The optimization of traffic control scheme for multi-depot emergency supplies transportation

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Abstract

In order to transport emergency supplies from multi-depot to the demand point as soon as possible, minimize disturbance and waiting time of vehicles, and solve the problem of congestion that may appear when vehicles of multi- depot arrive at the same point simultaneously, this paper establishes a traffic control model to minimize disturbance caused by control under time requirement of emergency supplies transportation, designs the optimized algorithm to solve the model, and gets waiting scheme of congested vehicles using scheduling strategy First In First Out. Moreover, the optimized control scheme for roads is obtained. Finally, the model and algorithm are analyzed and validated by Sioux-Fall road network. Experimental results show that the optimized control scheme can improve the transportation efficiency of emergency supplies transportation, and meet the requirement of emergency rescue.

Keywords

Emergency supplies transportation,Traffic control scheme,Optimization algorithm of traffic control scheme, Demi control mode

1. Introduction

After the disaster, a large quantity of emergency supplies will inevitably be required, in order to reduce losses in disasters and speed up the transfer of the reconstruction and restoration of production and living order, etc. Due to the higher time limit of emergency supplies transportation, we need to take appropriate control measures on roads when multi-depot vehicles transport emergency supplies. However, traffic control will interfere with social vehicles to some degree. At the same time, traffic congestion will occur when vehicles of multi-depot arrive at the same point simultaneously. Therefore, it is necessary to optimize the traffic control scheme so that there is no congestion when vehicles reach the same point without intervals and disturbance caused by control is the minimum within time limit.

Traffic control as an effective solution to traffic congestion has been widely used. Yet the traffic control as an impact factor in the studies of emergency rescue has only begun to appear in recent years. A M. Caunhye, X.Nie, et al. [1] emphasized the significance of traffic control in rescue. By considering the road network partially destroyed by earthquake and by the traffic control executed to avoid traffic congestion. S.L. Li and Z.J. Ma [2] studied the user equilibrium-based post-earthquake relief routing problems under traffic control. On that basis, they studied the multi-depot relief distribution under traffic control [3]. M.A. Konstantinidou, K.L. Kepaptsoglou, et al. [4] applied traffic control of lane retrograde to emergency relief evacuation, greatly improving the efficiency of rescue.

The current studies on emergency rescue based on traffic control mainly focus on the concrete application of traffic control measures, while it refers to the optimization of traffic control little and there is no executable, operational specific programs for the specific control modes and time of each section[5-10]. In the background of emergency supplies transportation, considering the specific traffic control mode of each section, demi control mode is introduced to control the section for different time intervals. In case of congestion that may occur when vehicles of multi-depot get to the same point together, FIFO strategy is used to get vehicles waiting scheme. At last, traffic control scheme of multi-depot emergency supplies transportation is optimized on the basis above.

2. Model construction

2.1 Problem description

Once the disaster in a region occurs, the corresponding multi-depot will transport emergency supplies to the affected area as soon as possible. Because of the higher limit of emergency transportation, there is the need for traffic control, which will affect the normal operation of the social vehicles. Meanwhile, congestion will show up when vehicles of multi-depot reach the same point together. So, how to carry out traffic control? Under traffic control, there is no congestion when vehicles of multi-depot arrive at the same point. Meanwhile, not only the rapid delivery of emergency supplies to the affected area is guaranteed but also the minimum disturbance due to traffic control.

1) Assumptions for the model are defined as follows:

(1) Traffic control information is fully disclosed. After the disaster, the emergency management department timely release traffic control information to the public through various channels, and the traveler can adjust their travel according to the information;

(2) According to War drop equilibrium guideline, it is assumed that travelers always select the shortest as their path [11];

(3) Suppose only a certain type of relief supplies is delivered;

(4) Transportation demand is known, obtained by conventional traffic statistics;

(5) There are three control modes for sections, namely full control, demi control, and no control. Under full control, only emergency vehicles is allowed; Under demi control, emergency vehicles in the same direction get through half of the lanes, while social vehicles the left; Without control, all the vehicles pass through the section.

For the convenience of modeling, this paper will abstract road network as graph $G(V, E)$. Where, V is the set of node i in the network, $i \in \{1, 2, ..., n\}$, E represents set of section connecting nodes, $(i, j) \in E$,and a path consists of several sections. The important variables are defined as follows:

O_i: a supply start node of emergency supplies, $O_i \in O$;

D: a demand point of emergency supplies, $D \subseteq V$;

O: the supply point set of emergency supplies, $O = \{O_1, O_2, ...O_i, O_j, ...O_n\}, O \subseteq V$;

T: the arrival time of emergency supplies required;

P_i :the shortest path from supply point O_i to demand point D;

T_i : the travel time of rescue vehicles in path P_i;

Q_{O_iD}: the traffic demand of OD between O_i and D, $O_i \in O$;

$\omega_{(i,j)}^{\varphi}$:the type of traffic control for section (i,j).When $\varphi = 1$, it implies no control for the section, signing $\omega_{(i,j)}^{1} = 0$; When $\varphi = 2$, it denotes demi control for the section, signing $\omega_{(i,j)}^{2} = \frac{1}{2}$; When $\varphi = 3$, it represents full control for the section, signing $\omega_{(i,j)}^{3} = 1$;

$x'_{(i,j)}$: the traffic flow of section (i,j) under no control, $(i,j) \in E$;

$x_{(i,j)}$:the traffic flow of section (i,j) under control, $(i,j) \in E$. Under full control, there is no social vehicles in the section; Under demi control, given the probability of bypassing for social vehicles, it is estimated that the flow of social vehicles is 80% of that under no control. Meanwhile, the road capacity is reduced by half;

$t_{(i,j)}(x)$: the travel time function of section (i,j);

t'_{ij}: the waiting time of vehicles at the same point when congestion occurs;

R_{O_iD}: the vehicle path set of OD between O_i and D, $R_{O_iD} = \{ P_1, P_2, \ldots, P_i, P_j, \ldots P_n \}$;

$f_{R_{O_iD}}^{P_i}$: the flow of path P_i in the travel path set R_{O_iD}, $P_i \in R_{O_iD}$;

$\delta_{R_{O_iD}}^{(i,j),P_i}$:the correlation coefficient between path and section, if section (i,j) belongs to path P_i in the travel path set R_{O_iD}, it is 1, otherwise, 0.

2.2 Mathematics Model

In order to achieve the goal of minimizing the disturbance for the social vehicles within the time limit of emergency supplies transportation, we define that for the social vehicles the disturbance is the ratio of delay time caused by control and travel time without control, details are as follows:

1) Without control, all the vehicles pass through the section. For the social vehicles, there is no delay, and the impact is so little that it can be negligible, denoted as 0;

2) Under demi control, delay time for social vehicles is the difference between travel time under demi control and that without control;

3) With full control, delay time for social vehicles is the time that emergency vehicles get through the section;

4) Disturbance caused by traffic control with different time intervals for the path is the sum of disturbance for the section. Expressions detailed are as follows:

$$Z = \sum_{(i,j)\in R_{O_iD}} \frac{(2\omega_{(i,j)}^{2}\int_0^{x_{(i,j)}} t_{(i,j)}(x)dx - \left(1-\omega_{(i,j)}^{1}\right)\int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx) + \omega_{(i,j)}^{3} t_{(i,j)}(0)}{\left(1-\omega_{(i,j)}^{1}\right)\int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx}$$

Simplification is:

$$Z = \sum_{(i,j)\in R_{O_iD}} \frac{(\int_0^{x_{(i,j)}} t_{(i,j)}(x)dx - \int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx) + t_{(i,j)}(0)}{\int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx}$$

So the objective function is:

$$Z_1 = \min\left\{\sum_{(i,j)\in R_{O_iD}} \frac{(\int_0^{x_{(i,j)}} t_{(i,j)}(x)dx - \int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx) + t_{(i,j)}(0)}{\int_0^{x'_{(i,j)}} t_{(i,j)}(x)dx}\right\} \tag{1}$$

Subjected to.

$$max(T_i + \sum_{(i,j)\in P_i} t'_{ij}) \le T \tag{2}$$

$$\sum_{P_i \in R_{O_iD}} f_{R_{O_iD}}^{P_i} = Q_{O_iD} \quad \forall O_iD \tag{3}$$

$$x_{(i,j)} = \sum_{O_i \in O} \sum_{P_i \in R_{O_iD}} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(i,j),P_i} \quad \forall O_iD, \forall i,j \in V, \forall (i,j) \in E \tag{4}$$

$$x'_{(i,j)} = \sum_{O_i \in O} \sum_{P_i \in R_{O_iD}} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(i,j),P_i} \quad \forall O_iD, \forall i,j \in V, \forall (i,j) \in E \tag{5}$$

$$\sum_{j:(i,j)\in E} \delta_{R_{O_iD}}^{(i,j),P_i} - \sum_{j:(i,j)\in E} \delta_{R_{O_iD}}^{(j,i),P_i} = \begin{cases} 1, i = O_i \\ 0, i \in V / \{O_i, D\} \\ -1, i = D \end{cases} \forall i,j \in V \tag{6}$$

$$\sum_{j:(i,j)\in E} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(i,j),P_i} - \sum_{j:(i,j)\in E} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(j,i),P_i} = \begin{cases} f_{R_{O_iD}}^{P_i}, i = O_i \\ 0, i \in V / \{O_i, D\} \\ -f_{R_{O_iD}}^{P_i}, i = D \end{cases} \forall P_i, \forall O_iD, \forall i,j \in V \tag{7}$$

$$\sum_{O_i \in O} \sum_{P_i \in R_{O_iD}} \sum_{j:(i,j)\in E} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(i,j),P_i} - \sum_{O_i \in O} \sum_{P_i \in R_{O_iD}} \sum_{j:(i,j)\in E} f_{R_{O_iD}}^{P_i} \delta_{R_{O_iD}}^{(j,i),P_i} = 0 \quad \forall i,j \in V / \{O_i, D\} \tag{8}$$

$$f_{R_{O_iD}}^{P_i} \ge 0 \quad \forall O_iD \tag{9}$$

$$\delta_{R_{O_iD}}^{(i,j),P_i} = \{0,1\} \tag{10}$$

$$\omega_{(i,j)}^{\varphi} = \begin{cases} 0, \varphi = 1 \\ \frac{1}{2}, \varphi = 2 \\ 1, \varphi = 3 \end{cases} \tag{11}$$

Where,

Formula (1) means the minimum disturbance caused by traffic control for social vehicles under the time requirement.

Formula (2) suggests that travel time of the latest arrival emergency vehicles under control meets time requirement of emergency supplies transportation. The travel time of the latest arrival emergency vehicles is the maximum of the sum of travel time in the path and the waiting time in the case of congestion. Generally speaking, there are two cases for travel time of emergency vehicles. One is the free flow time by control, where control includes full and demi control. The other one is obtained by flow without control. Where,

$$T_i = \sum_{(i,j)\in P_i} (\left(\omega_{(i,j)}^3 + \frac{1}{\omega_{(i,j)}^2} \omega_{(i,j)}^2 \right) t_{(i,j)}(0) + \left(1 - \omega_{(i,j)}^1\right) \int_0^{x_{(i,j)}} t_{(i,j)}(x)\,dx)$$

Simplification is:

$$T_i = \sum_{(i,j)\in P_i} (2t_{(i,j)}(0) + \int_0^{x_{(i,j)}} t_{(i,j)}(x)\,dx) \tag{2'}$$

Formula (3) means demand balance between OD; Formula (4) and (5) are the section flow formula before and after control; Formula (6) indicates user path continuity constraints; Formula (7) denotes user path flow conservation constraints; Formula (8) means flow conservation of section; Formula (9) is non-negative constraint; Formula (10) is 0-1constraint; Formula (11) is the coefficient corresponding to control modes.

2.3 Travel time function

During traffic flow assignment, there is correlation between vehicle travel time and flow, usually denoted by impedance function $t_{(i,j)}(x)$. The function is mainly used to describe the performance of vehicle operation that may occur in a variety of traffic and road conditions. It is originated from the relationship between per unit time and average speed in the road network. The function is performed by capacity restrictions when flow is assigned to each section. Here, we use BPR function from Federal Highway Administration[12], and the expression is:

$$t_{(i,j)}(x_{(i,j)}) = t_{(i,j)}(0)[1+\alpha(\frac{x_{(i,j)}}{C_{(i,j)}})^{\beta}] \tag{12}$$

Where, α, β is regression coefficient, and the typical value is $\alpha = 0.15$, $\beta = 4$. $t_{(i,j)}(0)$ is free-flow travel time without resistance for section (i,j). $C_{(i,j)}$ is the capacity of section (i,j).

For traffic control studied here, according to equation (3) and (4), there is some capacity constraints for the road network. During traffic assignment, only the change of travel time is considered using the Frank-Wolfe algorithm[13], while serious congestion caused by flow beyond section capacity is ignored. It is assumed that travel time of control section is free flow time. $x_{(i,j)}$ is the allocated capacity of the section. When $x_{(i,j)} \geq C_{(i,j)}$, travel time of section tends to infinity, namely, $t_{(i,j)}(x_{(i,j)}) = t_{(i,j)}(C_{(i,j)}) \to \infty$, which indicates this section is closed. When $x_{(i,j)} < C_{(i,j)}$, travel time function is expressed as below.

For the emergency vehicles,

$$t_{(i,j)}(x_{(i,j)}) = \begin{cases} t_{(i,j)}(0), \omega^1_{(i,j)} = 1 \\ t_{(i,j)}(0), \omega^2_{(i,j)} = \frac{1}{2} \\ t_{(i,j)}(0)\left[1+\alpha(\frac{x_{(i,j)}}{C_{(i,j)}})^{\beta}\right], \omega^3_{(i,j)} = 0 \end{cases} \tag{13}$$

For the social vehicles,

$$t_{(i,j)}(x_{(i,j)}) = \begin{cases} t_{(i,j)}(0)[1+\left[1+\alpha(\frac{x_{(i,j)}}{C_{(i,j)}})^{\beta}\right]], \omega^1_{(i,j)} = 1 \\ t_{(i,j)}(0)\left[1+\alpha(\frac{x_{(i,j)}}{\frac{1}{2}C_{(i,j)}})^{\beta}\right], \omega^2_{(i,j)} = \frac{1}{2} \\ t_{(i,j)}(0)\left[1+\alpha(\frac{x_{(i,j)}}{C_{(i,j)}})^{\beta}\right], \omega^3_{(i,j)} = 0 \end{cases} \tag{14}$$

3. Algorithm construction

$$\begin{cases} \min Z(x) = \sum_a \int_0^{x_a} t_a(x)\,dx \\ s.t. \quad \sum f_k^{rs} = q_{rs}, \forall r,s \\ x_a = \sum_r \sum_s \sum_k f_k^{rs}.\sigma_{a,k}^{rs}, \forall a \\ f_k^{rs} \geq 0 \quad \forall k,r,s \end{cases} \tag{3-1}$$

Where, x_a is traffic flow of section a; t_a is expense of section a (usually measured in time); f_k^{rs} is the flow of a path k from supply point to disaster point; q_{rs} means all traffic demand from r to s during the time period studied, namely the amount of OD.

This model has proven to be convex programming model[14], so it has a global optimal solution. Nonnegativity and monotonically increasing of section expense function is the sufficient condition for the model (3-1) with a unique solution. It is evident that BPR function clearly is with such properties in the practical application. However, this convexity is not suitable for path flow. The non-uniqueness of the optimal solution of path flow will eventually become a serious obstacle in descent algorithm application when we solve the problem of traffic network design[15].

To solve this model, many scholars have designed algorithms, such as Frank-Wolfe, Logit equilibrium and variational inequalities, etc. In this paper, combining the objective function with section characteristics under the target, on the basis of Frank-Wolfe, algorithm is designed to solve the model.

3.1 Optimization algorithm of multi-depot traffic control based on greed

Details are as follows:

Step1: Validate the feasibility of scheme. For Fig G = (V, E), the shortest path from all the rescue points $O_1 \sim O_n$ to the demand point D and the time needed $T_1, T_2, \ldots T_i, T_j, \ldots, T_n$ are calculated by johnson algorithm when roads are under full control. It is time when there is no resistance in the road. If max> T, then there is no viable solution, quit; otherwise, turn to step2;

Step2: Find the feasible scheme under normal circumstances. For Fig G = (V, E), the shortest path from all the rescue points $O_1 \sim O_n$ to the demand point D and the time needed $T_1, T_2, \ldots T_i, T_j, \ldots, T_n$ are calculated by johnson algorithm when roads are without control. If max <= T, then turn to step6; otherwise, turn to step3;

Step3: Construct network G'. Carry out full control, demi control for each section in the path $P_1, P_2, \ldots, P_i, P_j, \ldots P_n$. Add parallel full control and demi control edges in Fig G to configure network G';

Step4: Calculate the disturbance z_{ij} and travel time t_{ij} of each newly-added edge in the network G' (the edge G'-G). Arrange the edges in non-descending order in terms of disturbance z_{ij} .If disturbance of section are the same, arrange the edges in non-descending order according to disturbance of per unit time z_{ij}, getting sequence Y;

Step5: Find the feasible scheme under control.

(1) sign $G'' = G$;

(2) Add the edge e one by one from sequence Y for G'', $G'' = G + \{e\}$ .The shortest path from all the rescue points $O_1 \sim O_n$ to the demand point D， the time needed $T_1, T_2, \ldots T_i, T_j, \ldots, T_n$ and disturbance Z caused by control are calculated by johnson algorithm. If max T_i >T, then return to continue to add edges; otherwise, turn to step6;

step6:Obtain vehicles waiting scheme. First, All the rescue points $O_1 \sim O_n$ as the starting points, breadth first search method is used to traverse Fig G_1 layer by layer. Fig G_1 is composed of path $P_1, P_2, \ldots, P_i, P_j, \ldots P_n$ from all the rescue points $O_1 \sim O_n$ to the demand point D. If the in degree of the upcoming visited point i is greater than 1, namely, $d_{G_1}^- > 1$, then vehicles are scheduled according to the FIFO strategy. If vehicles comes together at the same time, then the scheduling strategy is that the vehicles in the path with long travel time first enter. Arrange vehicles to wait in front of the upcoming visited point *i* side by side. Then, search the next layer until all the points access to the demand point D are traversed.

step7: Calculate waiting time. Plus time needed of each path $T_1, T_2, \dots T_i, T_j, \dots, T_n$, the sum of vehicles waiting time $\sum_{(i,j)\in P_i} t'_{ij}$ in each path of step 6 is calculated. If $max(T_i + \sum_{(i,j)\in P_i} t'_{ij})$ <=T, then output the scheme. Otherwise, turn to step 8;

step8: Adjust control scheme. For the path with travel time more than T in step7, vehicles waiting time $\sum_{(i,j)\in P_i} t'_{ij}$ is arranged in non-ascending order, getting sequence H. Then, adjust control scheme according to sequence H path by path. For each section of the path in G_1, control scheme is adjusted in terms of disturbance in non-descending order. That is, no control mode is upgraded to demi control, or demi control mode is upgraded to full control until travel time of all the path is no more than T. Correspondingly, waiting time t'_{ij} and disturbance z_{ij} are adjusted. Each time control mode is upgraded, waiting time after adjustment is 1/2 of the original time.

step9: Output control scheme after adjustment and waiting scheme, and the optimal scheduling scheme is obtained.

3.2 Algorithm complexity analysis

In network *G*, it is assumed that travel time of all sections without control is known. According to the description in 3.1, the main step and complexity analysis of the algorithm are as follows:

Using Johnson algorithm to find the shortest path P_1, P_2, …, P_i, P_j, … P_n from all the rescue points $O_1 \sim O_n$ to the demand point *D*, the complexity of the step is *O*(*mnlgm*). Adding control edges to the section, construct network graph G', the complexity of which is *O* (*n*). Calculate disturbance and travel time of the newly-added edges, arrange the edges in order of disturbance, and obtain sequence *Y*. Its complexity is *O* (*nlgn*). According to the sequence *Y*, add the edge to network *G* one by one, calculate disturbance and travel time, and obtain control program. The complexity is $O(mn^2lgm)$. As for the adjustment and solving of vehicles waiting scheme, its complexity is *O* (*nlgn*). All in all, the overall complexity of the algorithm is $O(mnlgm+ n+ nlgn+ mn^2lgm+nlgn)$, no more than $O(n^4)$.

4. Numerical experiment

In this paper, the Sioux-Fall Road Network topology abstracted from the US Northridge earthquake situation is employed to verify the algorithm [16]. There are 24 nodes, 76 sections, and the topology is shown in Figure 1. Capacity of each link (in 5000Vol / h, per hour 5000 standard car) and travel time (h) is marked in Figure 1, the format "link number (link capacity, travel time)". Traffic demand between each OD pair is shown in Table 1. It is assumed that emergency supplies are transported from rescue points 7,18,19,22 to the demand point 11. Each rescue point has 10 emergency vehicles, and this is composed of a fleet of 10 vehicles. It takes 0.5 hours for a fleet entirely through a point. Then, time of one vehicle entirely through a point is 0.05 hours. Traffic demand table between each OD pair can be got in reference [2].

Without control, travel time of emergency vehicles is the longest while disturbance is the minimal. In the case of control, travel time of emergency vehicles is the shortest, that is, free flow of time. There is disturbance to some degree. Accordingly, we can control the section for different time intervals, and optimize the traffic control scheme. Due to congestion that may appear when vehicles arrive at the same point simultaneously, traffic control is optimized on the basis of the vehicles waiting scheme. Algorithm experiment is programmed on the platform of Python2.7.10 and PyCharm5.0 platform, running on the machine of the Intel (R) Celeron (R) CPU G540 2.50GHz, 4G memory.

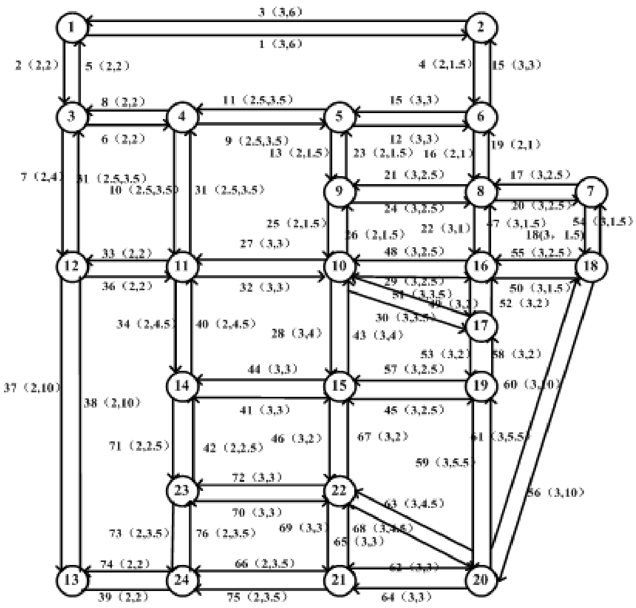

Fig 1. Sioux-Fall Road Network Topology

Experimentally obtained, the path P_1, P_2, P_3, P_4 is 7-8-9-10-11, 18-16-10-11, 19-17-10-11, 22- 15-10-11. The sequenced results of disturbance for sections added with full and demi control edges are shown in Table 1. In Table 2, the traffic control strategy without traffic congestion corresponds to the one with the minimum disturbance under different arrival time constraint. Some representative vehicles waiting scheme and traffic control scheme with congestion are shown in Table 3. Here, disturbance caused by traffic control strategy is normalized. It is the ratio of disturbance caused by traffic control strategy and the disturbance caused by the strategy of which the disturbance is maximum in order.

Table 1: Situation of disturbance sequence for sections

Disturbance sequence	section	Control mode	Travel time without control (h)	Free flow time(h)	Disturbance under control for different time intervals (%)
1	8-9	Demi control	2.5212	2.5	4.67
2	18-16	Demi control	2.5331	2.5	7.27
3	7-8	Demi control	2.5426	2.5	9.31
4	17-10	Demi control	3.819	3.5	46.38
5	19-17	Full control	4.303	2	46.48
6	9-10	Full control	2.5883	1.5	57.95
7	22-15	Full control	3.35	2	59.70
8	15-10	Full control	6.1451	4	65.09
9	10-11	Full control	4.4468	3	67.46
10	16-10	Full control	3.4008	2.5	73.51

From Table 1, take the first row for example. For all newly-added edges, disturbance is the minimum when section 8-9 is under demi control. Travel time of emergency vehicles through the section is the free flow time 2.5 h. Disturbance for social vehicles caused by demi control is 4.67%. Without control, travel time of vehicles is 2.5212 h.

From Table 2, take the sixth row for example. When the arrival time range of emergency vehicles is (13.0 ~ 14.0) h, multi-depot transport emergency supplies at the same time without control. According to section sequence, section 7-8 and 18-16 are in demi control, section 19-17 in full control, while the remaining sections in non-regulated status. Once emergency vehicles pass through the sections above, remove the control. Take section 8-9 and 17-10 in demi control, while the remaining sections are in non-regulated status. From the rescue points 7,18,19,22 to the demand point 11, travel time of the latest arrival emergency vehicles is 13.94h, and disturbance generated is 11.89%.

Table2: Traffic control strategy without congestion corresponding to the minimum disturbance under different arrival time requirement

Arrival time requirement T (h)	The longest transportation time (max T_i) (h)	Disturbance (%)	Traffic control strategy Demi control full control
13.0~14.0	13.94	0	
		0.49	8-9
		1.24 2.21	8-9,18-16 8-9,18-16,7-8
		7.04	8-9,18-16,7-8,17-10
		11.89	8-9,18-16,7-8,17-10 19-17
		17.91	8-9,18-16,7-8,17-10 19-17, 9-10
11.0~13.0 9.0~11.0	12.59 10.95 9.5	24.13 30.91 59.00 66.67 100	8-9,18-16,7-8,17-10 19-17, 9-10,22-15 8-9,18-16,7-8,17-10 19-17, 9-10,22-15,15-10 8-9,18-16,7-8,17-10 19-17, 9-10,22-15,15-10,10-11 8-9,18-16,7-8,17-10 19-17, 9-10,22-15,15-10,10-11,16-10 8-9, 18-16, 7-8, 17-10, 19-17, 9-10, 22-15,15-10,10-11,16-10

Table3. Some representative vehicles waiting scheme and traffic control scheme with congestion

Arrival time requirement $T(h)$	The longest transportation time $\max T_i(h)$	Congest or not	Vehicles waiting scheme(vehicles waiting time at public point 10)(h)				The final transportation time (the sum of the longest transportation time and waiting time)	Traffic control scheme		Disturbance (%)
			P_1	P_2	P_3	P_4		Demi control	Full control	
T>=13.94	13.94	Yes			0.05		13.94			0
12.59<=T<13.94	12.59	Yes		0.1			12.59	8-9, 18-16, 7-8, 17-10	19-17, 9-10, 22-15	24.13
10.95<=T<12.59	10.95	Yes	0.5	0.1		0.5	11.45	8-9, 18-16, 7-8, 17-10	19-17, 9-10, 22-15, 15-10	30.91
9.5<=T<10.95	9.5	Yes	0.25	0.05		0.25	9.75	8-9, 18-16, 7-8, 17-10	19-17, 9-10, 22-15, 15-10, 10-11	59.00
	9.5	Yes	0.5	0.5		0.5	10		8-9, 18-16, 7-8, 17-10, 19-17, 9-10, 22-15, 15-10, 16-10, 10-11	100
T<9.5	—	—	—	—	—	—	—	—	—	

From Table 3, take the fourth row for example. When the arrival time range of emergency vehicles is (10.95 ~ 12.59) h, section 8-9,18-16,7-8, 17-10 are in demi control, while section 19-17, 9-10, 22-15, 15-10 are in full control. Under the control scheme, when vehicles arrive at point 10, congestion occurs. According to scheduling strategy First In First Out, vehicles in path P_2 need to wait for 0.1 hours, leading to vehicles in path P_4 wait for 0.5 hours. Then, vehicles in path P_1 wait for 0.5 hours. The latest arrival vehicles derive from path P_1, and it takes 11.45 hours to reach the demand point finally.

In conclusion, with the growth of the latest arrival time of emergency vehicles, fewer sections are in need of traffic control, and disturbance caused by control gradually decreases. When the latest arrival time requirement is not critical, we can take only one section in demi control, and disturbance at this time can almost be negligible. When multi-depot transport emergency supplies simultaneously, strategy First in First Out is employed to obtain vehicles waiting scheme for congestion. Traffic control scheme is optimized on that basis. It can be seen that traffic control is an effective measures to ensure emergency supplies transportation. When congestion occurs in emergency supplies transportation, combining strategy First in First Out with optimization of traffic control scheme can effectively guarantee the emergency supplies transportation.

5. Conclusion

In the background of emergency supplies transportation, considering the specific traffic control mode of each section, the demi control mode is introduced to control the section for different time intervals. Meanwhile, in case of congestion that occurs in multi-depot supplies transportation, Strategy First In First Out is used to design vehicles waiting scheme, which is based on to optimize traffic control scheme. Finally, Sioux-Fall road network is employed to validate the algorithm. It is concluded that traffic control scheme is feasible and can be tested in practice, which will provide effective theoretical support for emergency rescue work. The next study may be extended to the optimization of traffic control scheme for emergency supplies transportation under incomplete information conditions.

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