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A PATH SELECTION MODEL FOR MULTIMODAL TRANSPORTATION PROBLEM OF FRESH FRUITS IN ONLINE SUPERMARKET

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Abstract. *Multimodal transportation, as an effective way and method to improve the transport efficiency of the fresh fruits in online supermarket, involves a complicated decision process. Its complexity is of threefold: the unique transportation network structure of online supermarket, the multiple demands of each warehouse, and the restrictions of transshipment times and the delivery time. A mixed integer programming model of multimodal routing problem for fresh fruits in online supermarket is proposed in this paper using Demand Split Method. The objective is to minimize the total cost of online supermarket considering multiple origins, destinations, and products, and the restriction of transshipment times. The effectiveness of the proposed model is evaluated by a case study of an online supermarket. Results indicate that the proposed model can contribute to scientific decisions on multimodal transportation of online supermarket.*
Keywords: Multimodal transportation, Multimodal routing problem, Path selection, E-commerce, Fresh fruits

1. **Introduction.** China is experiencing a rapid development in fresh fruit e-commerce along with the improvement of living standard. Online supermarket, as a new e-commerce model, is becoming one of the most popular methods to sell fresh fruits. The fresh fruits production in China influenced by geography and climate, is regional, seasonal and periodical attribute to the vast territory and varied topography. There is a great difference between the fresh fruits produced in southern and northern China. For example, Nanguo pears grow in northeast China, while pineapples grow in southern China. Thus, long-distance transportation is required to meet the demand for fresh fruits that are produced elsewhere.

Due to the unique characteristics of fresh fruits, it is necessary to adopt multimodal transportation to meet its special requirements. Fresh fruits are perishable (with a short life cycle) and vulnerable (hard to maintain freshness), which make them different from other commodities. Besides, the regional and seasonal characteristics of fresh fruits also greatly increase the difficulties to deal with the logistics of fresh fruits. Multimodal transportation can not only satisfy the various logistics demands of enterprises, reduce the vulnerability of the single transportation mode, but also improve the efficiency of logistics and reduce the transportation costs. For example, highway and railway are usually more economical than air transportation. However, air transportation is also needed to meet the tight deadlines and to reduce the damage of fresh fruits in some cases. Moreover, some places can only adopt multimodal transportation due to its particularity of geography, such as Hainan province of China, which should adopt highway and waterway or air transportation to transport its local fresh fruits to other provinces.

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However, the multimodal transportation of fresh fruits in online supermarket has many unique characteristics, such as the unique transportation network structure of online supermarket, multiple demands of each warehouse as well as the restrictions of transshipment times and the delivery time, making the multimodal transportation problem of fresh fruits in online supermarket more complex. For example, there are multiple warehouses across the country and each warehouse not only needs to transport its local fresh fruits to other warehouses but also needs the fresh fruits from other places. Thus, the multimodal transportation problem of fresh fruits in online supermarket is more complex with multiple origins, destinations, and products, and the origin can also be the destination and the restrictions of transshipment times. It is a challenge to model the multimodal routing problem of fresh fruits in online supermarket under these unique characteristics.

Multimodal multi-commodity flow problem is an NP-Hard (Non-deterministic Polynomial-time Hard) problem [1,2]. SteadieSeifi et al. [3] conducted a comprehensive review on multimodal transportation system from the traditional strategic, tactical, and operational levels of planning. Multimodal transport can promote the economic development of regions and countries and help reduce the negative impact on the environment [4,5]. Wang and Meng [6] considered a discrete intermodal network design problem for freight transportation and formulated the problem as a mixed-integer nonlinear and non-convex program. García et al. [7] described a new hybrid approach which addressed complex intermodal transport problems. They combined OR (Operational Research) techniques with AI (Artificial Intelligence) search methods to obtain good quality solutions. Sun and Lang [8] considered multicommodity, capacitated multimodal transportation network and carbon dioxide emissions to assign optimal routes to move commodities through a multimodal transportation network. They developed a linearization method to transform the proposed model into a linear one and solved this problem in Lingo. Leleń and Wasiak [9] developed an optimization task for the selection of multimodal transport technologies for perishable products considering the cargo safety and transport costs.

The existing research on multimodal transportation system mainly focuses on planning transportation activities. Most of them just put emphasis on the transportation of general products and each product only needs to be transported from one origin to one destination. Research about multimodal transportation of fresh products focuses only on the transport technologies selection problem. Besides, the considerations of time urgency of cold-chain transport and transshipment times of fresh fruits are not studied. To the best of our knowledge, there exist no studies investigating the multimodal routing problem of fresh fruits with characteristics of unique transportation network structure, multiple demands of each warehouse, as well as the restrictions of transshipment times. This paper intends to solve the key question of how to choose the paths and transport modes to minimize the total cost with the unique characteristics of fresh fruits in online supermarket.

The remainder of this paper is organized as follows. In Section 2, a formulation in multimodal routing problem for fresh fruits is presented. A case study is given in Section 3. Finally, concluding remarks are summarized in Section 4.

2. A Mixed Integer Programming Model for Multimodal Routing Problem of Fresh Fruits in Online Supermarket.

2.1. **Problem description and symbol representation.** In this paper, we study the multimodal routing problem of fresh fruits in online supermarket. It refers to the selection of the best transportation paths and modes of online supermarket to transport various fresh fruits from multiple origins to multiple warehouses under the combinations of highway, railway and air transportation. The relationships between warehouses and fresh fruits can be described as follows. 1) Each kind of fruit needs to be transported to multiple destination warehouses. 2) Each warehouse has a need for a variety of fruits.

The transportation network structure of online supermarket is very special with multiple origins, multiple destinations and the origin can also be destination. Due to the unique transportation network structure of online supermarket, multiple demands of each warehouse and the restrictions of transshipment times, the relationships between transportation paths are very complex. It is difficult to model this problem directly.

We propose the Demand Split Method to model the multimodal transportation problem of fresh fruits in online supermarket. Each demand in this problem represents that one of the warehouses has the demand for one of the fresh fruits. The steps of Demand Split Method we used are as follows:

Step 1. We find all the demands of warehouses for fresh fruits;

Step 2. We extract each demand from the original problem by using two symbols h and m. We use h to represent the demand warehouse and m to represent the fresh fruit in demand.

The basic symbols are defined as follows.

Sets:

V: The set of warehouses in the transportation network of online supermarket;

K: The set of transport modes, including highway, railway and air transportation;

M: The set of fresh fruits.

Variables:

d_{ij}^k: The distance from warehouse i to warehouse j by transport mode k;

v_{ij}^k: The average speed of transport mode k from warehouse i to warehouse j;

c_{ij}^k: The average unit cost from warehouse i to warehouse j by transport mode k;

u_{ij}^k: The transport capacity from warehouse i to warehouse j by transport mode k;

$c_i^{k,q}$: In warehouse i, the transshipment cost from transport mode k to mode q;

$t_i^{k,q}$: In warehouse i, the transshipment time from transport mode k to mode q;

Q_{im}: The demand of warehouse i for fresh fruit m;

T_{im}: The time limit for fresh fruit m of warehouse i;

G_m: The upper limit of the transshipment times of fresh fruit m;

S_{sm}: The production of fresh fruit m in origin warehouse s.

Decision variables:

x_{ijhm}^k: Set to one if the demand of warehouse h for fresh fruit m is transported between warehouse i and warehouse j by transport mode k, and zero otherwise;

q_{ijhm}^k: The weight transported between warehouse i and warehouse j by transport mode k meets the demand of warehouse h for fresh fruit m;

$y_{ihm}^{k,q}$: Set to one if the demand of warehouse h for fresh fruit m is transshipped in warehouse i from transport mode k to transport mode q, and zero otherwise.

2.2. **Mathematical model.** The mathematical model of the multimodal routing problem in online supermarket is described as follows:

$$\min \sum_{k\in K}\sum_{i\in V}\sum_{j\in V}\sum_{h\in V}\sum_{m\in M} c_{ij}^k d_{ij}^k x_{ijhm}^k q_{ijhm}^k + \sum_{k\in K}\sum_{q\in K}\sum_{i\in V}\sum_{h\in V}\sum_{m\in M} Q_{im} c_i^{k,q} y_{ihm}^{k,q} \tag{1}$$

s.t.

$$\sum_{k\in K} x_{ijhm}^k \le 1,\ \forall i,j,h\in V,\ m\in M \tag{2}$$

$$\sum_{k\in K}\sum_{q\in K} y_{ihm}^{k,q} \le 1,\ \forall i,h\in V,\ m\in M \tag{3}$$

$$\sum_{g\in V} x_{gihm}^k \ge y_{ihm}^{k,q},\ \forall i,h\in V,\ k,q\in K,\ m\in M \tag{4}$$

$$\sum_{j\in V} x_{ijhm}^q \ge y_{ihm}^{k,q},\ \forall i,h\in V,\ k,q\in K,\ m\in M \tag{5}$$

$$y_{ihm}^{k,q} \geq \min\left(x_{gihm}^{k}, x_{ijhm}^{q}\right), \ \forall g,i,j,h \in V,\ k,q \in K,\ m \in M \tag{6}$$

$$\sum_{i\in V}\sum_{k\in K} q_{ijhm}^{k} \geq Q_{hm},\ j = h,\ \forall h \in V,\ m \in M \tag{7}$$

$$\sum_{i\in V}\sum_{h\in V}\sum_{k\in K} q_{ijhm}^{k} - \sum_{g\in V}\sum_{h\in V}\sum_{k\in K} q_{jghm}^{k} \geq Q_{jm} - S_{jm},\ \forall j \in V,\ m \in M \tag{8}$$

$$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} \frac{x_{ijhm}^{k} d_{ij}^{k}}{v_{ij}^{k}} + \sum_{i\in V}\sum_{k\in K}\sum_{q\in K} y_{ihm}^{k,q} t_{i}^{k,q} \leq T_{hm},\ \forall h \in V,\ m \in M \tag{9}$$

$$\sum_{h\in V}\sum_{m\in M} q_{ijhm}^{k} \leq u_{ij}^{k},\ \forall i,j \in V,\ k \in K \tag{10}$$

$$q_{ijhm}^{k} \leq N x_{ijhm}^{k},\ \forall i,j,h \in V,\ k \in K,\ m \in M \tag{11}$$

$$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} x_{ijhm}^{k} \leq G_{m},\ \forall h \in V,\ m \in M \tag{12}$$

$$x_{ijhm}^{k} \in \{0,1\},\ \forall i,j,h \in V,\ k \in K,\ m \in M \tag{13}$$

$$y_{ihm}^{k,q} \in \{0,1\},\ \forall i,h \in V,\ k,q \in K,\ m \in M \tag{14}$$

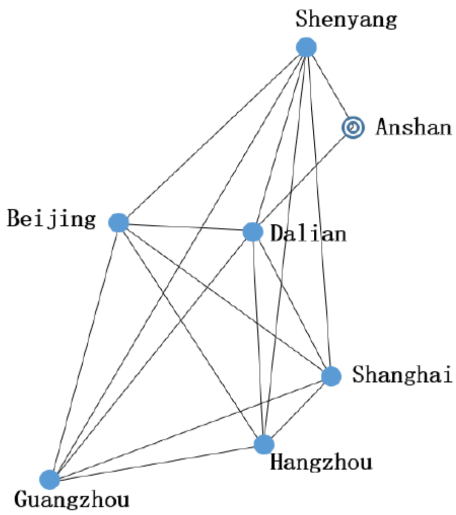
$$q_{ijhm}^{k} \geq 0,\ \forall i,j,h \in V,\ k \in K,\ m \in M \tag{15}$$

Objective function (1) is to minimize the total cost of online supermarket, including the transportation cost during the logistics and the transshipment cost between transport modes. Constraint (2) ensures warehouse h can only choose one transport mode when the demand of fruit m is transported in two adjacent warehouses. Constraint (3) represents that the demand of warehouse h for fruit m can only be converted by one transport mode in warehouse i. Constraints (4), (5) and (6) represent the relationship between transportation and transshipment. Constraint (7) represents the demand of warehouse h for fruit m. Constraint (8) represents the relationships between inflow and outflow of fruit m in warehouse j. Constraint (9) ensures that the delivery time of fruit m must meet the time limit of warehouse h. Constraint (10) represents the capacity constraint of transport mode k of warehouse j. Constraint (11) represents that there is a freight volume between warehouse i and warehouse j by transport mode k only when the fruit is transported from warehouse i to warehouse j by transport mode k, where N is a large enough constant. Constraint (12) represents that to reduce the damage of fruits during the process of loading, unloading, handling and sorting, there is a limit of times to transship fruits. Constraints (13), (14) and (15) represent the domain of decision variables.

3. **A Case Study of Nanguo Pears Multimodal Transportation.** In this section, we use a case study of Nanguo pears multimodal transportation to demonstrate the effectiveness of the proposed model. The Branch-and-Bound method (BB) is applied to solving the mixed integer programming model. CPLEX is used for the solution of this case. The data of numerical example is based on a large online supermarket in China. The model runs on the computer with the Intel Core 1.86GHz processor, 4GB memory and Windows 10 system.

3.1. **Design of experiments.** A large online supermarket in China needs to transport Anshan Nanguo pears to multiple warehouses built around the country. The transport network is shown in Figure 1(a).

The transport modes between warehouses are highway, air transportation and railway. We set the average speed (unit: kilometers per hour) of these three transport modes with 100, 800 and 220 respectively. The distance (unit: kilometer) and unit transportation cost (unit: yuan per ton-kilometer) between warehouses can get from Baidu Map website, the official website of Southern Airlines and the website of Railway Customer Service Center



(a)

Warehouse	Highway	Air	Railway
Anshan	30	0	20
Shenyang	25	15	20
Dalian	10	15	10
Beijing	25	20	30
Shanghai	25	20	30
Hangzhou	15	15	25
Guangzhou	25	20	25

(b)

	Highway	Air	Railway
Highway	30/2	50/4	40/3
Air	50/4	70/6	60/5
Railway	40/3	60/5	50/4

(c)

FIGURE 1. (a) The transport network topology diagram; (b) the capacities of different warehouses using different transport modes; (c) the transshipment cost and transshipment time between different transport modes (unit cost/time)

of China. The capacities of warehouses using different transport modes (unit: ton) are shown in Figure 1(b). The transshipment cost (unit: yuan per ton) and transshipment time (unit: hour) between different transport modes are shown in Figure 1(c).

To compare the influences of different delivery time limits on the selection of transportation paths and modes, this paper designs two sets of time limit data (unit: hour) for Shenyang, Dalian, Beijing, Shanghai, Hangzhou and Guangzhou. One group is of loose delivery time limits (LTL) with 12, 12, 24, 24, 24, 24. The second group of time is more urgent than the first group, which is of tight delivery time limits (TTL) with 12, 12, 12, 12, 12, 12. The demands of these warehouses (unit: ton) are 5, 3, 6, 6, 5, 5 respectively.

For reducing the damage of fresh fruits during the process of loading, unloading, handling and sorting, we set the transshipment times limit to 2.

3.2. **Performance analysis under loose delivery time limits.** We analyze the calculation results when the delivery time limits are loose (group LTL). The transportation schemes are shown in Table 1.

In Table 1, the transportation path and transport mode of each warehouse are given. The first column represents the destination warehouses. For example, we use SH to represent Shanghai warehouse. The second column shows the transportation path for each destination. For example, "AS-DL-SH" in the fifth row means that the demand of Shanghai needs to be transported from Anshan to Dalian and then Dalian to Shanghai. The third column shows the transport modes used in each path. For example, "Highway-Air" in the fifth row represents that the demand of Shanghai is transported from Anshan to Dalian by highway and Dalian to Shanghai by air. The transportation cost (unit: yuan) and transshipment cost (unit: yuan) of each path are also calculated. The transportation paths, transport modes and freight volumes between warehouses are shown in Figure 2(a). The numbers in the figure indicate the freight volumes between two warehouses. For example, Highway-16 means to transport 16 tons of Anshan Nanguo pears from Anshan to Shenyang by highway.

We can find the following from Table 1 and Figure 2(a). 1) Under the circumstance that the time limit is relatively loose, the highway transport mode will be more cost

TABLE 1. The transport schemes between warehouses (under group LTL)

Destination*	Path	Mode	Total cost	Transportation cost	Transshipment cost
SY	AS-SY	Highway	1020	1020	0
DL	AS-DL	Highway	1794	1794	0
BJ	AS-SY-BJ	Highway-Railway	8887.68	8647.68	240
SH	AS-DL-SH	Highway-Air	19527.96	19227.96	300
HZ	AS-DL-SH-HZ	Highway-Air-Highway	18283.3	17783.3	500
GZ	AS-SY-GZ	Highway-Air	21316.4	21066.4	250
	Total		70829.34	69539.34	1290

* SY: Shenyang, DL: Dalian, BJ: Beijing, SH: Shanghai, HZ: Hangzhou, GZ: Guangzhou.

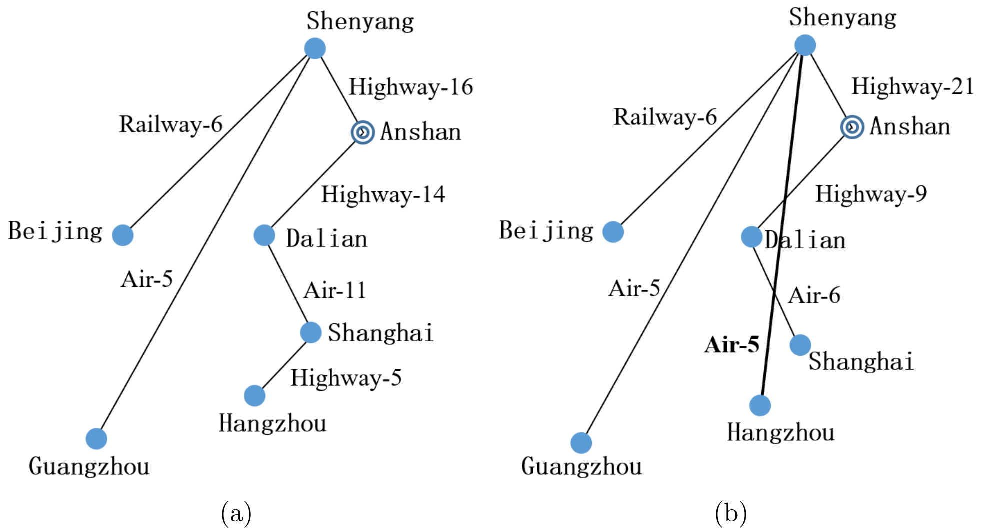


FIGURE 2. (a) Transportation paths, transport modes and traffic volumes between warehouses under the group of loose delivery time limits; (b) transportation paths, transport modes and traffic volumes between warehouses under the group of tight delivery time limits

effective if the distance between two warehouses is closer. However, if the distance is farther, air transportation or railway will be more economical than highway. For example, the distances between Anshan to Shenyang, Anshan to Dalian, Shanghai to Hangzhou are shorter, and then using highway transport mode is optimal. The distances between Dalian to Shanghai, Guangzhou to Shenyang, Shenyang to Beijing are farther, and by air or railway transport mode can reduce the transportation cost. 2) On the premise that the time limits and the transshipment times are satisfied, if the destination warehouse is far from the origin, the total cost can be reduced by transshipment. For example, the demand of Hangzhou warehouse for Anshan Nanguo pears is transported to Dalian warehouse by highway first. Due to the fact that the cost by air transport mode is lower, then it is transshipped by Shanghai warehouse and is transported from Shanghai to Hangzhou at last. In this case, the cost by transshipment is lower than that through transportation.

3.3. **Performance comparison between loose and tight delivery time limits.** We carry out the numerical tests under different delivery time limits. The transportation

TABLE 2. The comparison of the results under different time limits

Delivery time limit	Total cost	Transportation cost	Transshipment cost
The loose group	70829.34	69539.34	1290
The tight group	73813.14	72773.14	1040

paths, transport modes and freight volumes between different warehouses under the limit of the second group delivery time are shown in Figure 2(b). The costs of two transportation schemes (yuan) are shown in Table 2. It can be found from Figure 2(a) and Figure 2(b) that with the increase of the delivery time urgency, the chances of choosing through transportation and adopting air transportation are increasing. For example, the demand of Hangzhou warehouse for Anshan Nanguo pears can be transshipped by Shanghai warehouse under the group of loose delivery time limits. However, under the group of tight delivery time limits, it can only be transported from Shenyang warehouses directly and by air transport mode to meet the requirements of the delivery time. As can be seen from Table 2, the increase in time limit has also brought about a rise in total costs and transportation costs.

4. **Conclusions.** This study discussed a method for multimodal transportation problem of fresh fruits in online supermarket. 1) The multimodal transportation problem of fresh fruits in online supermarket has many unique characteristics including the unique transportation network structure of online supermarket, the multiple demands of each warehouse and the restrictions of transshipment times. Therefore, the multimodal routing problem of fresh fruits in online supermarket needs to be studied. 2) Considering the characteristics of the multimodal transportation of fresh fruits in online supermarket, this paper built a mixed integer programming model by using the Demand Split Method and the effectiveness of the proposed model is validated by computation experiment based on an online supermarket.

Compared with the existing research, the contributions of this paper are shown as follows. 1) Consider a more complicated multimodal transportation problem with unique transportation network structure, multiple demands of each destination, and the restrictions of transshipment times. The research scope of multimodal transportation is extended. 2) The model constructed in this paper through Demand Split Method can be used to solve the challenging multimodal routing problem of fresh fruits in online supermarket effectively.

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