

Multi-objective Vehicle Routing Optimization Model for Emergency Logistics Considering Aftershock Effects

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Abstract

Earthquake is a kind of common and terrible sudden natural disaster. Frequent earthquake disasters bring inestimable loss of people and property to human society. Based on the earthquake background and considering the impact of aftershocks on emergency rescue activities, this paper constructs a multi-objective vehicle routing optimization model with the objectives of time, risk, fairness of material distribution and minimum cost. Through simulation examples, conclusions are drawn: Decision makers should first consider risk and time, when considering time, focus on considering the time window to meet the fairness of material distribution, and finally consider the cost.

Keywords

Emergency Logistics; Multi-objective; Vehicle Routing Optimization.

1. Introduction

Earthquake is a common and terrible sudden natural disaster. Frequent earthquake disasters bring incalculable casualties and property losses to human society. The strong destructiveness of the earthquake will often damage the urban road network, leading to the blockage of some roads in the affected areas. The interruption or blockage of roads has seriously affected the efficiency of rescue and relief work after the earthquake. The continuous and unpredictable aftershocks after the earthquake have increased the risks in the process of material transportation. The psychological panic of the driver responsible for the transport of relief materials will increase with the increase of the number of disaster areas over time, and this panic is very detrimental to the smooth completion of the transport of relief materials. Therefore, this paper studies multi-objective vehicle path planning considering the impact of aftershocks, aiming to improve the safety and timeliness of emergency materials transportation under the background of continuous aftershocks after earthquakes, and make suggestions for decision-makers based on different weight preferences.

2. Model Construction

2.1. Time

Time is the primary consideration in emergency rescue activities. Usually the number of rescue vehicles is less than the point of demand, so the total transit time is:

$$T = \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^k t_{ij} \cdot x_{ij}^{mk} + \sum_{i=1}^n t_i^* \cdot z_i^k \quad (1)$$

Where, t_i^* represents the residence time of vehicle at node i , and z_i^k represents whether vehicle k is the last node at node i .

2.2. Road Capacity

Road capacity is a factor to judge whether the road can pass and the length of the passing time after the earthquake, which is related to the road damage rate, pavement width, traffic flow and so on.

2.2.1. Generalized Transportation Distance.

Due to the different damage rates of roads, generalized transportation distance is introduced to measure transportation time for convenience of research. Its expression is as follows:

$$d_{ij}^s = \begin{cases} d_{ij}, \theta_{ij} = 0 \\ d_{ij}(1 + \theta_{ij}), 0 < \theta_{ij} < \delta \\ F, \delta < \theta_{ij} \end{cases} \quad (2)$$

Where, d_{ij} and d_{ij}^s represent the actual distance and the generalized distance respectively, and θ_{ij} represents the road damage rate.

2.2.2. The Effect of Pavement Width

The road capacity of different roads is different, so the width correction factor should be used to correct it:

$$A_{ij} = \gamma_{ij} \cdot A_{ij}^0 \quad (3)$$

Where, A_{ij} represents the actual traffic capacity, A_{ij}^0 represents the basic traffic capacity, and γ_{ij} represents the width adjustment coefficient. The width correction coefficient is quoted as follows:

$$\gamma_{ij} = \lambda \cdot W_{ij} + \nu \quad (4)$$

Where, W_{ij} represents the road width and λ, ν are the correction factors.

2.2.3. The Effect of Traffic Flow

Due to the well-established research on the relationship between vehicle speed and traffic flow, it is concluded that:

$$V_{ij} = \begin{cases} a \cdot \exp \left[b \cdot \left(\frac{B_{ij}}{A_{ij}} \right)^2 \right] & \frac{B_{ij}}{A_{ij}} \leq M \\ a_1 + b_1 \left(\frac{B_{ij}}{A_{ij}} \right) & \frac{B_{ij}}{A_{ij}} > M \end{cases} \quad (5)$$

Where, B_{ij} represents the actual traffic flow from node i to node j in time t .

2.3. Equity of Material Distribution

Suppose that the direct passage time between the distribution center and a disaster point is t_{0j} , the actual arrival time of the distribution vehicle at the disaster point is t_j , the number of people at the disaster point is N_j , and the total number of people affected by the disaster is N^* , then the objective function based on the fairness of material distribution is as follows:

$$\min U = \sum_{j=1}^n \frac{N_j}{N^*} \cdot \frac{t_j}{t_{0j}} \tag{6}$$

This formula indicates that the smaller the value, the more equitable the distribution of materials.

2.4. Risk

2.4.1. Probability of Building Collapse on the Street

Whether the buildings facing the street collapse is mainly determined by the earthquake grade and the seismic strength of the buildings. Suppose ρ_{ij} is node i to node j , the seismic strength of the street-facing buildings will gradually decrease with the increase of the service life of the street-facing buildings, so the collapse probability P_{ij} of the street-facing buildings is:

$$P_{ij} = \begin{cases} 1 & \rho_{ij} < \rho_d \\ 1 - \frac{1 - \exp(-M_{ij} \cdot (\rho_{ij} - \rho_d))}{1 - \exp(-M_{ij} \cdot (\rho_u - \rho_d))} & \rho_d < \rho_{ij} < \rho_u \\ 0 & \rho_u < \rho_{ij} \end{cases} \tag{7}$$

Where, ρ_u represents the upper limit of aftershock size, ρ_d represents the lower limit of aftershock size, and M_{ij} represents the existence years of buildings from node i to node j .

2.4.2. Road Block Degree

If the building is not tall, but the road is wide, even if the building collapses under the influence of the earthquake, it will not completely block the road. On the other hand, if the building is too high and the road is not wide, the collapse of the building will certainly block the road. Therefore, the ratio of the building height to the road width is used to define the road section blocking degree:

$$I_{ij} = \frac{H_{ij}}{W_{ij}} \tag{8}$$

Where, I_{ij} represents the degree of road section blocking from node i to node j , H_{ij} represents the average height of buildings from node i to node j , and W_{ij} represents the road width from node i to node j .

2.4.3. Risk Function Construction

Through the obtained building collapse probability and road section blocking degree, the risk function of the distribution route can be obtained as follows:

$$r_{ij} = P_{ij} \cdot I_{ij} \tag{9}$$

Then, for the distribution path risk $R = r_1 \cdot r_2 \cdots r_n$ composed of n road sections, logarithm is taken to obtain:

$$\lg R = \lg r_1 + \lg r_2 + \cdots + \lg r_n \tag{10}$$

According to the properties of logarithmic functions, the smaller R is, the smaller lgR is. Therefore, the objective function based on risk is:

$$minR = \sum_{i=0}^n \sum_{j=0}^n [lg(P_{ij} \cdot I_{ij})] \cdot x_{ij}^{mk} \tag{11}$$

2.5. Total Cost

In this paper, the total cost consists of the following three parts: one is the material distribution cost, the second is the driver's psychological cost, and the third is the time window penalty cost.

2.5.1. Material Transportation Cost

The cost of material transportation is composed of three parts: the fixed cost of the vehicle, the transportation cost when the vehicle is running, and the cost of the two drivers equipped with each vehicle. The fixed cost of each vehicle equipped with a distribution center is C_k , the material transportation cost is C_1 , the driving cost of the vehicle is c_k , and the salary of each driver is c_r , then the material transportation cost function can be established as follows:

$$C_1 = \sum_{k=1}^{k_m} x_{ij}^{mk} \cdot (C_k + 2c_r) + \sum_{k=1}^{k_m} \sum_{i=1}^n \sum_{j=1}^n x_{ij}^{mk} \cdot d_{ij} \cdot c_k \tag{12}$$

2.5.2. Driver Psychological Cost

Drivers will face many dangers in the distribution process, such as road obstruction, debris flow and other secondary disasters, disaster areas, etc., their psychological panic will increase sharply after a certain period of time, and research shows that a certain rest time and wage incentives can reduce their psychological panic. The driver's psychological cost function is constructed as follows:

$$C_2 = \begin{cases} -(t_0 - t_i)^\alpha + C_0 - P_s \times S_0 - P_r \times t_i^* & t_i \leq t_0 \\ \mu(t_0 - t_i)^\beta + C_0 - [(t_i - t_0) \times S_1 + S_0] \times P_s - P_r \times t_i^* & t_i > t_0 \end{cases} \tag{13}$$

Where, $P_s \in (0,1)$ is the incentive coefficient, S_0 and S_1 are the incentive cost of the first and second stages respectively, t_i^* is the driver's rest time, and $P_r \in (0,1)$ is the rest compensation coefficient.

2.5.3. Time Window Penalty Cost

Combined with the actual situation of post-earthquake rescue, in view of the importance of post-earthquake rescue timeliness, and considering the complexity of post-earthquake road conditions, this paper only considers the delivery after the time window, and sets a unilateral soft time window to measure the penalty cost. Therefore, the time window penalty cost function $P(t_j)$ is established as follows:

$$P(t_j) = \begin{cases} 0 & 0 < t_j < LT_i \\ p_d(t_j - LT_i) & t_j < LT_i^* \end{cases} \tag{14}$$

Then, the time window penalty cost function of the overall system is expressed as follows:

$$C_3 = p_d \sum_{i=1}^N \sum_{k=1}^{K_m} \max(t_j - LT_i, 0) \tag{15}$$

Where, p_d represents the penalty cost coefficient and $[0, LT_i]$ represents the time window given by the disaster point.

2.6. Model Building

In summary, a multi-objective vehicle path planning model considering aftershock effects is constructed as follows:

$$\min C = C_1 + C_2 + C_3 \tag{16}$$

$$\min T = \sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^K t_{ij}^k \cdot x_{ij}^{mk} + \sum_{i=1}^N t_i^* \cdot z_i^k \tag{17}$$

$$\min R = \sum_{i=1}^N \sum_{j=1}^N [\lg(P_{ij} \cdot I_{ij})] \cdot x_{ij}^{mk} \tag{18}$$

$$\min U = \sum_{j=1}^N \frac{N_j}{N^*} \cdot \frac{t_j}{t_{0j}} \tag{19}$$

S.T

$$x_{ij}^{mk} \in \{0,1\} \tag{20}$$

$$y_i^{mk} \in \{0,1\} \tag{21}$$

$$z_i^k \in \{0,1\} \tag{22}$$

$$t_{ij}^k = \frac{d_{ij}^s}{v_{ij}} \tag{23}$$

$$0 < t_i^k \leq LT_i \tag{24}$$

$$\sum_{j=1}^N \sum_{k=1}^K x_{ij}^{mk} \leq k, i = m \in \{N + 1, N + 2, \dots, N + K\} \tag{25}$$

$$\sum_{j=1}^N x_{ij}^{mk} = \sum_{j=1}^N x_{ji}^{mk} \leq 1, i = m \in \{N + 1, N + 2, \dots, N + K\} \tag{26}$$

$$\sum_i^{N+M} \sum_{m=1}^M \sum_{k=1}^K x_{ij}^{mk} = 1, j \in \{1,2,\dots,N\} \tag{27}$$

$$\sum_j^{N+M} \sum_{m=1}^M \sum_{k=1}^K x_{ij}^{mk} = 1, i \in \{1,2,\dots,N\} \tag{28}$$

$$\sum_{i=1}^N \sum_{j=1}^{N+M} q_i x_{ij}^{mk} \leq Q, m \in \{N + 1, N + 2, \dots, N + M\} \tag{29}$$

Where, formula (16) is the objective function, indicating the minimum total distribution cost. Formula (17) is the objective function, indicating the minimum total delivery time. Formula (18) is the objective function, indicating the minimum total distribution risk. Formula (19) is the objective function, indicating the smallest difference in the fairness of total material distribution. Formula (20) indicates whether vehicle k of the parking lot m is moving from node i to node j . Formula (21) indicates whether vehicle k of parking lot m serves demand point i . Formula (22) indicates whether node i is the last node of the path. Formula (23) represents the time for vehicle k to pass node j from node i . Formula (24) indicates that vehicle k needs to arrive within the maximum tolerance time of node i . Formula (25) indicates that the number of vehicles dispatched by each distribution center does not exceed its maximum number of vehicles. Formula (26) indicates that all vehicles in the distribution center depart from their respective distribution centers and return to the original distribution center after completing the distribution task. Formulas (27) and (28) indicate that there is and only one vehicle providing delivery service at any demand point. Formula (29) is the capacity constraint, indicating that the total material demand at each demand point does not exceed the maximum load of the vehicle for distribution service.

3. Simulation and Results

3.1. Simulation Introduction

Table 1. Information about disaster sites

Serial number	Position coordinate	Number of people affected	Proportion of affected people	Material demand	Time window
1	(3,25)	2000	0.03	4	6
2	(7,20)	5000	0.08	8	3
3	(5,12)	2200	0.04	5	6
4	(10,30)	1700	0.03	3	4
5	(11,15)	5500	0.09	8	4
6	(14,21)	6000	0.10	8	3
7	(15,28)	4000	0.07	6	3
8	(8,8)	2300	0.04	4	3
9	(18,13)	5400	0.09	8	6
10	(20,28)	4300	0.07	6	4
11	(22,8)	1600	0.03	3	5
12	(25,25)	2500	0.04	5	6
13	(24,15)	6100	0.10	8	5
14	(21,20)	5800	0.10	8	4
15	(15,5)	4800	0.08	7	5
16	(29,28)	1400	0.02	3	3

Table 2. Parameter data of road capacity

Serial number	path	W_{ij}	γ_{ij}	A_{ij}	B_{ij}	v_{ij}	θ_{ij}	d_{ij}^s	t_{ij}
1	0-1	7	1.00	801.6	650	23.91	0.08	34.49	1.44
2	0-2	8	1.29	1030.4	900	20.73	0.18	43.63	2.10
3	0-3	7	1.0	801.6	700	20.74	0.04	21.88	1.05
4	0-4	8	1.9	1030.4	950	18.26	0.05	50.93	2.79
5	0-5	7	1.00	801.6	750	17.57	0.25	44.46	2.53
6	0-6	8	1.29	1030.4	800	25.66	0.20	51.31	2.00
7	0-7	8	1.29	1030.4	900	20.73	0.05	49.84	2.40
...									
98	7-14	7	1.00	801.60	550	28.77	0.30	21.03	0.73
99	7-15	6	0.72	572.80	550	16.32	0.27	37.10	2.27
100	7-16	5	0.43	344.00	300	20.80	0.08	28.17	1.35
101	8-9	6	0.72	572.80	300	33.01	0.13	30.91	0.94
102	8-10	8	1.29	1030.40	400	36.00	0.23	52.74	1.47
103	8-11	6	0.72	572.80	500	20.76	0.22	26.79	1.29
104	8-12	5	0.43	344.00	290	22.27	0.15	45.50	2.04
...									
131	13-14	6	0.72	572.80	540	17.21	0.12	16.56	0.96
132	13-15	7	1.00	801.60	550	28.77	0.30	35.46	1.23
133	13-16	6	0.72	572.80	500	20.76	0.18	24.54	1.18
134	14-15	7	1.00	801.60	400	33.60	0.14	33.93	1.01
135	14-16	6	0.72	572.80	300	33.01	0.29	38.30	1.16
136	15-16	5	0.43	344.00	300	20.80	0.09	50.10	2.41

Table 3. Transport risk partial parameter data

Serial number	path	M_{ij}	ρ_d	ρ_u	ρ_{ij}	P_{ij}	H_{ij}	I_{ij}	r_{ij}
1	0-1	25.03	5	6	5.30	0.00	9.27	1.32	0.00
2	0-2	35.47	5	6	5.22	0.00	6.59	0.82	0.00
3	0-3	25.44	5	6	5.16	0.02	11.33	1.62	0.03
4	0-4	27.08	5	6	5.14	0.02	7.99	1.00	0.02
5	0-5	23.12	5	6	5.15	0.03	6.55	0.94	0.03
6	0-6	34.44	5	6	5.16	0.00	7.41	0.93	0.00
7	0-7	33.67	5	6	5.26	0.00	9.46	1.18	0.00
...									
98	7-14	15.68	5	6	5.27	0.01	7.59	1.08	0.02
99	7-15	11.38	5	6	5.17	0.15	8.92	1.49	0.22
100	7-16	21.61	5	6	5.24	0.01	8.51	1.70	0.01
101	8-9	10.76	5	6	5.14	0.21	10.19	1.70	0.36
102	8-10	35.82	5	6	5.14	0.01	8.83	1.10	0.01
103	8-11	11.11	5	6	5.14	0.22	9.10	1.52	0.33
104	8-12	37.37	5	6	5.15	0.00	11.79	2.36	0.01
...									
131	13-14	29.34	5	6	5.19	0.00	8.71	1.45	0.01
132	13-15	20.20	5	6	5.22	0.01	11.49	1.64	0.02
133	13-16	28.95	5	6	5.10	0.05	11.62	1.94	0.10
134	14-15	32.86	5	6	5.05	0.19	10.85	1.55	0.30
135	14-16	19.63	5	6	5.22	0.01	11.69	1.95	0.02
136	15-16	29.79	5	6	5.30	0.00	8.70	1.74	0.00

Now assume that a magnitude 6 earthquake occurs in a place where the roads are all general secondary roads, there is a distribution center, equipped with 3 rescue vehicles, 16 disaster sites, and the location coordinates, number of people affected, material demand and acceptable time window of each disaster site are known. The disaster site coordinates are from Solomon's classical data set, and the remaining parameters are assigned randomly. The specific data are shown in Table 1, Some parameter data of road capacity are shown in Table 2, Some parameters of transportation risk are shown in Table 3.

3.2. Result Analysis

The population size of NSGA-II algorithm is set to 300, the maximum number of iterations is 1000, the crossover probability is 0.8, the mutation probability is 0.15, and the Pareto optimal solution set meeting the conditions is obtained by running the solution using MATLAB2023a.

Based on the different weights of the four objectives of total cost, transportation time, transportation risk and material distribution fairness, the following five groups of Pareto optimal solutions satisfying the constraints can be obtained:

1) With the minimum cost as the main focus goal, four target weights were set as: 0.7, 0.1, 0.1, 0.1, and the result was Plan No. 102: Total cost = 21,275.75 yuan, transportation cost =18111.87 yuan, driver psychological cost =2350.35 yuan, time window penalty cost =813.52 yuan, transportation time =21.91 hours, transportation risk = -82.25 (the previous risk is logarithmic for convenience calculation, so the value is negative), Material distribution fairness difference =1.43. The three transport routes are: 0-1-2-5-6-4-7-0; 0-8-15-9-13-14-12-0; 0-3-10-16-11-0.

2) With the shortest time as the main focus goal, four target weights were set up: 0.1, 0.7, 0.1, 0.1, and the result was the No. 2 plan: Total cost = 22,519.45 yuan, transportation cost = 18,150.77 yuan, driver psychological cost = 2342.51 yuan, time window penalty cost = 2,026.17 yuan, transportation time =20.94 hours, transportation risk =-76.82, equity difference of material distribution =1.50. The three transport routes are: 0-1-2-5-6-4-8-0; 0-15-9-13-0; 0-3-7-14-12-10-16-11-1.

3) With the minimum risk as the main focus goal, four weights were set up: 0.1, 0.1, 0.7, 0.1, and the result was No. 64: Total cost = 26,753.77 yuan, transportation cost = 20,042.92 yuan, driver psychological cost =2312.85 yuan, time window penalty cost = 4398.00 yuan, transportation time = 27.87 hours, transportation risk =-143.31, fairness difference of material distribution =1.92. The three transport routes are: 0-6-9-13-12-2-0; 0-3-15-8-14-10-11-0; 0-1-4-16-5-7-0.

4) With the minimum difference in the fairness of material distribution as the main focus goal, four weights were set up: 0.1, 0.1, 0.1, 0.7, and the result was No. 190: Total cost = 21,675.03 yuan, transportation cost = 18448.61 yuan, driver psychological cost =2352.54 yuan, time window penalty cost = 873.89 yuan, transportation time = 22.07 hours, transportation risk =-77.77, fairness difference of material distribution =1.31. The three transport routes are: 0-8-15-14-7-12-0; 0-3-9-13-10-16-11-0; 0-1-2-5-6-4-0.

5) Consider the four goals equally, regardless of the primary or secondary, and set the four weights as: 0.25, 0.25, 0.25, 0.25 respectively. The results are as follows: Total cost =22160.58 yuan, transportation cost = 18551.83 yuan, driver psychological cost = 2347.80 yuan, time window penalty cost = 1260.95 yuan, transportation time = 22.45 hours, transportation risk = -98.16, fairness difference of material distribution =1.41. The three transport routes are: 0-1-2-5-6-4-7-0; 0-15-8-14-12-0; 0-3-9-13-3-9-13-0

After five Pareto optimal solutions with different weights are obtained, these results are summarized and analyzed again, and Table 4 is obtained:

Table 4. focuses on different Pareto optimal solutions based on decision-maker weights

Target weight preference	Total cost	Transportation cost	Psychological cost	Time window penalty cost	Transit time	Transportation risk	Equity difference
Least cost	21275.75	18111.87	2350.35	813.52	21.91	-82.25	1.43
Shortest time	22519.45	18150.77	2342.51	2026.17	20.94	-76.82	1.50
Minimal risk	26753.77	20042.92	2312.85	4398.00	27.87	-143.31	1.92
Maximum fairness	21675.03	18448.61	2352.54	873.89	22.07	-77.77	1.31
Parity consideration	22160.58	18551.83	2347.80	1260.95	22.45	-98.16	1.41

With the fifth set of data, the data results of equal consideration of the four objectives were taken as the benchmark, and the data of each group were compared horizontally to explore the relationship between cost, transportation time, transportation risk and fairness of material distribution based on different weight preferences of decision-makers. Because these five sets of data are all the results of Pareto optimal solution sets, only the data with large differences are analyzed.

1) By comparing the "least cost" group with the "baseline" group, it is found that the main factor of the better cost is the time window penalty cost, which is nearly 55% smaller than the baseline group, but the transportation risk is nearly 16% larger. This indicates that in order to meet the time window requirements of each disaster point faster, the transportation vehicles choose the road section with greater risk, in exchange for greater transportation risk.

2) By comparing the "shortest time" group with the "baseline" group, it is found that the penalty cost of the time window is nearly 61% higher, and the transportation risk is 22%. The former indicates that meeting the demand of the time window at each disaster point may not necessarily meet the demand for material delivery as soon as possible, and the latter indicates that the shortest time is also the material transport vehicle to take more roads with greater traffic risk.

3) Comparing the "least risk" group with the "baseline" group, the transport risk was indeed significantly smaller, by almost 46%, but the cost, time-window penalty cost, transport time and fairness were significantly larger, at 21%, 249%, 24% and 36%, respectively, suggesting that the pursuit of the least risk required a great distance. Choosing the path with less risk will increase the cost and transportation time, and make the distribution of materials less fair;

4) Comparing the "fairness maximum" group with the "baseline" group, it was found that in addition to the greater fairness of material transportation, the penalty cost of time window also decreased significantly. This is because one of the indicators of the fairness of material distribution is the time that transport vehicles directly deliver materials to the disaster site, which is similar to the time window, but the transportation risk increased significantly, by nearly 21%. This is similar to the previous cost-maximum-group analysis.

4. Conclusion

In this paper, NSGA-II algorithm is used to solve the constructed model, and a Pareto optimal solution set satisfying four objectives is obtained. Then, with the four objectives as the main focus and the four objectives equally, five groups of transport paths are selected from the Pareto optimal solution set. After comparative analysis of four objective values of cost, transportation time, transportation risk and fairness of material distribution, the following conclusions are drawn:

1) Considering the minimum cost, the shortest transportation time and the fairness of material distribution will inevitably increase the transportation risk, and vice versa;

2) Considering that the shortest transportation time can't better meet the time window requirements of each disaster point, that is, the shortest transportation time does not necessarily mean that the fairness of material distribution is smaller, but on the contrary, better meet the time window requirements of each disaster point will certainly lead to shorter transportation time.

Based on the above conclusions, the following suggestions are made for decision makers when facing the four consideration target weights:

1) Considering the transportation risk is an inevitable choice, and the increase in cost is also within a certain range, which is acceptable, but the transportation time should be taken into account, and no risk can be borne;

2) Instead of blindly pursuing the shortest transportation time, it may not reduce the fairness difference of material distribution, but also lead to increased transportation risks, and the final result is more than worth the loss.

3) When considering the transportation time, we can first focus on the time window of each disaster site, which can not only reduce the transportation time to a certain extent, reduce the penalty cost caused by exceeding the time window, but also reduce the fairness difference of material distribution.

In summary, these four objectives need to prioritize transport risk and transport time; Then, when considering the transportation time, we should focus on the time window requirement of the disaster point, which can optimize the cost and fairness. Finally, consider the cost.

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References

- [1] Gu Shan. Research on dynamic dispatch optimization of emergency materials after disaster considering psychological factors of disaster victims [D]. Nanjing University of Information Science and Technology,2018.
- [2] Wang Xuping, Zhang Nana, Zhan Hongxin. Research on emergency materials distribution considering the irrational comparison psychology of disaster victims [J]. Management Science,2016, 13(07):1075-1080.
- [3] Zhang Naiping, Xu Jianhang, Lv Wei et al. Emergency materials distribution-transportation model considering road damage after earthquake [J]. Journal of Wuhan University of Technology (Information and Management Engineering),2019,41(02):119-123. (in Chinese).
- [4] Zhang Jianfei. Estimation of highway capacity and establishment of speed-flow relationship [J]. Highway,1997(10):16-23. (in Chinese).
- [5] Guo Xuwen. Research on a new model of earthquake hazard degree [D]. Taiwan: Chenggong University, 1991.
- [6] Fan Yu 'e. Research on vehicle routing problem of emergency materials after earthquake based on multiple objectives [D]. Shenyang University,2015.
- [7] Yin Siyang. Research on Vehicle routing optimization of emergency materials distribution after disaster considering personnel psychological cost [D]. Wuhan University of Technology,2021.