ISSN: 2688-8653

Research on Path Planning of Emergency Rescue Vehicles based on Time-space Network

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Abstract

This paper studies the path planning of emergency supplies after disasters. Applying the Time-space network to the emergency rescue process, by constructing the Time-space network chart of time and disaster point, the mathematical model with the shortest time as the objective function is established and solved by genetic algorithm. Through the analysis of the example, 15 disaster points are randomly generated, and 2 distribution centers are selected. In the process, the changes of the road network information are considered, and the second decision is made to the path planning. The feasibility and effectiveness of Time-space network in emergency rescue route planning are verified by the result analysis.

Keywords

Emergency Rescue; Time-space Network; Genetic Algorithm; Path Planning.

1. Introduction

In recent years, my country's frequent natural disasters have caused huge losses to the country and people. In order to improve my country's ability to respond to sudden disasters, the country has established an emergency management department to formulate comprehensive rescue plans for possible natural disasters. However, the damage caused by the disaster is complex and diverse, and the damage ability is very strong. It is likely to cause the destruction of roads and bridges, making it difficult to implement the pre-established rescue plan. Therefore, after the disaster occurs, the complex road conditions can be provided for timely rescue. The optimal path planning program is of great significance to reduce the loss of life and property.

At present, many scholars have done research on the path planning of emergency rescue. Chen Daqiang et al. [1] studied the selection of multiple rescue points with supply constraints under time-varying conditions, and established a multi-objective decision-making model with the shortest emergency response time and the minimum number of rescue points in the emergency logistics system. To verify the effectiveness of the model and algorithm. Zhi-Hua Hu[2] established a linear integer programming model for emergency rescue in the logistics system for the supply chain container network flow design and vehicle path optimization design in natural disaster environments, and demonstrated the feasibility and effectiveness of the model through simulation . Du Lijing [3] established a stochastic location-inventory-route problem optimization model. On the basis of transforming nonlinear mixed integer programming into a linear integer set covering model, a column generation algorithm was used to obtain an approximate optimal solution. The branch pricing method is used to improve the initial solution in order to achieve the "fully integrated" optimization of the entire problem. Wang Haijun[4] considered the distribution of emergency supplies under uncertain conditions, assuming that the demand for emergency supplies at each demand point and the vehicle transportation time

ISSN: 2688-8653

between two points are uncertain, using the opportunity constraint method to establish a certain emergency restriction period, A dual-objective stochastic programming model with time minimization and cost minimization, and a genetic algorithm is designed to solve the model. Liu Changshi[5] studied the positioning-path problem in the post-earthquake emergency logistics system, and at the same time comprehensively considered the characteristics of the post-earthquake emergency logistics system, with the goal of minimizing the total delivery time of emergency supplies and the total cost of the system, a post-earthquake was constructed. A hybrid heuristic algorithm is designed to solve the multi-objective positioning-path optimization model in the emergency logistics system. Duan Manzhen et al. [6] did research on the emergency rescue route selection model under uncertain information.

The above research shows that previous scholars have considered the uncertainty of demand and multi-objective issues in the rescue process of emergency supplies, but there are not many studies in considering the changes of road traffic information over time, so you can consider the Spatio-temporal network It is used in the selection of emergency material distribution routes, and previous scholars' research on Spatio-temporal network models is mostly used in transportation. From the perspective of actual flight operation, Le Meilong [7] constructed a flight operation Time-space network, established a space-time network-based optimization model for cabin control, and used particle swarm algorithm to solve the model. Chen Jingwei [8] proposed an unmanned vehicle-mounted passenger system model based on Time-space road network for the formulation of the operation plan of passenger unmanned vehicles. By using Time-space network technology, he described the operation of passengers and unmanned vehicles in the road network in detail. Trajectory converts the original dynamic road network into a static Time-space road network, reducing the complexity of the model. Mou Xuedi [9] did a research on the recovery of abnormal flights based on discrete Time-space networks, and analyzed the constraints that must be met during the recovery process of abnormal flights and the main difficulties in modeling, and set the goal to minimize delays and cancellation costs. Based on the abnormal flight recovery model based on the path flow, the particle swarm algorithm with the introduction of inertial weights was then proposed for the first time to solve the model. Dai Fuqing [10] based on the original Spatio-temporal network model and comprehensively considered uncertain factors such as airport closures and aircraft failures. By constructing a two-dimensional plane Spatio-temporal network diagram of airport nodes and time nodes, an aircraft based on Spatio-temporal network was established. Route restoration optimization model. From scholars' research on the application of Time-space network, it can be seen that the Time-space network model is widely used in aviation and urban transportation. This also shows the wide application of Time-space network in the field of transportation. Therefore, the application of Time-space network to emergency supplies can also be considered. In the path planning of, it is feasible to establish a corresponding solution model under consideration of the different constraints from conventional traffic.

2. Path Planning Model

Usually, after a disaster occurs, it is necessary to establish a number of emergency material distribution centers in the disaster area, and select the optimal path to transport emergency materials from the distribution center to various demand points under limited time, space and resource constraints. The distribution process of post-disaster relief materials is closely related to the road network information. During the emergency material distribution process, the road network information may change at any time. It may be that some roads have been partially or completely repaired, or some roads have been partially or completely repaired. The impact was destroyed again. After the above information changes, depending on the degree of change, the original decision plan may no longer be optimal, or even no longer applicable. The decision plan needs to be adjusted according to the current information, and in the space-time network, the path can be planned in time intervals, which can be very good. To solve the problem of dynamic changes.

2.1. Build a Spatio-temporal Network

The Spatio-temporal network model is a method of developing mathematical expressions by transforming the problem into a time-based network and then using the network diagram. The Spatio-temporal network diagram is a two-dimensional plane network composed of nodes and lines between nodes. The nodes are uniquely determined by the horizontal axis space coordinates and the vertical axis time coordinates. The horizontal axis coordinates correspond to the distribution centers involved in the path planning. And demand points, the vertical axis coordinates are the time points arranged in order from bottom to top, and the appropriate time interval is selected [11]. The line between the link nodes represents the path plan of the vehicle. The coordinates of the starting point represent the location and time of the starting point, and the coordinates of the point pointed by the arrow represent the location and time of reaching the point. The following briefly introduces the related concepts of the Spatio-temporal network diagram through Figure 1. In the figure, ri represents each point in the path planning, tj represents the time node with equal time difference, the dotted line linking the two points represents the initial planned route, and the solid line represents the actual driving route.

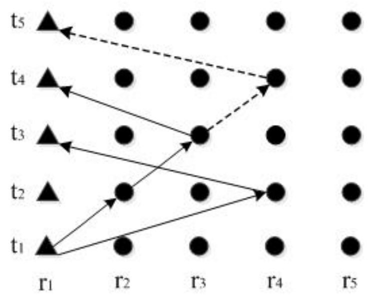

Figure 1. Time-space network chart

Compared with the traditional physical network model, the spatiotemporal network model fully considers the spatiotemporal characteristics of the vehicle route, and can directly determine the departure and arrival time of the vehicle through the spatiotemporal network diagram. The key to the entire model lies in the construction of the spatiotemporal network diagram and the mathematical model. Build and solve. The solution process is based on time periods rather than a single network distribution. According to the dynamically updated road network status information, the transportation path from the distribution center to each demand point is determined in stages while meeting the capacity constraints of the emergency material distribution center and the distribution vehicle. , So that the material needs of all demand points can be met. The dynamic change of road network status information generally occurs at some discrete time points. The time period that does not change can be regarded as a constant, and the node when the vehicle receives new information or is about to go to the node on the way is defined As a new decision point. Assuming that the initial time is t1, there are t2, ... tn is a different time period different from t1, so the dynamic decision-making problem that changes with time can be transformed into a series of static decision-making problems at discrete time points [12].

ISSN: 2688-8653

2.2. Build a Mathematical Model

2.2.1. Symbol Description

$A\{a|a=1,2,3,\cdots n\}$: A collection of distribution centers has been established in the Spatio-temporal network; $B\{b|b=1,2,3,\cdots m\}$: The collection of disaster-affected points in the Spatio-temporal network; R: The collection of all points in the spatiotemporal network, $R=\{A\}\bigcup\{B\}$; $V\{k|k=1,2,3,\cdots p\}$: Collection of all vehicles; T_{abk}: The time of vehicle k from point a to b; t: A certain period of time the vehicle is in; s_{abt}: Material inflows from a to b in time t; q_a: Demand for point a; Q_k: Vehicle capacity.

2.2.2. Decision Variables

x_{abtk}: During t period, the vehicle from node a to node b is 1, otherwise it is 0.

2.2.3. Model Building

$$\min Z = \sum_{a,b\in R}\sum_{k\in V} T_{abk}x_{abtk} \tag{1}$$

$s.t.$

$$\sum_{i\le k<j} t_k = t_i \tag{2}$$

$$\sum_{a\in R}\sum_{b\in B} s_{abt} - \sum_{a\in R}\sum_{b\in B} s_{bat'} = q_a \tag{3}$$

$$\sum_{a\in B}\sum_{k\in V} q_{ak} \le Q_k \tag{4}$$

$$\sum_{a\in R} x_{abtk} - \sum_{a\in R} x_{bat'k} = 0, \forall b\in R, \forall k\in V \tag{5}$$

$$\sum_{r_i\in A} x_{r_iatk} - \sum_{r_i\in A} x_{ar_itk} = 0, \forall a\in B, \forall k\in V \tag{6}$$

$$x_{r_ir_jtk} = 0,\quad \forall r_{i,}r_j\in A, \forall k\in V \tag{7}$$

The goal formula (1) makes the emergency supplies reach the disaster point in the shortest time; formula (2) expresses that the starting point of a certain time node represents the entire period; formula (3) expresses that the demand point meets the flow balance constraint in a certain period of time; formula (4) It means that the total demand of the demand points served by the vehicle is less than the vehicle capacity; Equation (5) means that the vehicles arriving at each demand point must leave from that point; Equation (6) means that the vehicle returns to the original distribution center after completing the task; Equation (7) means that there is no traffic between the distribution centers.

2.3. Algorithm Design

In this paper, the solution process can be divided into two stages according to the characteristics of the space-time network model. The first stage is to solve the initial demand

ISSN: 2688-8653

and road network information, and the second stage is to solve the information after the demand and road network conditions change. Genetic algorithms are used respectively. Find the optimal solution for the acquired information [13]. The boundary between the two stages is the new decision point that the vehicle is about to arrive after receiving new information. The delivered demand points are no longer considered, and the remaining demand points are solved and solved to find a new optimization plan.

2.3.1. Chromosome Encoding and Decoding

In the emergency logistics location routing problem, the relationship between the distribution center, the demand point and the vehicle needs to be considered, so this article selects the method of serial number encoding. The distribution centers and demand points are coded with a uniform sequence number. The specific coding process is as follows:

First, set the emergency logistics distribution to two, which are numbered "1" and "2", and 15 demand points, which are numbered "3", "4", "5", "6", and "7". , "8", "9", "10", "11", "12", "13", "14", "15", "16", "17", the number of vehicle demand is to be determined. First, a chromosome of length 15 is randomly generated from the demand point, such as: (10 9 8 12 4 14 6 13 7 16 11 15 17 5 3). The reorganized chromosome only contains the demand point, so we need to insert the distribution center into it . The processing method is determined according to the distance from each point to the distribution center and the relationship between the demand of each demand point and the maximum load of the vehicle. The specific processing method is as follows: insert the delivery closest to the demand point before the first digit of a randomly generated set of chromosomes. For example, if the first digit of the chromosome generated above is "10", insert the number of the distribution center closest to the demand point before "10". If it is "1", a new set of chromosomes will be generated: (1 10 9 8 12 4 14 6 13 7 16 11 15 17 5 3) Then consider the demand of each demand point, add the demand in order, if the maximum load capacity of the vehicle is exceeded, the task of the vehicle will be ended and return to the starting point The distribution center, and insert the new number in the starting point distribution after the last demand point that completed the distribution. For example, the vehicle starts from the distribution center "1" and passes through the three demand points "10", "9", and "8". If the demand at the next point has exceeded its load capacity, insert the number "1" after "8" to get A new set of chromosomes: (1 10 9 8 1 12 4 14 6 13 7 16 11 15 17 5 3). With this chromosome, we can see that 1-10-9-8-1 is the driving path of vehicle 1. Repeat the above steps to know the coding sequence numbers of all demand points until the processing is completed. The obtained chromosome is: (1 10 9 8 1 2 12 4 14 6 2 1 13 7 16 11 15 1 2 17 5 3 2). According to the chromosome code, it can be seen that it contains 4 sub-paths:

Vehicle 1:1-10-9-8-1

Vehicle 2:2-12-4-14-6-2

Vehicle 3:1-13-7-16-11-15-1

Vehicle 4:2-17-5-3-2

The above analysis shows the distribution relationship between the emergency logistics distribution center and the vehicle, and the distribution relationship between the vehicle and the material demand point. The initial population is randomly generated. According to the number of candidate emergency logistics distribution centers and the number of vehicles, a natural number is randomly generated for each gene position of the chromosome. If the constraints of the distribution center and vehicle capacity are met, an initial chromosome can be obtained. Method to get the initial population.

2.3.2. Fitness Function Construction

In the genetic algorithm, the fitness value is the basis for evaluating the quality of a solution. The fitness function is also called the evaluation function. It is a standard for distinguishing the quality of individuals in the group based on the objective function. It is always non-negative,

ISSN: 2688-8653

and in any case. Hope that the larger the value, the better. Since the objective function sought in this article is its minimum value, only the objective function needs to be inverted. The formula is as follows:

$$F = 1/Z \tag{8}$$

3. Case Analysis

According to the characteristics of disaster occurrence, supplement and improve related data to generate test cases. The specific method is as follows: ①So 15 simulated disaster points are randomly generated in the area, and the coordinates of two distribution centers are assumed to be known; ②All points are in the algorithm The code of the distribution center is 1 and 2, and the codes of all disaster-affected points are 3-17; ③Set the demand for each disaster-affected point based on experience; ④Set the maximum capacity of the vehicle to 20T. The specific data is shown in Table 1.

Table 1. Analog point data

coding	X	Y	Demand(T)	coding	X	Y	Demand(T)
1	8	78	-	10	85	47	3.0
2	35	90	-	11	62	34	3.5
3	67	32	6.0	12	51	37	5.5
4	62	40	5.5	13	40	11	6.5
5	14	42	4.0	14	24	39	5.0
6	87	5	4.5	15	12	24	4.0
7	58	90	7.0	16	18	40	5.0
8	55	94	6.0	17	24	10	5.0
9	14	49	5.0	-	-	-	-

Since the distribution of materials after a disaster has a strong dependence on road network information, it is necessary to obtain the road traffic situation as soon as possible, and select the optimal path plan from the feasible route. Obtaining the road network situation of the disaster-stricken point in the above-mentioned area is shown in Figure 2, and the current optimal path can be selected according to the location of the disaster-stricken point and the road conditions above. Combining the mathematical models and algorithms of 1.2 and 1.3, use Matlab R2014a to solve them.

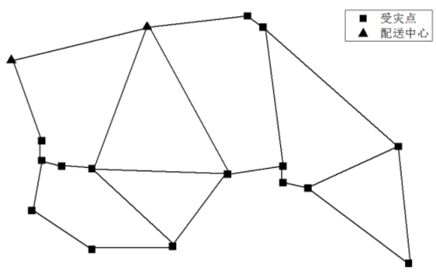

Figure 2. Current road network status

This article considers that the road information may change after the vehicle is sent. Therefore, the estimated rescue time range is divided into multiple equal time stages. The appropriate time interval selected is 1h. The vehicle is regarded as about to arrive on the way at each time node. If new information is obtained in the process, the path will be re-planned at that time node. As shown in Figure 3, after the vehicle has set off, some roads have been damaged due to post-disaster factors, as shown by the dotted line in Figure 3, so the original route needs to be re-planned. Combine the previous method to solve the new information to get a new solution.

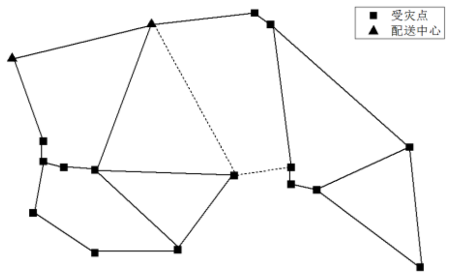

Figure 3. Road network condition after destruction

According to the results obtained from the above data, the current route planning of the current distribution center 1 vehicle before departure is 1-9-5-15-17-1-1-13-14-16-5-9-1, so there are 2 vehicles from The distribution center 1 sends out that the disaster point served by vehicle 1 is (9 5 15 17), and the disaster point served by vehicle 2 is (13 14 16). It will take 16 hours to complete the task and return to the starting point. The route before the departure of the distribution center 2 vehicle is planned as 2-8-7-10-2-2-6-3-11-4-2-2-12-2, so there are 3 vehicles sent from the distribution center 2, vehicle 1 The disaster point served is (8 7 10), the disaster point served by vehicle 2 is (6 3 11 4), and the disaster point served by vehicle 3 is (12). It takes 20 hours to complete the task and return to the starting point. The specific data is shown in Table 2.

Table 2. Current path planning

Distribution Center 1	Service point	Demand(T)	Distribution Center 1	Service point	Demand(T)
vehicle 1	9-5-15-17	18.0	vehicle 1	8-7-10	16.0
vehicle 2	13-14-16	16.5	vehicle 2	6-3-11-4	19.5
-	-	-	vehicle 3	12	5.5

After the road network information changes, a new feasible route is selected at the new decision point. The new route plan for the distribution center 1 vehicle is 1-9-5-15-17-1-1-13-12-14-1-1-16-5-9-1, so there are 3 vehicles sent from distribution center 1, the disaster point served by vehicle 1 is (9 5 15 17), the disaster point served by vehicle 2 is (13 12 14), and vehicle 3 The disaster point of the service is (16), and it took 17 hours to return to the starting point. The new route plan of the vehicles in distribution center 2 is 2-8-7-10-2-2-6-3-11-4-7-8-2, so there are 2 vehicles sent from the distribution center 2, and the vehicle 1 serves The disaster point is (8 7 10), the disaster point served by vehicle 2 is (6 3 11 4), and it takes 21 hours to return to the starting point. The specific data is shown in Table 3.

Table 3. Post-change path planning

Distribution Center 1	Service point	Demand(T)	Distribution Center 1	Service point	Demand(T)
vehicle 1	9-5-15-17	18.0	vehicle 1	8-7-10	16.0
vehicle 2	13-12-14	17.0	vehicle 2	6-3-11-4	19.5
vehicle 3	16	5.0	-	-	-

Arrange the above calculation results to get a Spatio-temporal network diagram as shown in Figure 4.

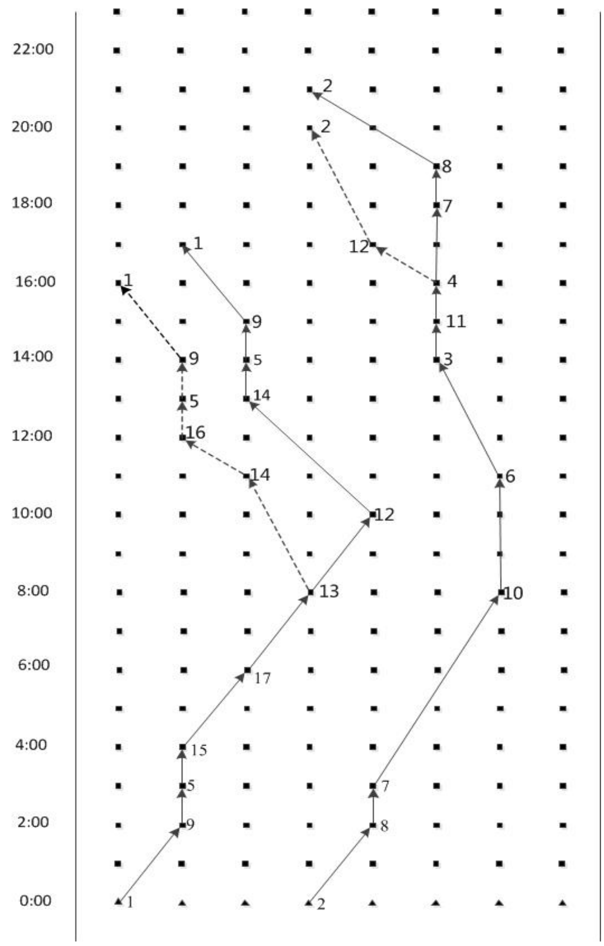

Figure 4. The result Time-space network chart

In Figure 4, the abscissa is the position of the point, the ordinate is the time point, the time interval is 1h, the number at the midway point is the code number of the disaster-stricken point, the dashed line is the delivery path selected before the vehicle departs, and the solid line is the acquisition The newly selected path plan after the road network information changes. It can be seen that after re-planning the route, the time consumption is only increased by 1h on the premise of completing the delivery task, which avoids the inability to modify the original route in time after the road information changes and the vehicle cannot complete the task. It is guaranteed that the rescue vehicle can complete the task. Under the premise, unnecessary time-consuming is also reduced.

ISSN: 2688-8653

4. Conclusion

In this paper, considering multiple distribution centers for distribution to multiple disaster-stricken points, a mathematical model is established using Spatio-temporal networks to solve the problem that the original route cannot be completed due to the changes in the road network information encountered by the vehicle during the distribution process. The distribution process is divided into multiple stages in time. At each stage, the optimal route can be re-selected according to whether new information changes are received as a new decision point. At the same time, considering the limitation of vehicle capacity, the solution is based on The mathematical model of the Spatio-temporal network, which can help rescuers choose the most suitable rescue route. However, this article only considers the changes of road information in the Spatio-temporal network model, and does not consider that one or more new disaster points may appear in a certain time node. Therefore, in the follow-up research, it can be considered under the condition of road network information changes. , Add multiple disaster-stricken points, use the space-time network to establish a model to solve it, and provide a more complete solution for the planning of the emergency material distribution path after the disaster.

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