

OPTIMIZATION OF LOGISTICS OF JOINT DISTRIBUTION WITH IMPROVED HEURISTIC ALGORITHM

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ABSTRACT: With the deterioration of transportation and environmental damage during the development process of modern logistics, more attention has been increasingly paid to the side effects of urban logistics and the coordination between logistics operations and urban development. Following the principle of optimal research on urban logistics, this paper investigates logistics efficiency in terms of improving the urban logistics by means of joint distribution which involves determining the number of distribution centers needed, locating the distribution center to be used and optimizing the transportation routing. To this end, a modified heuristic algorithm is proposed to resolve these kinds of problems. In the last part of the paper, a simulation analysis is given to demonstrate the outstanding advantage of joint distribution, which gives further consideration to urban logistics distribution.

KEY WORDS: Urban logistics, Joint distribution, Local model, Optimal routing problem.

1. INTRODUCTION

The Urban logistics refers to material goods in physical mobility within cities, goods distribution and waste clean-up in urban and suburban regions. An urban logistics system is the comprehensive consideration of the various modes of transport, to adjust the urban land planning, based on the adjustment of urban road network planning and logistics resources to maximize the integration and optimization. By considering the urban logistics for social, environmental, economic, financial, and source of energy aspects, the urban logistics process can achieve the best overall results (Wang, 2004).

Urban logistics external economy is a general term for the negative effects of urban logistics activities of urban traffic problems and energy consumption issues, urban ecological environment, urban quality of life issues.

Firstly, negative effect is the urban traffic problem. The urban economy is the basis of urban logistics, and it plays a role in promoting urban logistics. High-speed urban economic development can promote the expansion of city size, deepening the industrial cluster effect and increasing the city's population density. These factors directly or indirectly cause an increase in demand for goods, which leads to a rise in cargo traffic. In order to satisfy consumers' diversified and personalized demand, manufacturers use a multi-variety, small batch production method and a multi-batch, high

frequency mode of transport, resulting in increased total social traffic.

Secondly, is the energy consumption problem. Energy is the driving force of the basic means of transport, and is needed to ensure the smooth operation of city logistics activities. Currently, most urban transport vehicles use fossil fuels. However, outdated means of transport and unreasonable transportation organization often result in repeated transportation, circuitous transportation and empty transport, etc. which unnecessarily increases the running time of the vehicle. These factors have led to a reduction in energy efficiency.

Thirdly, is the urban ecological environment problem. Urban logistics and auto transport result in an increase in the urban transport volume and will inevitably cause an increase in vehicle exhaust emissions, and intensify noise pollution. According to the relevant survey, 80% - 90% of CO, 70% - 80% of NO and other pollutants in urban air are from vehicle exhaust (Cheng et al., 2005). Urban logistics activities also create other contaminants, such as non-degradable packaging materials, and an increase in solid wastes, the accumulation of waste tires, spent fuel potential hazards and safety threats of toxic waste and other goods. Urban logistics causes contaminants to accumulate in an urban environment which exceeds the self-purification capacity of the environment, and destroy the balance of the urban ecological environment.

The last negative effect is related to the life quality of urban residents. With economic development, the scale of urban logistics continues to expand. Environmental pollution caused by the expansion of the scale of urban logistics will directly affect the health of residents. Construction of urban logistics infrastructure (such as logistics

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nodes and logistics channels) will inevitably utilize much of urban land resources. This scales back the construction of urban green spaces and sports facilities and other public resources. Furthermore, the reduction of available urban land for construction will also lead to increased urban real estate prices, thus increasing the cost of living, and leading to lower quality of life (Wang, 2007; City Logistics Solutions; Eiichi et al., 2001).

In 1977, the Japanese government formally proposed the "joint distribution" concept. Japan's Ministry of Transport Circulation Countermeasures Headquarters promoted the idea of a "Cooperation platform to promote import transportation system" in the joint distribution as defined as: in the city, for the rationalization of logistics, with the cooperation of several persons who have regular freight demand, there is a trucker using a transport system distribution of the "modern logistics details" (Xu, 2002). The 2006 edition of "People's Republic of China national standard logistics term" described joint distribution as being "organized and implemented by multiple syndication distribution activities" (GB/T18354 -200, 2007). In summary, joint distribution is the number of units in a circulation processing system with homogeneous or heterogeneous commodities and together promote their common use of warehouse, vehicles and other facilities and equipment. By making a small amount of goods into commercial products cargo, a large quantity of distribution can be formatted, and low-cost and high-level logistics services can be realized (Wang, 2005; Qi et al., 2014; Hu, 2006). Therefore, joint distribution is distributing resources to the entire logistics network system, including users and shippers, and thus realizing low-cost delivery service. Joint distribution is a major development trend, being an efficient logistics and distribution model, and has been widely used in practice in developed countries for quite some time now. For example, the Japan Franchise Association in its 2001 logistics survey states that the rate of joint distribution is as high as 55.4%. Many prominent global companies have adopted the common distribution model, such as the international chain of convenience stores, 7-Eleven, and Wal-Mart supermarket chain.

The Japanese Ministry of Transport's original June 1992 release of "establish market logistics system efficiency survey" shows that in addition to the department stores, a wholesale trade logistics center was set up. The efficiency of the joint distribution resulted in a reduction in delivery truck drivers in Bremen, Germany, led by the Bremen logistics centers, with 14 logistics enterprises

consisting of city distribution Ltd, and the dispersed distribution was centered into a common distribution, unifying vehicle scheduling and installing GPS on the vehicle (Global Positioning System). After the implementation of the program, as few as 12 vehicles per day were needed for delivery to urban areas, a reduction from the previous 400 vehicles per day, with the capacity to save 80%. The city of Kassel, Germany has reduced freight traffic as well as environmental pollution since the introduction of the common distribution since 1994 (Hu, 2006; Wang et al., 2007). The advantages of joint distribution can be considered as a social impact of economic development.

For emerging small and medium enterprises who do not enjoy large investments, setting up distribution centers involves a long period of cost recovery because the distribution size too small to achieve economies of scale, and management costs result in a rise in product cost. These will suffer a decline in efficiency and will be unable to optimally configure their existing resources. With limited manpower, their material and financial resources should be concentrated on the enterprise's core business, improving the market competitiveness of enterprises. From the perspective of social development, enterprises' scattered distribution prompts increase in the number of transit vehicles, staggered back-and-forth driving, increased traffic congestion, environmental pollution and other problems that go against the ideas of a "harmonious society" and "green logistics" development. Joint distribution aims to utilize a vehicle's maximum load limit as often as possible, thus reducing the number of transport vehicles needed, easing urban traffic pressure, and reducing vehicle pollution in the city. Joint distribution is conducive to the logistics infrastructure of centralized planning, and a sensible plan for distributions reduces the occupation of land resources, to realize the effective integration of social resources.

In the actual logistics and distribution, Japan, the United States and other developed countries continue to explore the development of a variety of common distribution models. These specific modes of operation can be divided into two categories: one has the owner as the main joint distributor; the other is the logistics industry as the main common distributor. To the owner determining the main joint distribution pattern, it can be subdivided into a number of types of enterprise-based cooperation. These patterns of joint distribution require each organization or individual unit to coordinate cooperation in the use of mixed multi-vehicle owners, or through the establishment of a common

distribution depot, taking advantage of shared complementary resources, and improving the efficiency of distribution. Disadvantages may arise due to differences in corporate philosophy and background, so much time and effort must be spent on the coordination of cooperation between enterprises. The co-distribution of the main body of the logistics industry is the third party logistics company that provides the logistics service to provide service for the customers. This model can make use of modern equipment of a professional logistics enterprise. It is conducive for an enterprise to conduct its own logistics, with investment risk aversion, to focus resources on the core business and enhance the competitiveness of products and enterprises. This model not only can meet the basic requirements of customers regarding distribution, but also can develop the optimal number of arrangements, route selections and other aspects of the system. On the basis of this, the distribution enterprises are formed in a certain distribution area, and making use of the distribution resources together to realize the cooperative distribution of the centralized distribution area.

2. PROBLEM DESCRIPTION

The optimization of urban logistics based on co-distribution includes three essential aspects: the number of distribution centers, the location of distribution centers, and the optimization of distribution routes.

(1) Optimization of distribution route

In the joint distribution activities, the distribution line arrangement affects the distance of a delivery route, which is affected by traffic conditions, in an effort to optimize the distribution route to city residents is significant. Temporal and spatial characteristics of the distribution route optimization problem can be divided into three categories based on the problem: only on the basis of spatial placement of the line is called the vehicle routing problem; considering the time-line arrangements calling for vehicle scheduling problem; taking into account the spatial and temporal issues is called mixed problem. At present, China's urban logistics distribution is not particularly stringent, except in special cases of materials that require a specific timeliness (Wei et al., 2015).

(2) Description of distribution path optimization problem

A distribution center is established for a certain geographical range of customers to carry out the logistics and distribution services, and each delivery

does not exceed the maximum load of each truck, and the total operating distance of the delivery has a certain limit. In order to complete the task of transportation, the distribution center must send numerous vehicles, with all distribution paths consisting of a circuit or a plurality of circuits. Each delivery vehicle, starting from the distribution center, covers certain customer routes and eventually returns to the distribution center. In improving vehicle utilization and the efficiency of the logistics of distribution, routing optimization problems includes: the collocation of distribution of goods; vehicles bypass order on each delivery route.

(3) The distribution center selection and the joint optimization of distribution routing

It is assumed that there are multiple distribution centers in an area, and each distribution center is responsible for service to a certain number of customers. The first step of joint optimization is to choose one joint distribution center among the original distribution centers, and then arrange the routing of vehicles from the distribution center to each customer. Each distribution weight of every vehicle should no more than the maximum load for that vehicle, and the total running distance of the vehicle is limited. In order to improve the utilization of vehicles and the efficiency of the logistics of distribution, joint optimization includes: the collocation of delivery of the goods and distribution routing of the vehicle.

Due to large differences in customers' demands and the various properties of goods in joint distribution, it is necessary to be equipped with various types of vehicles in order to meet the diversity of customers' demands. Therefore, this paper assumes that each distribution center has a variety of different types of vehicles when studying the distribution center selection and the joint optimization of distribution routing.

3. MATHEMATIC MODEL

The assumptions are as follows:

- (1) There are different types of transport vehicles;
- (2) The vehicle load of the goods distribution is less than the demand;
- (3) There is no prior loading sequence or direction constraints;
- (4) All goods can be mixed loading;
- (5) The pickup time and delivery time are not considered;
- (6) The customer demand of a year is known, and evenly distributed among weekdays, calculated

at 300 working days a year;

(7) Each vehicle is responsible for only one route, and can be arranged only once per day;

(8) Operation costs of the distribution center is divided into variable cost and fixed cost, and variable cost is only related to distribution and is

linear;

(9) Each distribution center has sufficient resources, and sufficient transport capacity.

All the symbols involved in the model are shown in Table 1 as follows:

Table 1. Symbols used in the model

No.	Symbol	Explanation
1	D	Sum of the distribution centers $d \in D$, refers to the d distribution center
2	N	Sum of the customers, $n \in N$ refers to the n customer
3	S	Sum of types of the vehicles. $s \in S$ refers to the s type of the vehicle
4	P_d^s	Sum of the vehicles. $p \in P_d^s$ refers to the p vehicle of s type in d distribution center
5	W_s	Maximum load weight of s type of the vehicles
6	L_s	Maximum distance of the s type of the vehicles
7	Q_n	Yearly demand of n customer
8	CF_d	Fixed cost of d distribution center for one year
9	CV_d	The of d distribution center
10	CU_s	Fixed cost of s type of vehicle for one delivery
11	CT_s	Variable cost of unit distance of s type of vehicle
12	C_{ij}	Distance from i to j , $i, j \in D \cup N$
13	x_d	Decision variable, $d \in D$, $x_d=1$ indicates that d is identified as the joint distribution center; otherwise, $x_d=0$
14	y_p	Decision variable, $p \in P_D^s$, $y_p=1$ indicates that p vehicle of s type in d distribution center is identified for distribution; otherwise, $y_p=0$
15	Z_{ij}^p	Decision variable, $p \in P_d^s$, $i, j \in D \cup N$, $Z_{ij}^p=1$ indicates that p vehicle of s type in d distribution center travels from i to j ; otherwise, $Z_{ij}^p=0$

The objective of this model is to minimize the operation costs, and the total cost equals the costs of the distribution centers plus the costs of the vehicles.

(1) Cost of the distribution center equals the fixed cost of the distribution center plus the variable cost of the distribution center.

Fixed cost:

$$C1 = \sum_{d \in D} x_d \cdot CF_d ;$$

Variable cost:

$$C2 = \sum_{d \in D} \sum_{s \in S} \sum_{p \in P_d^s} \sum_{j \in N} \sum_{i \in N} z_{ij}^p \cdot Q_i \cdot CV_d$$

(2) Cost of vehicles equals the fixed cost of vehicles plus the variable cost of vehicles.

Fixed cost of vehicles:

$$C3 = 300 \cdot \sum_{s \in S} y_i^p \cdot CU_s ;$$

Variable cost of vehicles:

$$C4 = 300 \cdot \sum_{d \in D} \sum_{s \in S} \sum_{p \in P_d^s} \sum_{j \in D \cup N} \sum_{i \in D \cup N} z_{ij}^p \cdot c_{ij} \cdot CT_s$$

The mathematical formulas of model are shown as:

$$\min Z = C1 + C2 + C3 + C4 \tag{1}$$

$$\text{s.t. } \sum_{j \in N} \sum_{i \in N} \frac{Q_i}{300} \cdot z_{ij}^p \leq W_s, p \in P_d^s, s \in S, d \in D \tag{2}$$

$$\sum_{j \in N} \sum_{i \in N} c_{ij} \cdot z_{ij}^p \leq L_s, p \in P_d^s, s \in S, d \in D \tag{3}$$

$$\sum_{d \in D} \sum_{s \in S} \sum_{p \in P_d^s} y_i^p = 1, i \in N, \tag{4}$$

$$\sum_{i \in D \cup N} z_{ij}^p = \sum_{i \in D \cup N} z_{ji}^p, p \in P_d^s, s \in S, d \in D \tag{5}$$

$$\sum_{j \in D \cup N} z_{ij}^p = y_i^p, i \in N, p \in P_d^s, s \in S, d \in D \tag{6}$$

$$\sum_{j \in D \cup N} z_{ji}^p = y_i^p, \quad i \in N, p \in P_d^s, s \in S, d \in D \quad (7)$$

$$\sum_{j \in D \cup N} z_{ji}^p = y_i^p, \quad i \in N, p \in P_d^s, s \in S, d \in D \quad (8)$$

Eq. (1) refers to the objective function: minimize the total yearly cost. Eq. (2) means that the goods distribution vehicle load is less than the allowed maximum weight. Eq. (3) means that the distance of each vehicle is less than the allowed max distance. Eq. (4) means that the customer can only be served once a day. Eq. (5-7) mean that if a vehicle goes to serve one customer, it should leave for the next delivery from this customer. Eq. (8) refers to the decision variable value constraints.

4. IMPROVED FUZZY GENETIC ALGORITHM

Particle swarm optimization (PSO) algorithm was first proposed in paper (Wei et al., 2015), which is a population-based searching method. Different particles compose the swarm and the positions of the particles are considered as solutions in the original PSO algorithm. The position of each particle is generated randomly and the velocity of particle is 0 in the first iteration. Then the position and velocity are updated by the following Eq. (9) and (10):

$$V_{i,j}(t+1) = w \cdot V_{i,j}(t) + c_1 \cdot r_{1,i}(t) \cdot [P_{i,j}(t) - X_{i,j}(t)] + c_2 \cdot r_{2,i}(t) \cdot [P_{g,j}(t) - X_{i,j}(t)] \quad (9)$$

$$X_{i,j}(t+1) = X_{i,j}(t) + V_{i,j}(t+1) \quad (10)$$

According to the paper (Kennedy and Eberhart, 2001), in order to make sure the convergence, the particles should converge to attractor C_i :

$$C_{i,j}(t) = \left(\frac{c_1 \cdot r_1 \cdot P_{i,j}(t) + c_2 \cdot r_2 \cdot P_{g,j}(t)}{c_1 \cdot r_1 + c_2 \cdot r_2} \right), \quad j=1,2,\dots,d, \quad c_1, c_2 \in U(0,1) \quad (11)$$

$$C_{i,j}(t) = \alpha \cdot P_{i,j}(t) + (1 - \alpha) \cdot P_{g,j}(t), \quad \alpha \in U(0,1) \quad (12)$$

where $\alpha = (c_1 \cdot r_1) / (c_1 \cdot r_1 + c_2 \cdot r_2)$, P_i and P_g represent the personal and global best particles

respectively.

Quantum-behaved Particle Swarm Optimization Algorithm (QPSO) was proposed in paper (Liu, 2006) based on the convergence characteristic of the PSO, which can improve the search efficiency by fewer parameters.

The quantum state of a particle is depicted by a wave function $\psi(\vec{x}, t)$ (Lin et al., 2013). Then a global point can be derived in QPSO (Tang et al., 2014). The global point, $mbest$, is defined as the mean of the $Pbest$ positions of all particles, and the equation is as follows:

$$mbest(t) = (mbest_1(t), mbest_2(t), \dots, mbest_d(t)) = \left(\frac{1}{n} \sum_{i=1}^n P_{i,1}(t), \frac{1}{n} \sum_{i=1}^n P_{i,2}(t), \dots, \frac{1}{n} \sum_{i=1}^n P_{i,d}(t) \right) \quad (13)$$

The new position of a particle is:

$$X_{i,j}(t+1) = C_{i,j}(t) \pm \beta \cdot |mbest_j - X_{i,j}(t)| \cdot \ln(1/u), \quad u = rand(0,1) \quad (14)$$

where β denotes for the contraction-expansion coefficient.

(1) Decoding method

Multi-depots are included in the model, so a new particle encoding is designed with $3 \times n$ matrix, which refers to T depots, n clients and v vehicles. For example, A case with 2 depots and 10 clients is taken for an example. There are 2 vehicles in Depot 1 and 3 vehicles in Depot 2, then the decoding is shown in Fig. 1.

Client	1	2	3	4	5	6	7	8	9	10
X_d	1	1	2	1	2	2	2	1	2	2
X_v	1	1	3	2	4	4	4	2	5	5
X_t	0.3	1.2	0.6	2.3	4.8	1.1	2.9	3.9	2.8	1.7

Figure 1. Decoding example

The routes should be adjusted based on X_t to make sure that all the clients severed by each vehicle must be identified and then sorted by the value of X_t .

(2) Local search heuristics

According to the paper (Sun et al., 2004), 2-opt heuristic and inner-tour swap are employed to improve the solution. There are 2 tours in 2-opt heuristic. The tours are divided into two sections, and there is a node for each tour in the first step. Then the first tour joins to the second part of the second tour.

An inner-tour swap can be used in the tour during the local search. In the first step, two clients that are assigned in one tour and then switch the sequences. The length of the tour refers to the number of clients; then the clients are exchanged. If this change produces a tour with lower cost, then it is accepted, otherwise it is rejected and we need to choose another pair of clients.

Client	1	2	3	4	5	6	7	8	9	10
X_d	1	1	2	1	2	2	2	1	2	2
X_v	1	1	3	2	4	4	4	2	5	5
X_r	1	2	1	1	3	1	2	2	2	1

↓

Depot1	Vechile1: 1 → 2
	Vechile2: 4 → 8
Depot2	Vechile3: 3
	Vechile4: 6 → 7 → 5
	Vechile5: 10 → 9

Figure 2. The decoding process

5. SIMULATION ANALYSIS

There were three retail enterprises in a city, where every retail enterprise uses their own distribution centers for individual delivery of goods. There were seven distribution centers and twenty-five retail outlets for these three enterprises, as shown in Fig. 3.

Due to the strong competition in the market, the operation costs of the distribution center were

too high for these three retail enterprises. In addition, the logistics business is not their main business, so the technology in logistics distribution was relatively low. In order to improve the distribution efficiency and reduce distribution costs, these three retail enterprises decided to conduct joint distribution. They needed to select a distribution center as the joint distribution center out of the original seven distribution centers, and the number of joint distribution centers and their locations are calculated by the model. The coordinates and operation costs of the distribution centers are shown in Table 2. The demand of coordinate sales outlets are shown in Table 3. The vehicle model and maximum load and maximum distance data are shown in Table 4.

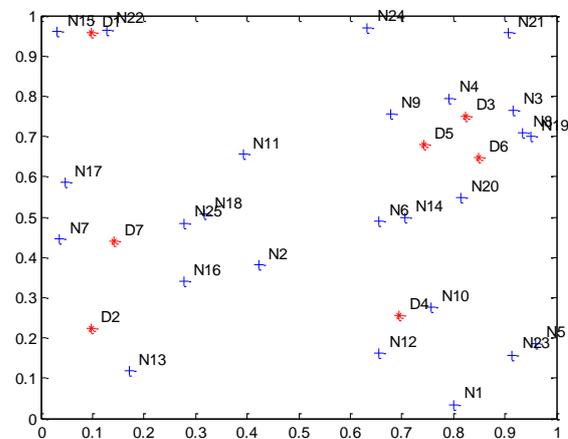


Figure 3. Locations of distribution centers and retail outlets

Table 2. Calculation results based on the test function

Distribution center	Abscissa	Ordinate	Yearly fixed cost	Variable cost
D1	0.0975	0.9572	198000	10
D2	0.0971	0.2238	263000	10
D3	0.8235	0.7513	173000	15
D4	0.6948	0.2551	126000	15
D5	0.7431	0.6797	259000	10
D6	0.8491	0.6463	125000	10
D7	0.1419	0.4387	138000	15

Table 3. The retail outlets locations and their yearly demands

Retail outlets	Abscissa	Ordinate	Yearly demand
N1	0.8003	0.0344	1200
N2	0.4218	0.3816	1620
N3	0.9157	0.7655	330
N4	0.7922	0.7952	950
N5	0.9595	0.1869	850
N6	0.6557	0.4898	1750
N7	0.0357	0.4456	790
N8	0.9340	0.7094	560
N9	0.6787	0.7547	1740
N10	0.7577	0.2760	1220
N11	0.3922	0.6551	680

N12	0.6555	0.1626	290
N13	0.1712	0.1190	1410
N14	0.7060	0.4984	450
N15	0.0318	0.9597	580
N16	0.2769	0.3404	530
N17	0.0462	0.5853	670
N18	0.3171	0.5060	1050
N19	0.9502	0.6991	1190
N20	0.8147	0.5469	1850
N21	0.9058	0.9575	1000
N22	0.1270	0.9649	850
N23	0.9134	0.1576	880
N24	0.6324	0.9706	350
N25	0.2785	0.4854	670

Table 4. Types of the vehicles

Type	Maximum weight (kg)	Maximum distance (km)
S1	5	5
S2	10	9
S3	15	12

We tested the above data and obtained the optimal solution: only D3, D4 and D7 are kept, and D3 serves ten retail outlets which are N3, N4, N6, N8, N9, N14, N19, N20, N21, N24. D4 serves five

retail outlets including N1, N5, N10, N12, N23. D7 serves ten retail outlets including N2, N7, N11, N13, N15, N16, N17, N18, N22, N25. The results and the distribution routing are shown in Table 5:

Table 5. Results and the distribution routing

No.	Distribution routing	Distribution center	Type	Average loading weight	Average routing distance
R1	D3-N3-N8-N19-D3	D3	S1	6.9333	0.3087
R2	D3-N20-N14-N6-D3	D3	S3	13.5	0.6853
R3	D4-N10-N5-N23-D4	D3	S3	13.4667	1.3554
R4	D3-N9-N24-N21-N4-D3	D4	S3	4.9667	1.7413
R5	D4-N1-N12 -D4	D4	S2	9.8333	0.5384
R6	D7-N7-N17-N15-N22-D7	D7	S2	9.6333	1.2429
R7	D7-N11-N18-N25-D7	D7	S2	8	0.6860
R8	D7-N2-N16-N13-D7	D7	S3	11.8667	1.0027

It should be noted that the results and the distribution routing in Table 5 are theoretical values, and in the actual process of distribution, the loading capacity and distance will vary slightly from day to day, but it will not heavily influence the final results.

6. CONCLUSION

Joint distribution is a major trend around the whole world, and it is an efficient logistics and distribution method which has been widely used in practice in developed countries. This paper is an attempt to investigate the logistics efficiency in terms of improving the urban logistics by means of joint distribution which involve determining the number of distribution centers needed, locating the distribution centers and optimizing the transportation routing. To this end, a modified heuristic algorithm is proposed to solve these kinds of problems. A simulation analysis is illustrated and

the results show that the models and the algorithm proposed in this study can improve the efficiency of the logistics and reduce the related cost.

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