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Logistic Distribution Disruption Management Model Based on Distribution Time Delay

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Abstract

Distribution delay is a common problem that causes logistics distribution plan difficult to implement. This paper using the customer satisfaction degree, the vehicle drivers' satisfaction degree, the logistics company deviation cost and the customer future selection lost cost to measure the disturbing degree of disruption events. In this paper, a Genetic Algorithm based on improved elitist strategy is designed, and using re-scheduling and disruption management to solve the instance respectively, it demonstrated the effectiveness and feasibility of disruption management methods.

Keywords: *Logistics distribution; Distribution time delay; Disruption management; Vehicle scheduling; New evolutionary algorithm*

1. Introduction

With the continuous development of e-commerce, logistics distribution industry is developing rapidly. It is the core link of the entire distribution system to provide customers efficient and in-time delivery service, and it is also the life of enterprise. In the distribution, uncertain disruption events occur frequently, and they are also unpredictable. Distribution delay is the most popular and common form. Changes in traffic information, traffic jams, accidents, weather conditions, *etc.*, will cause different degrees of distribution delay. When the disruption events occur, it requires immediate attention, otherwise it will affect the entire distribution plan, even not able to continue to execute, it may affect the logistics companies and customers.

In recent years, disruption management attracted international academia's attention and it is a very cutting-edge research direction. In the field of aviation, supply chain and project management, it has made certain achievements. But in the logistics field it is only just begun. Because of the complexity and uncertainty of logistics activities, the research of logistics distribution disruption management has great theoretical significance and practical value.

At present, domestic and foreign scholars studied the disruption events of logistics distribution in different angles using different methods and made a lot of achievements. Zhu Zhijun *et. al.*, [1] analyzed the disruption recovery strategy based on blockage point unrecoverable type of vehicle routing problem, the results showed that the reset policy has the best competitive ratio. Hu Maolin *et. al.*, [2] analyzed the recovery strategy based on the blockage point recovery type of vehicle scheduling issues, and the result shows that selection strategy which is the combination of greedy strategy, reposition strategy and waiting strategy has the best competitive ratio. Eiichi Taniguchi and Hiroshi Shimamoto [3] developed a vehicle scheduling and route planning model fusing dynamic vehicle

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travel time information, and designed an effective solution algorithm. Jean-Yves Potvin *et. al.,* [4] established a model for new customers' needs and travel time disruption problems, and using insertion algorithm to solve the problems. Zhong Shiquan *et. al.,* [5] researched the vehicle's emergency scheduling problem based on time windows and shipments change, and realized the emergency vehicle scheduling by designing a virtual parking lot and other methods. Li Jing Quan *et. al.,* [6-7] try to study the reschedule method, adjusted the entire system after the disruption events. Although the re-scheduling method can achieve the optimal system cost, it may bring great disruption to the system, and it may touch the factors that the original proposal didn't take into account so that the rescue plan cannot be performed [8].

Disruption events are unpredictable and occur frequently, and disruption management provides an effective idea to solve them in real time. Its input information is the original program, and it generates the smallest disruption and cost recovery program quickly based on the state of disruption occurs [9-10]. Wang Mingchun *et. al.,* [11] starting from the original problem of VRPTW, established a disruption recovery model as the target with the minimum deviation between the new plan and the original plan after the disruption occurred, aiming at customers' increase or decrease, the time window, customer needs and route feasibility of disruption and other issues. Wang Xu Ping *et. al.,* [12] analyzed the rescue demand of damaged vehicles in time window service type vehicle routing problem, established a service-oriented vehicle routing problem disruption recovery model, and presented two vehicles damaged relief strategies based on disruption management thought. On this basis, they studied the disturbed transport capacity of logistic distribution disruption issues in depth [13-14]. At the same time, they took the customer demand changes disruption events as an object, considering three disruption aspects including distribution costs, travel route and customer service time, and established vehicle scheduling disruption management model and designed the corresponding algorithm [15-17]. In addition, Wang Zheng *et. al.,* [18], Jiang Li *et. al.,* [19], Q Mu *et. al.,* [20] were also using disruption management to study the disruption problems of logistic distribution.

However, there are still a few logistics disruption problems need to be solved: ① Extraction of disruption factors; ②Measurement of disruption degree; ③Construction of disruption management model; ④Efficient solution method. In the current existing research results, the disruption factors are mostly customer satisfaction and business costs, they are not comprehensive enough. The single objective model established is not appropriate with the real picture. A more efficient solving method need to be discovered. In short, the disruption management system of logistics distribution has not been fully formed.

This paper compared the disruption management methods and re-scheduling methods. Using the re-scheduling method, could make the program feasible because the big system disruption, or cannot take the interests of many parties into account but only take cost minimization. In fact, after disruption occurs, we need to balance the customers, vehicle drivers, logistics business operators and other parties' interest, not just cost minimization. When the system occurred disruption, disruption management is not re-modeling and optimizes the system, but adjusts the system, and it will cause minimal disruption to the system. Based on this idea, this paper studied the logistics distribution disruption management problem based on distribution delay, and established the mathematical model of the problem and found its solution method, providing decision support for the development of multi- satisfactory distribution disruption recovery programs.

2. Disruption Management Model Construction

2.1. Problem Description

In the initial plan implementation, the original plan become unavailable, because the disruption events which caused by the internal and external uncertainties. So the new plan should generate timely. And the new plan should consider the original optimization objectives, and minimize the side effects caused by the disruption.

If the delivery delay occurs, but can recover in an acceptable time and arrive in the window specified by the client or client's tolerance range, it can't be identified as disruption events. Assume that Et is the earliest service time customers can accept, Lt is the latest service time customers can accept, Δt is the tolerance degree of customers, and St is start time of customers be serviced. The formulas are as follow:

If $Et - \Delta t \le St \le Lt + \Delta t$, the program has not been disturbed, doesn't need to adjust.

If $St < Et - \Delta t$ or $St > Lt + \Delta t$, the program has been disturbed, need to adjust.

There is an example of the adjustment of the vehicle route after the disruption. Left graph is the initial driving plan, it has three routes (R_1, R_2 and R_3) to ensure it can service for 14 customers. But the vehicle on R_3 delving from customer 12 to customer 13 is delay on the point A, and it cannot service customer 13 within the time window which customer required. And the right graph is an adjustment of the program, the routes (R_1, R_2 and R_3) are all changed. The dotted lines are the differences of the two charts.

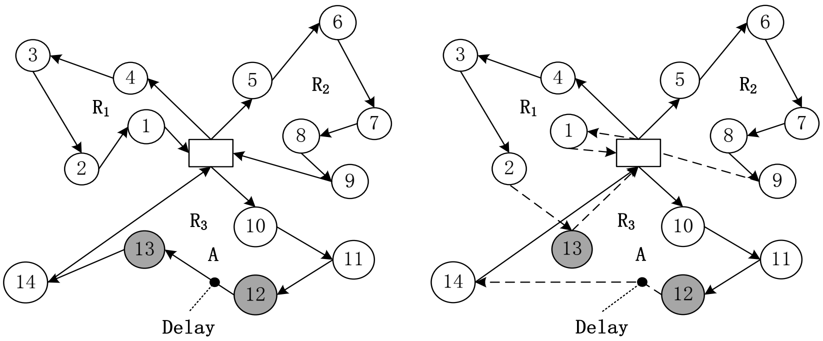

Figure 1. The Vehicle Route Adjustment Chart of Disruption Management

2.2. Disruption Measurement

This paper combines behavior theory, refines disruption factors from each subject in distribution. The subjects in distribution are customers, drivers and logistics operation businesses. And we will choose four factors to quantitative analyze the influence of the four factors impact the disruption management program. The four factors are customer dissatisfaction degree, driver dissatisfaction degree, enterprise deviation cost and the customer future selection lost cost.

2.2.1. Customer: This paper choose betimes and accuracy to describe customer satisfaction degree. The betimes can be described by the time window of vehicles reach the customers. Besides, because the customer demand in this paper can be split, customers will consider about whether they can receive their goods in one time. And the cooperation between vehicles will make one customer receives his goods in many times. So receiving times is the measurement index of accuracy. Since the optimization direction of objective function is minimization, so customer satisfaction degree should transform to customer dissatisfaction degree, then minimize the customer dissatisfaction degree.

In distribution, if the vehicles can deliver the goods under the time $[Et, Lt]$ which customers asked, it is the best level of delivery service and the customer satisfaction degree is the highest. Otherwise, if the vehicles deliver the goods under the time $[Et - \Delta t, Lt + \Delta t]$, the customer satisfaction degree will go down. And other service time will not accept by the customers. Assume that n is the number of vehicles service for customer j; S'_{1jk} is the dissatisfaction degree of customer j to vehicle k 's betimes; Et_j is the earliest service time customer j can accept; Lt_j is the latest service time customer j can accept; Δt_j is the biggest tolerance degree of customer j ; S'_{1jk} is the start time vehicle k service for customer j ; D_{jk} is the delivery amount of vehicle k delivery for customer j ; D_j is demand amount of customer j .The dissatisfaction degree of customer j to the betimes is as follow:

$$S'_{1jk} = \begin{cases} 0 & Et_j \le St_{jk} \le Lt_j \\ \dfrac{St_{jk} - (Et_j - \Delta t_j)}{Lt_j - Et_j + 2\Delta t_j} \cdot \dfrac{D_{jk}}{D_j} & Et_j - \Delta t_j \le St_{jk} < Et_j \\ \dfrac{St_{jk} - Lt_j}{Lt_j - Et_j + 2\Delta t_j} \cdot \dfrac{D_{jk}}{D_j} & Lt_j < St_{jk} \le Lt_j + \Delta t_j \\ 1 & St_{jk} < Et_j - \Delta t_j ; Lt_j + \Delta t_j < St_{jk} \end{cases}$$

Although customers can receive their goods in acceptable time window, but if they cannot receive their goods in one time, the satisfaction degree will go down. So this paper takes receiving times as an influence factor of customer satisfaction degree. Assume that S''_{1j} is the dissatisfaction degree to the receiving times, Ra_j is the real delivery times for customer j , Oa_j is the planned delivery times for customer j .So the function of dissatisfaction degree of customer j to delivery time is:

$$S''_{1j} = \begin{cases} 0 & Ra_j \le Oa_j \\ \dfrac{Ra_j - Oa_j}{Ra_j} & Ra_j > Oa_j \end{cases}$$

If we use λ_1'' and λ_1' to represent the weight of betimes and accuracy, $\lambda_1' + \lambda_1'' = 1$, $\lambda_1', \lambda_1'' \in (0,1)$, and the dissatisfaction degree of customer j is S_{1j} ,so:

$$S_{1j} = \lambda_1' \sum_{k=1}^{n} S'_{1jk} + \lambda_1'' S''_{1j}$$

Above all is the dissatisfaction degree function of customer j , is based on the single customer's dissatisfaction degree. The general dissatisfaction degree can obtain though summation method, which is:

$$S_1 = \sum^{m} \beta_j S_{1j}, \sum^{m} \beta_j = 1$$

In this function, m is the number of customers who have not been served, β_j is the weight of dissatisfaction degree of customer j .

2.2.2. Vehicle Drivers: After the disruption events, vehicle drivers are the first part to be disrupted. There are a lot of factors can influence drivers. This paper chooses working time and working contents to measure the impact of disruption events to the drivers. Otherwise, if we need more vehicles, we should also consider the disruption cost of add more drivers.

Considering the distribution routes may need to adjust after the distribution delay caused by the disruption events. This paper uses deviation degree of distribution routes to measure the impact of drivers' working content changes. Considering the deviation cost is positive deviation's penalty value add negative deviation's penalty value. Assume that variable sets a^+_j represent vehicle j belong the new route x_j but not belong the original route x_0 , and a^-_j represent vehicle j belong the original route x_0 but not belong the new route x_j . Assume that the cost of add an edge from the original route is k^+ , and the cost of cut an edge from the original route is k^- , a_j is the total length of driver j derived. So the dissatisfaction degree of driver's working content is:

$$S_{2j1} = \frac{k^+ \left|a^+_j\right| + k^- \left|a^-_j\right|}{a_j}$$

And to make sure that all the deviation of new plan can regress to the original plan:

$$x_j - a^+_j + a^-_j = x_0 (a^+_j +, a^-_j \geq 0)$$

The extended of driving time and waiting time caused by distribution delay will extend the drivers working time. So we can use the time that drivers come back to the distribution center to measure the influence degree of working time to the drivers. R_{tj} and O_{tj} represent the time that drivers arrive distribution center in real and in plan respectively. k' is the delay cost of drivers arrive distribution center. So the dissatisfaction degree of the working time is:

$$S_{2j2} = \frac{k^+ \left|a^+_j\right| + k^- \left|a^-_j\right| + k'(R_{tj} - O_{tj})}{a_j}$$

Assume it need more vehicles, the disruption cost of more vehicles is k' .

And the dissatisfaction degree of the driver in vehicle j is:

$$S_{2j} = \begin{cases} S_{2j1} & R_{tj} \leq O_{tj},\ j \in \{x_0\} \\ S_{2j2} & R_{tj} > O_{tj},\ j \in \{x_0\} \\ k'' & j \notin \{x_0\} \end{cases}$$

$$S_2 = \sum_{j=1}^{n} S_{2j}$$

In this formula, n is the number of servicing vehicles, and assume that each vehicle related to a particular driver.

2.2.3. Business Cost: After the disruption events, logistics distribution operators often have to pay more costs to solve the influence of disruption and make the system operate normally. The operators mainly care about the transportation cost and the vehicle dispatch cost. The vehicle dispatch cost is different with the drivers disruption cost, it is the cost of operators to add more vehicles. Assume that n_0 is the number of additional vehicle, c_0 is the cost of add one vehicle, c_{ij} is the transportation cost of vehicle drive from customer i to customer j. So the logistics distribution operators cost is the transportation cost add the vehicle dispatch cost:

$$S_3 = n_0 c_0 + \sum_{k=1}^{n+n_0} \sum_{i=0}^{m} \sum_{j=0}^{m} c_{ij} x_{ijk}$$

2.2.4. Customer Future Selection Lost Cost: The dissatisfaction will influence the customers to choose their suppliers in next time, and cause new loss of the suppliers which called the customer future selection lost cost. This deviation cost is caused, because the customers didn't receive their goods in time, and they will reduce the selection number of logistics suppliers. Customer future selection lost cost of one customer is:

$$y = b_i - c_i x^2$$

$$S_{4i} = c_1 (b_i - c_i x^2)$$

In this two formulas, y is customer i 's future purchase quantity, x is distribution delay time, b_i, c_i are related index. Because the customer's future selection is related to many factors, such as income, time preference, loyalty, substitute and so on, so it can obtain from digging the historical data. c_1 is the lost cost of reduce one time for purchase. By using the summation method, the customer future selection lost cost is:

$$S_4 = \sum^{m'} \beta_i' S_{4i}, \sum^{m'} \beta_i' = 1$$

m' is the number of customers of the selected suppliers, β_i' is the weight of customer i.

2.3. Model Construction

2.3.1. Symbol Description:

S_3^0 : The initial distribution cost of the system;

d_1^+, d_1^- : The positive and negative deviation variables of customer dissatisfaction degree S_1 and the initial plan customer dissatisfaction degree.

d_2^+, d_2^- : The positive and negative deviation variables of driver's dissatisfaction degree S_2 and the initial plan driver dissatisfaction degree.

d_3^+, d_3^- : The positive and negative deviation variables of system distribution cost S_3 and the initial plan distribution cost S_3^0.

d_4^+, d_4^- : The positive and negative deviation variables of customer future selection lost cost.

M, M' : The sets of visited and unvisited customers.

K, Y : The sets of used and non-used vehicles.

d_{ki} : The delivery quantity of vehicle k complete for customer i.

d_i : The demand quantity of customer i.

Q : The deadweight of vehicles.

s_{ik} : The start time of vehicle k service for customer i.

t_{si} : The service time customer i need.

t_{ij} : The driving time from customer i to customer j.

ET_i, LT_i : Means the mission i should be completed within the time window $[ET_i, LT_i]$.

L : The maximum driving distance of vehicles (the maximum driving cost).

In the original plan, when the vehicle k pass though (i, j) , $x_{ijk} = 1$, otherwise $x_{ijk} = 0$, and $\forall i, j \in M \cup M', \forall k \in K$. In the new plan, when vehicle k pass though (i, j) , $x_{ijk} = 1$, or $x_{ijk} = 0$, and $\forall i, j \in M \cup M', \forall k \in K \cup Y$. y is the number of additional vehicles.

P is the in-route vehicles visiting customers. Assume that P_k is the customer vehicle k is visiting, and $P_k = \{i\}$. If and only if vehicle k is during the time from finish the service at point for customer i at $i = 1$ to finish the service for customer i , $P \subseteq M$.

2.3.2. Model and Constraint Condition:

$$\min\{d_1^+, d_2^+, d_3^+, d_4^+\}$$

$$s.t. \quad S_1 + d_1^- - d_1^+ = 0 \tag{1}$$

$$S_2 + d_2^- - d_2^+ = 0 \tag{2}$$

$$S_3 + d_3^- - d_3^+ = S_3^0 \tag{3}$$

$$S_4 + d_4^- - d_4^+ = 0 \tag{4}$$

$$d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^- \geq 0 \tag{5}$$

$$\sum_{k \in K \cup Y} \sum_{j \in M} x'_{ijk} \geq 1, \forall i \in M' \tag{6}$$

$$\sum_{j \in M} x'_{ijk} - \sum_{j \in M} x'_{jik} = 0, \forall i \in M', \forall k \in K \cup Y \tag{7}$$

$$\sum_{k \in K \cup Y} \sum_{i \in M} x'_{i0k} = K + y \tag{8}$$

$$\sum_{k \in Y} \sum_{j \in M} x'_{0jk} = y \tag{9}$$

$$\sum_{k \in K} \sum_{j \in M} x'_{ijk} = K, \forall i \in P \tag{10}$$

$$\sum_{k \in K} d_{ik} = d_i, \forall i \in M' \tag{11}$$

$$\sum_{i \in M \cup M'} d_{ki} \Big(\sum_{j \in M \cup M'} x_{ijk} + \sum_{j \in M \cup M''} x'_{ijk} \Big) \leq Q, \forall k \in K \tag{12}$$

$$\sum_{i \in M} d_{ki} \left(\sum_{j \in M} x'_{ijk} \right) \leq Q, \forall k \in Y \tag{13}$$

$$x_{ijk} + x'_{ijk} \geq 1 \Rightarrow \begin{cases} d_{ik} > 0 \\ d_{jk} > 0 \end{cases}, \forall i, j \in P \cup M', \forall k \in K \tag{14}$$

$$\begin{cases} s_{ik} + t_{si} + t_{ij} = s_{jk}, \forall i, j \in P \cup M', \forall k \in K \\ ET_i - \Delta t_i \leq s_{ik} \leq LT_i + \Delta t_i, \forall i \in M', \forall k \in K \end{cases} \tag{15}$$

$$\sum_{i \in M \cup M'} \sum_{j \in M \cup M'} C_{ij} (x_{ijk} + x'_{ijk}) \leq L, \forall k \in K \cup Y \tag{16}$$

In these constraint functions, (1) – (5) is the disruption degree calculated by the disruption measure method; (6) is to make sure that the unvisited customers will be visited at least once; (7) represent that any vehicles should leave the customers after they visited them; (8) represent that all vehicles should come back to the parking lot; (9) represent that the additional vehicles should start from the yard; (10) represent that all the in-route vehicle should start from current service customer; (11) represent that every customer's demand should be satisfied; (12) and (13) represent that the constraint volume of the in-route vehicles and additional vehicles; (14) represent that when a vehicle pass by a customer, it should service for the customer; (15) is the constraint of time window;(16)is the constraint of the maximum driving distance.

3. Algorithm Design

This paper combined genetic algorithm and the improved elitist strategy, constructed an genetic algorithm based on improved elitist strategy. This paper uses the improved elitist strategy effectively improved immature early convergence problem of genetic algorithm. Genetic algorithm provides a common framework which is used to solve nonlinear, multi-model, multi-objective optimization problem of complex systems, and it does not depend on specific areas of the problem, it has a strong robustness for the kind of issue. In the improved elitist strategy, in order to ensure the search result convergence to the global optimal solution, the improved genetic algorithms ensured the understanding of diversity through the control of elite solutions range.

This paper adopted a new evolutionary algorithm which is based on dimensional chromosome structure and multi-objective fitness value calculation method. Simple design flow of the algorithm is as follows.

Step I: Adopt tournament selection as the selecting operation to select the initial population.

Step II: According the probability $P_c = 0.7$ to choose the chromosomes in the population to pair randomly, first is to gene pair, and then to implement the partial cross matching, and form a new population with the parent.

Step III: Make the two-dimensional structure chromosomes in the new population into decision-making value (x_{ijk}) with four-dimensional structure, and then take the value into each constraint equation of the model to check its feasibility. If it is not feasible, remove the chromosomes.

Step IV: Applying variation method mentioned before, using small probability P_m to select individuals from the stocks, and using mutation operation to change the individuals into a new stocks. Check the feasibility of individuals after the variation according to the method in step III. If it is not feasible, select other individuals randomly to do the variation until it reaches the predetermined number of variation P_m .

Step V: Using bubble sort method, sort the fitness values of all chromosomes in the way of pairwise comparisons.

Step VI: Select new individuals from the new population which have been trimmed into the next generation population.

Step VII: Determine whether the population reaches the evolution generations. If it reached, terminate the operation, the individuals with the highest fitness value in the current population is the ultimate driving program. Otherwise, go to step II. This paper assumes that the maximum evolution generation is 100.

4. Empirical Analysis

Logistics company A is a private logistics brand enterprise, it provides customers with a series of door to door logistics and e-commerce services, and it also customizes logistics solutions for large customers. Now logistics distribution networks of enterprise A are widely distributed in Handan, it's outlets located in Fengfeng, Handan County, Linzhang, Cheng'an, Daming County, Shexian, Cixian, Feixiang, Yongnian County, Qiuxian, Jize, Guangping County Guantao County, Weixian, Quzhou County, Wu'an and other regions. It is one of the most important national logistics enterprises in Handan.

Handan A Logistics Ltd. was established in 2001, and it has one million registered capitals, the number of currently employs is 80, the number of existing schedulable contract vehicle is 55. It established cooperative relations with dozens of freight, express company, so that the company has the advantage of convenient information source and vehicle scheduling, and its logistics business covers the city's districts and counties.

In order to verify the effectiveness of the model and algorithm in the paper better, the following table shows the selected 12 outlets of A company including the headquarters in Handan, put them as the main subject empirical. Specific data are shown in Table 1.

Table 1. Customer Order Information

Customer Number	X coordinate $/km$	Y coordinate $/km$	Demand $/t$
0	34	41.5	-
1	36.5	61	0.5
2	68	76.5	0.4
3	10	51.5	1.2
4	77.5	29	1.5
5	76	61	0.8
6	96	66.5	1.3
7	101	33.5	0.6
8	94.5	6.5	0.4
9	75	15.5	1.3
10	64	35.5	1.9
11	47	12	1.1
12	10.5	21	1.6

When the vehicle is running on the way to point 12 (Fengfeng) according to plan, if there happens traffic accidents on the traveling road of vehicle 1, and it will cause a significant delay on the road traveling time to the vehicle 1. And then the follow-up distribution points on the route 1 (Shexian), 2 (Wu'an), 3 (Yongnian) will not get distribution services within its allowed time frame. Faced with this disruption event, the headquarters and distribution centers need to make adjustments to the plan of the initial driving route. This adjustment should consider the initial distribution target, and also should minimize the disruption of the system. The scheduling results under re-scheduling strategy and disruption management strategy are as follows.

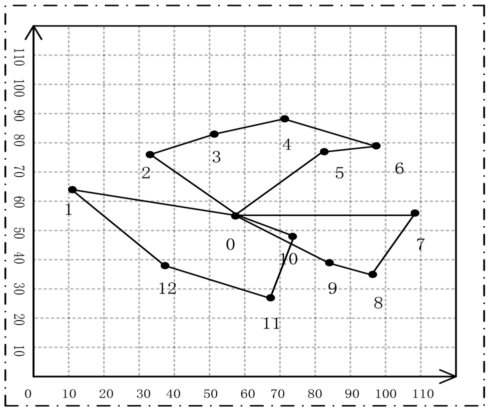

Figure 2. Road Map of Rescheduling

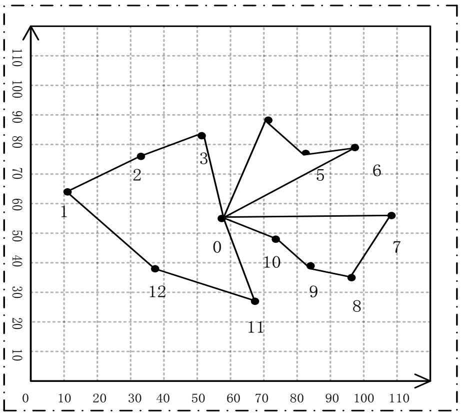

Figure 3. Road Map of Disruption Management

Table 2. The Contrast Table of Disruption Management and Rescheduling

Method	Customer dissatisfaction	Driver dissatisfaction	Business costs	Future selection lost cost
Rescheduling	8.34%	3.97%	102.7	56.2
Disruption Management	3.65%	1.17%	99.3	32.5

By analyzing the scheduling result of the two different strategies after the disruption events, it's not difficult to find out that the degree of customer dissatisfaction is significantly improved by using the rescheduling method. And it causes the overall cost increase while it requires the vehicle operator to change the more route. It also causes a greater degree of disruption to the system, the customer future selection lost cost is also larger, and it also has a greater impact on the credibility and service quality of logistics enterprises. In the actual logistics distribution, once the disruption occurred, the feasibility of re-scheduling is very small. Compare to the results of re-scheduling, disruption management optimization method greatly reduces the system disruption level of disruption events. Customer and vehicle drivers both have a relatively higher satisfaction and it could win the customers' second purchase, the quality of delivery service in the case of distribution delay can be effectively guaranteed.

5. Conclusions

This paper aiming at the problem that in distribution, the distribution plan cannot realize because of distribution delay on a road, using disruption management methods. And proposing the measure method of distribution system disruption degree, taking customer satisfaction degree, driver satisfaction degree, distribution costs and customer future selection lost cost in to account. This paper established a mathematical model of logistics disruption management, and designed a new evolutionary algorithm to solve the model. It overcomes the problem that in the traditional optimization methods, only considering the single goal minimize costs emergence customer and the driver's interest’s lack of effective protection. And it improve the feasibility and practicability of problems processing solutions, it is a successful application for disruption management thought in the field of logistics, and it is a useful exploration for solving the logistics disruption management problems.

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