have been conducted to effectively solve practical problem. Lysgaard [19] formulated an exact branch-and-cut-and-price algorithm for a restricted version of the capacitated vehicle routing problem named pyramidal capacitated vehicle routing problem (PCVRP). Liu et al. [20] established a mix integer programming model and an efficient memetic algorithm to the Close-Open Mixed Vehicle Routing Problem (COMVRP), with the objective of minimizing the variable and fixed costs for operating the private vehicles and the rental vehicles.

This paper was inspired by Sung et al. [6, 10] and Creemers et al. [16]. Sung et al. [6, 10] provided the idea of assortment packing decision with the objective of minimizing the mismatches between the supply and the demand. Creemers et al. [16] introduced the effective algorithms to realize collaborative shipping. They both investigated some challenges faced by supply chain operations management. However, from the perspective of improving the operational efficiency of entire fashion clothing supply chain, their research objects only contain the origins (manufacturers) and the destinations (stores), while some important nodes such as distribution centers in the supply chain are not included. Therefore, this paper incorporates distribution center and combines assortment packing decision with collaborative shipping optimization to optimize the entire supply chain from a systematic perspective.

In summary, assortment packing and collaborative shipping have attracted more and more attention in area of fashion clothing supply chain. The existing researches have studied these two problems for many years but seldom combine the two for research. With the increasing diversity of demand and the continuous reduction of resources in fashion clothing supply chain, the integration of assortment packing and collaborative shipping will be a major trend in the fashion clothing supply chain. Therefore, this study aims to endeavor to bridge a gap in the literature by integrating assortment packing decision and collaborative shipping optimization in the fashion clothing supply chain.

3. Model Formulation

We consider a problem of integrated optimization on assortment packing and collaborative shipping for fashion clothing and model this problem as a MINLP. The objective is to minimize the total costs, including the value of overload and underload items, shipping cost, and truck cost.

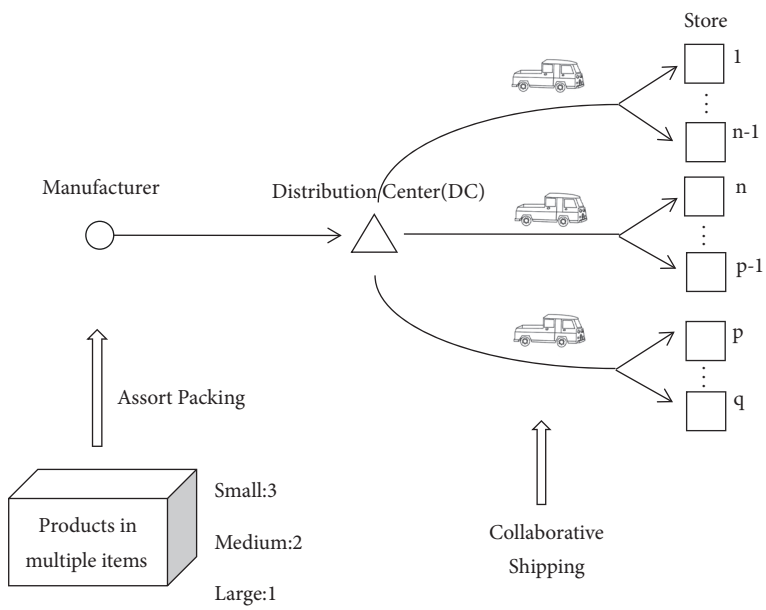

Figure 1: Fashion clothing supply chain process.

3.1. Problem Description. The integrated optimization problem on assortment packing and collaborative shipping for fashion clothing in this paper is depicted in Figure 1. It contains one manufacturer, one distribution center, various stores located in different locations, and multiple homogeneous trucks. Manufacturer sorts and packs items with multiple colors and sizes into box configurations according to the requirement of each store, and then the box configurations will be delivered to the distribution center. At the distribution center, instead of simply sending a fixed car to deliver fixed box configurations to a fixed store, the stuff will identify the collaborative shipping opportunities before delivering them and the box configurations will be delivered to the corresponding stores through collaborative shipping.

The decisions to be taken in this model are as follows: (1) how many of each item each box configuration should include, (2) how many of each box configuration should be delivered to each store, and (3) which box configuration is delivered by which truck to which store and the optimal served sequence, with the objective of minimizing the total costs including the value of overload and underload items, shipping cost, and truck cost.

Some assumptions are proposed to the integrated assortment packing and collaborative shipping problem. For assortment packing (1) type and quantity of items contained in a box configuration are fixed; (2) every store should receive at least one box and then the total number of boxes should be greater than or equal to the total number of stores; (3) configurations of box is limited; (4) number of each box configuration that can be used is limited; (5) box configurations must be full of items before delivery. Due to the assumptions of (1), (3), and (5), the number of items allocated to each store may not be exactly equal to the store's demand. If the number of items delivered to a store is more (less) than the store's demand, overload (underload) will occur. Therefore, we should minimize overload and underload simultaneously.

For collaborative shipping (1) we only consider the delivery of boxes from a single distribution center to multiple stores in this paper; (2) collaborative shipping can only be carried out when the geographical location of the two places is similar and the capacity of the truck is sufficient enough; (3) the cost and the load of all trucks are the same. Hence, the decision is to minimize shipping cost and truck cost.

3.2. Symbol Description

3.2.1. Index Sets

I = Items indexed with i.

S = Stores indexed with s.

DCS = Distribution center and stores. $DCS = S \cup \{0\}$, 0 indicates the distribution center.

K = Tracks indexed with k.

B = Box configurations indexed with b.

N = Maximum number of different box configurations that can be used for assortment packing.

3.2.2. Parameters

d_{is} = Demand quantity for item i in store s.

c_{mn} = Delivery cost from node m to node n.

Q = Set of possible box capacities. A capacity value in this set is expressed as $q \in Q$.

M_b = Maximum number of box b.

p_i = Production number of item i.

w = *Capacity of truck.*

g_i = *Weight of item i.*

c_i = *Production cost of item i.*

F = *The cost of using a truck.*

3.2.3. Decision Variables

t_{bs} = *Number of box configuration b distributed to store s.*

r_{ib} = *Number of item i in box configuration b.*

o_{is} = *Overload of item i to store s.*

u_{is} = *Underload of item i to store s.*

n_b = *Number of box configuration b distributed to distribution center.*

x_{mnk} = {1, *Truck k arrives at the store n from node m* ($m \in DCS, n \in S$); 0, *If not*}.

y_{ks} = {1, *Truck k delivers to store s*; 0, *If not*}.

f_{bq} = {1, *Capacity of box configuration b is q*; 0, *If not*}.

z_k = {1, *Truck k is used*; 0, *If not*}.

3.3. Objective Function. We consider three different objectives in this study, i.e., the value of overload and underload items, shipping cost, and truck cost.

3.3.1. The Value of Overload and Underload Items. In assortment packing process, please note that we have assumed that each box configuration should be full of items before delivery; hence the number of items allocated to each store may not be exactly equal to store's demand, which will bring loss to stores. Therefore, our first objective is to minimize the value of overload and underload items. The calculation is given in

$$obj1 = \sum_{i\in I}\sum_{s\in S} c_i\left(u_{is} + o_{is}\right) \tag{1}$$

3.3.2. Shipping Cost. Let c_{mn} denote the shipping cost from node (distribution center or stores) m to node (stores) n. x_{mnk} is a binary decision variable, taking a value 1 if the truck k arrives at store n from node m and 0 otherwise. Shipping cost can be calculated in

$$obj2 = \sum_{m\in DCS}\sum_{n\in S}\sum_{k\in K}\left(c_{mn}x_{mnk}\right) \tag{2}$$

3.3.3. Truck Cost. Let F denote the usage cost of a single truck, and z_k is a binary decision variable, taking a value 1 if the truck k is used and 0 otherwise. Truck cost can be calculated in

$$obj3 = \sum_{k\in K} F z_k \tag{3}$$

3.4. Constraints. We formulate the model as a MINLP problem. The constraints are given as follows (note that some constraints are modified according to Sung et al. [6]).

$$\sum_{b\in B} r_{ib}t_{bs} - o_{is} + u_{is} = d_{is}, \quad i \in I,\ s \in S \tag{4}$$

$$o_{is}u_{is} = 0, \quad i \in I,\ s \in S \tag{5}$$

$$\sum_{i\in I} r_{ib} = \sum_{q\in Q} q f_{bq}, \quad b \in B \tag{6}$$

$$\sum_{q\in Q} f_{bq} = 1, \quad b \in B \tag{7}$$

$$\sum_{b\in B}\sum_{s\in S} t_{bs} \le \sum_{b\in B} M_b \tag{8}$$

$$\sum_{b\in B} t_{bs} \ge 1, \quad s \in S \tag{9}$$

$$\sum_{s\in S}\sum_{b\in B} r_{ib}t_{bs} \le p_i, \quad i \in I \tag{10}$$

$$\sum_{s\in S}\left[\sum_{i\in I}\left(\sum_{b\in B} r_{ib}t_{bs}\right) g_i\right] y_{ks} \le w z_k, \quad k \in K \tag{11}$$

$$\sum_{k\in K} y_{ks} = 1, \quad s \in S \tag{12}$$

$$\sum_{m\in DCS} x_{mnk} = y_{kn}, \quad n \in S,\ k \in K \tag{13}$$

$$\sum_{n\in DCS} x_{mnk} = y_{km}, \quad m \in S,\ k \in K \tag{14}$$

$$\sum_{b\in B} r_{ib}n_b \ge \sum_{j\in J} d_{ij}, \quad i \in I \tag{15}$$

$$n_b = \sum_{s\in S} t_{bs}, \quad b \in B \tag{16}$$

$$\sum_{n\in S} x_{0nk} = z_k, \quad k \in K \tag{17}$$

$$\begin{aligned} t_{bs} &\ge 0, \\ r_{ib} &\ge 0, \\ o_{is} &\ge 0, \\ u_{is} &\ge 0, \\ n_b &\ge 0 \end{aligned} \tag{18}$$

$$\begin{aligned} f_{bq} &\in \{0,1\}, \\ x_{mnk} &\in \{0,1\}, \\ y_{ks} &\in \{0,1\}, \\ z_k &\in \{0,1\} \end{aligned} \tag{19}$$

Equation (4) calculates the amount of overload and underload based on the distribution quantity and stores' demand. If the number of the items distributed to a store is smaller than the store's demand, we calculate the underload as the demand minus the distribution quantity. If the number of the items distributed to a store is greater than the

store's demand, we calculate the overload as the distribution quantity minus the demand. Equation (5) limits at least one of the overloads or underloads of allocating item i to store s to be 0. That is, if overload occurs, underload must equal to 0. Conversely, if underload occurs, overload must equal to 0. If the number of item i allocated to store s is exactly equal to the store's demand, the overload and underload are both 0. Equation (6) indicates that every box configuration has a certain capacity. Equation (7) denotes that there is only one possible capacity for each box configuration. Equation (8) limits the total number of box configurations. Equation (9) limits each store to receive at least one box. Equation (10) limits the total number of each item that can be used for distribution so that it cannot exceed its production quantity. Equation (11) points out that the load of each truck cannot exceed its rated capacity. Equation (12) limits each store can be served by one truck. Equation (13) limits the following: if store n is delivered by truck k, then the truck k must arrive at the store n from a node m. Equation (14) limits that if store m is delivered by truck k, then the truck k will reach another node n after the delivery. Equation (15) limits that the number of item i received by the distribution center must be greater than or equal to all stores' demand for item i. Equation (16) connects the manufacturer, the distribution center, and the stores; that is, the number of received box configurations by the distribution center must be equal to the number of delivered box configurations, which indicates that the box must pass through the distribution center before reaching stores. Equation (17) denotes that if the truck is used, the starting point must be the distribution center. Equations (18)—(19) define the conditions on the decision variables.

As a result of the product of two decision variables in (4), (5), (10), (11), and (15), the proposed model becomes nonlinear and is hard to solve. One possible method to linearize the model is to decompose one of the decision variables into its binary expansion [8]. However, with this approach, the model will introduce more variables and constraints, which will make the model too complex to solve [10]. Taking the actual production of boxes into account, if the production of box configurations is based on the real demand of stores for items, the production cost of raw materials will be greatly increased. To control the raw material costs within a certain level, the type of box configurations produced by the box manufacturers should be limited and fixed. Therefore, we convert the proposed model into a simplified model, which can obtain a feasible and timely solution for the industry-size problem.

3.5. Model Conversion. According to the practical operations, we use a set of feasible box configurations to simplify the proposed model (Sung et al. [6]). Therefore, the variable r_{ib} in the original model becomes a parameter; we only determine the type and quantity of each box configuration allocated to each store, without deciding the type and quantity of items to be included in each box configuration.

Let e_{ib} denote the number of item i that can be accommodated in box configuration b, which is given in advance. h_b is a binary decision variable, taking a value 1 if the box configuration b is used and 0 otherwise. The converted model is given as follows:

$$\text{Minimize} \quad obj1 + obj2 + obj3 \tag{20}$$

$$\sum_{b\in B} e_{ib}t_{bs} - o_{is} + u_{is} = d_{is}, \quad i \in I,\ s \in S \tag{21}$$

$$o_{is}u_{is} = 0, \quad i \in I,\ s \in S \tag{22}$$

$$\sum_{b\in B} h_b \le N \tag{23}$$

$$\sum_{b\in B}\sum_{s\in S} t_{bs} \le \sum_{b\in B} M_b \tag{24}$$

$$\sum_{s\in S} t_{bs} \ge h_b, \quad b \in B \tag{25}$$

$$\sum_{b\in B} t_{bs} \ge 1, \quad s \in S \tag{26}$$

$$\sum_{s\in S}\sum_{b\in B} e_{ib}t_{bs} \le p_i, \quad i \in I \tag{27}$$

$$\sum_{s\in S}\sum_{i\in I}\sum_{b\in B} e_{ib}t_{bs}g_i y_{ks} \le wz_k, \quad k \in K \tag{28}$$

$$\sum_{k\in K} y_{ks} = 1, \quad s \in S \tag{29}$$

$$\sum_{m\in DCS} x_{mnk} = y_{kn}, \quad n \in S,\ k \in K \tag{30}$$

$$\sum_{n\in DCS} x_{imnk} = y_{km}, \quad m \in S, \quad k \in K \tag{31}$$

$$\sum_{b\in B} e_{ib}n_b \ge \sum_{j\in J} d_{ij}, \quad i \in I \tag{32}$$

$$n_b = \sum_{s\in S} t_{bs}, \quad b \in B \tag{33}$$

$$\sum_{n\in S} x_{0nk} = z_k, \quad k \in K \tag{34}$$

$$\begin{aligned} &t_{bs} \ge 0,\\ &o_{is} \ge 0,\\ &u_{is} \ge 0,\\ &n_b \ge 0 \end{aligned} \tag{35}$$

$$\begin{aligned} &x_{mnk} \in \{0,1\},\\ &y_{ks} \in \{0,1\},\\ &z_k \in \{0,1\},\\ &h_b \in \{0,1\} \end{aligned} \tag{36}$$

4. Numerical Experiments

The numerical experiments are implemented on a DELL laptop with 2.30 GHz Inter(R) Core(TM) and 4GB RAM. Please note that the converted model given in Section 3.5 is a nonlinear problem and extremely difficult to obtain the

Table 1: Numbering the downjacket based on different size and color.

Size	Color		
	Black	White	Blue
Small	1	2	3
Medium	4	5	6
Large	7	8	9

Notes. Downjackets with different sizes and colors have different numbers. For example, the number 5 shows that the downjacket is white and of medium size.

Table 2: Production, weight, and unit price of each downjackets.

Item	Production (unit)	Weight (kg)	Unit Price (CNY)
1	188	10	32
2	163	6	32
3	175	9	30
4	185	9	26
5	195	7	27
6	198	8	34
7	177	5	27
8	157	5	33
9	157	8	30

Note. Item 1 shows that this kind of downjacket has a total production of 188 pieces, each weighing 10 kg, and the unit price is 32 CNY.

Table 3: Demand on different items for different stores.

Item	Store							
	1	2	3	4	5	6	7	8
1	8	4	11	10	4	12	4	6
2	5	5	6	8	9	9	7	5
3	7	6	9	5	3	10	8	7
4	9	9	5	5	4	7	7	6
5	9	4	3	11	8	7	9	12
6	7	9	10	3	4	10	9	11
7	6	4	8	7	10	4	6	3
8	12	9	7	5	10	4	7	10
9	3	7	11	12	10	5	3	5

Note. The demand for nine items in store 1 is 8, 5, 7, 9, 9, 7, 6, 12, and 3, respectively.

global optimal solution. In this section, we adopt LINGO 11.0 as the MINLP solver to solve the converted model and to approximate the optimal solution.

4.1. Example Setting. In this example, the fashion clothing supply chain consists of one distribution center, 8 stores, and 9 different items: downjackets available in 3 different sizes (small, medium, and large) and 3 different colors (black, white, and blue). The distribution center has 5 available box configurations (the available number of each box configuration is 5, 7, 6, 9, and 7, respectively) and 5 available trucks (the capacity of truck is 5 tons and the usage cost for each truck is 50 CNY). Table 1 gives the serial number of downjackets according to different sizes and colors. Table 2 gives the production, weight, and unit price of each downjacket. Table 3 gives demand on different items for different stores. Table 4 gives the shipping cost between each node located in different geographical locations. Table 5 presents the number of each downjacket that can be included in each box configuration and the available number of each box configuration.

4.2. Numerical Results. The numerical results are reported in Table 6 and Figure 2. It can be seen that the number of each box configuration delivered to the distribution center is 5, 0, 1, 7, and 7, respectively. The optimum route of truck k_1 starts from distribution center and serves the stores with the sequence $s_7 \longrightarrow s_5$. Similarly, the optimal route of truck k_2 is $s_1 \longrightarrow s_2 \longrightarrow s_3 \longrightarrow s_6 \longrightarrow s_8 \longrightarrow s_4$.

Table 7 presents the most detailed results. It is obvious that 8 stores are served by 2 trucks. The driving route for truck k_1 is as follows. First, truck k_1 collects the shipments of store s_7 and s_5 at distribution center and then departs for store s_7; upon arrival at store s_7, k_1 drops off the shipments for store s_7 and then continues to store s_5. Finally, truck k_1 backs to distribution center. Similarly, for truck k_2, it collects the shipments of stores s_1, s_2, s_3, s_6, s_8, and s_4, then delivers

Table 4: Shipping costs for the node pairs (CNY).

	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7	Store 8
D/C	35	42	44	41	41	44	38	34
Store 1	0	30	43	37	39	31	48	44
Store 2	50	0	31	32	48	35	30	39
Store 3	45	36	0	42	40	34	39	33
Store 4	37	33	36	0	49	43	38	37
Store 5	42	34	41	38	0	47	39	42
Store 6	32	38	43	32	49	0	45	34
Store 7	48	32	38	35	35	46	0	45
Store 8	48	42	46	33	44	44	46	0

Note. If the shipping is reversed, the shipping cost between two same nodes may vary.

Table 5: Number of each downjacket that can be included in each box configuration and the available number of each box configuration.

Box configuration	Item									No. of corresponding boxes
	1	2	3	4	5	6	7	8	9	
1	3	5	4	5	5	3	4	4	4	5
2	2	6	5	4	5	4	5	4	5	7
3	2	2	2	4	4	3	5	5	5	6
4	3	5	2	4	4	5	4	4	5	9
5	3	4	3	2	5	3	4	5	3	7

Note. Box configuration 1 containing the number of nine items is 3, 5, 4, 5, 5, 3, 4, 4, and 4, respectively. For this configuration, 5 boxes are available.

Table 6: Distribution routings of each trucks.

Truck	Distribution Routing
k_1	$DC \longrightarrow s_7 \longrightarrow s_5 \longrightarrow DC$
k_2	$DC \longrightarrow s_1 \longrightarrow s_2 \longrightarrow s_3 \longrightarrow s_6 \longrightarrow s_8 \longrightarrow s_4 \longrightarrow DC$

the shipments to those stores in sequence. After delivering all stores, it heads back to the distribution center finally.

4.3. Sensitivity Analysis. We further conduct sensitivity analysis in terms of different capacity of truck and whether to carry out collaborative shipping. The input data is generated randomly. To make the approximate local optimal result more accurate, we implement 10 experiments and take their average value as the approximate optimal result for each numerical case in this subsection. The numerical results show that the error of optimal objective for each case is within [-7%, +7%].

4.3.1. Sensitivity Analysis on Capacity of Truck. We vary the capacity of truck from 3.5 to 7.0. The numerical results are reported in Table 8, and Figure 3 depicts the relationship between the capacity of truck and the optimal objective value. It can be seen that the optimal objective value is decreasing with the growing of the capacity of truck. In other words, if the truck has a low capacity, the distribution center will adopt more trucks to distribute items to stores, so as to meet the diversified demand of customers and improve the service satisfaction.

4.3.2. Sensitivity Analysis on Whether to Carry Out Collaborative Shipping. Whether to carry out collaborative shipping will bring different costs to the entire supply chain. If collaborative shipping is implemented, the total costs of the supply chain are as described above, i.e., the value of overload and underload items, shipping cost, and truck cost. If collaborative shipping is not implemented, then the total costs will be different. First, for the value of overload and underload, since the existence of box configurations is to assort and pack different items for a single store rather than for multiple stores, therefore, whether or not to implement collaborative shipping will not influence the value of overload and underload and the cost of $obj1$ is unchanged. Second, for shipping cost, since every store needs one truck to serve, the shipping cost converts to the round-trip cost between distribution center and stores, which will increase the cost of $obj2$. Third, for truck cost, since every store needs one truck, the number of trucks must be greater than or equal to the number of stores, which will definitely increase the cost of $obj3$. Obviously the total costs of noncollaborative shipping are higher than that of collaborative shipping.

We change the number of stores from 3 to 8 and calculate the optimal objective value under two cases, denoted as collaborative shipping and noncollaborative shipping. Figure 4 shows that, with the increasing number of stores, the objective value is increased, and the cost of combined assortment packing and collaborative shipping is always lower than the cost of noncombined one. In other words, the collaborative

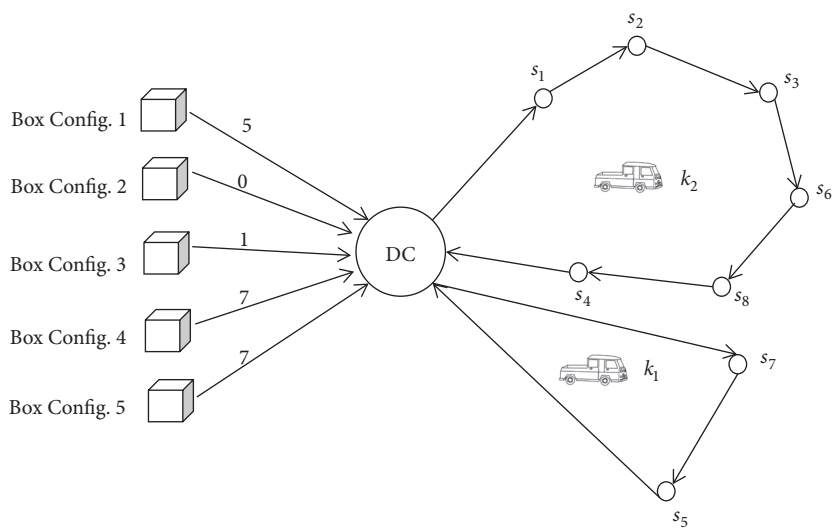

Figure 2: Delivery number for different box configurations and optimal route of two trucks.

Table 7: Routing of collaborative shipping and changes of different box configurations in each truck.

Truck	Departure location	Box configurations in truck	Arrival location	Box configurations dropped off upon arrival	Box configurations in truck after arrival
k_1	*DC*	Box config.1: 1	s_7	Box config.1: 1	Box config.4: 2
		Box config.4: 3		Box config.4: 1	
	s_7	Box config.4: 2	s_5	Box config.4: 2	/
	s_5	/	*DC*	/	/
k_2	*DC*	Box config.1: 4	s_1	Box config.1: 1	Box config.1: 3
		Box config.3: 1		Box config.5: 2	Box config.3: 1
		Box config.4: 4			Box config.4: 4
		Box config.5: 7			Box config.5: 5
	s_1	Box config.1: 3	s_2	Box config.1: 1	Box config.1: 2
		Box config.3: 1		Box config.4: 1	Box config.3: 1
		Box config.4: 4			Box config.4: 3
		Box config.5: 5			Box config.5: 5
	s_2	Box config.1: 2	s_3	Box config.4: 1	Box config.1: 2
		Box config.3: 1		Box config.5: 2	Box config.3: 1
		Box config.4: 3			Box config.4: 2
		Box config.5: 5			Box config.5: 3
	s_3	Box config.1: 2	s_6	Box config.1: 1	Box config.1: 1
		Box config.3: 1		Box config.4: 1	Box config.3: 1
		Box config.4: 2		Box config.5: 2	Box config.4: 1
		Box config.5: 3			Box config.5: 1
	s_6	Box config.1: 1	s_8	Box config.3: 1	Box config.1: 1
		Box config.3: 1		Box config.5: 1	Box config.4: 1
		Box config.4: 1			
		Box config.5: 1			
	s_8	Box config.1: 1	s_4	Box config.1: 1	/
		Box config.4: 1		Box config.4: 1	
	s_4	/	*DC*	/	/

Table 8: Optimal objective value under different truck capacity.

Truck capacity (t)	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Optimal objective value (CNY)	7243.8	7227.7	7231.1	7229.2	7194.1	7193.2	7193.9	7187.5

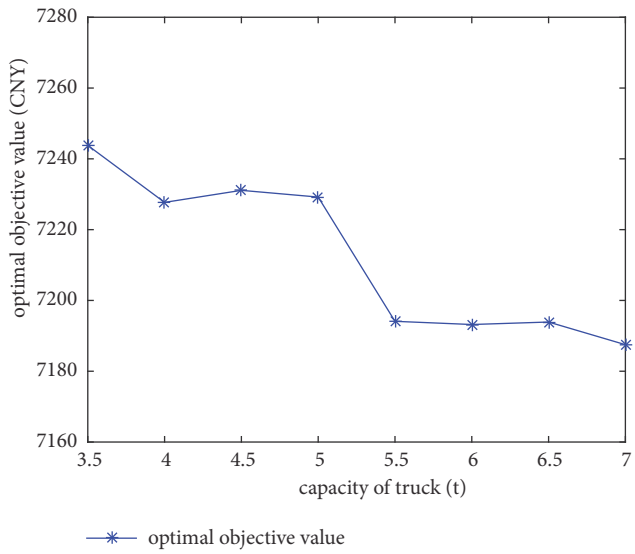

Figure 3: Relationship between the capacity of truck and the optimal objective value.

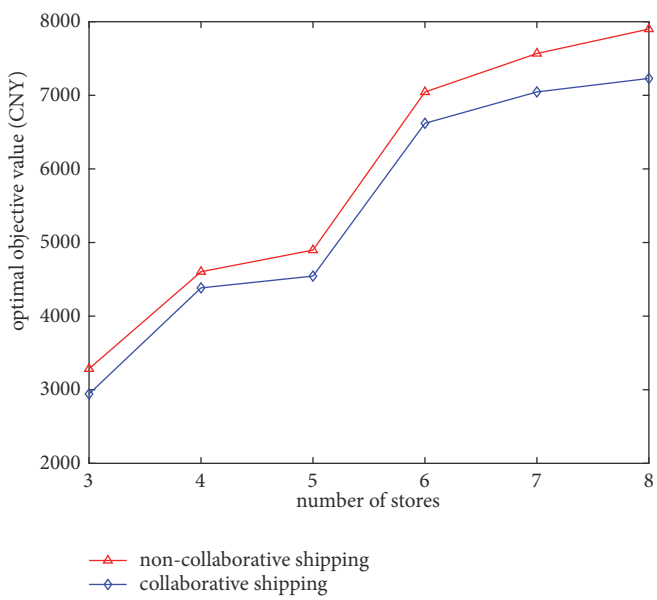

Figure 4: Optimal objective value under different number of stores and whether to carry out collaborative shipping.

shipping is always effective throughout the operation of the supply chain, since it can not only reduce the total cost, but also can improve the operational efficiency.

5. Conclusions

In this study, we have introduced the integrated optimization problem on assortment packing and collaborative shipping. A MINLP model is presented for the problem, with the objective of minimizing the value of overload and underload items, shipping cost, and truck cost. The main decisions are as follows: how many of each box configuration should be delivered to each store, and which box is delivered by which truck to which store as well as the optimal served sequence. In the proposed model, taking the actual production of boxes into account, we transform one of the decision variables into parameter and convert the initial model into a simplified model. In addition, numerical experiments have verified the effectiveness and efficiency of the converted model, and the

numerical results and sensitivity analysis have also been reported. Our study contributes to endeavoring to bridge a gap in the integration of assortment packing decision and collaborative shipping optimization of the fashion clothing supply chain.

There are specific areas in this study that can be considered as useful extensions. First of all, this research only considered a single distribution center served multiple stores; hence multiple distribution centers serving multiple stores could be considered as a prospect. Next, collaborative shipping can be extended between distribution centers, between manufacturers, between multiple distribution centers and stores, etc. Finally, items can fully meet the customer's demand to improve the customer satisfaction, which will result in the underload of 0 and we only need to consider the overload. We leave these directions for further study.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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