A Novel Emergency Vehicle Scheduling Model to deal with Dynamic City Conditions

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***Abstract* — To improve emergency response efficiency under uncertainty, an urban emergency vehicle scheduling model is optimized by mathematical planning. The existing scheduling models are only built in accordance with current incidents while ignoring future incidents. To deal efficiently with future incidents, we adopt a different and novel approach in this paper by establishing a mathematical model which minimizes the overall response time cost with weights as the objective function. In terms of time and space constraints, the travel time calculation of the emergency vehicle is considered under different traffic flow conditions. Case results show that if the potential incidents really occur, the overall response time cost will be minimized by the scheduling policy. Furthermore, the selection of the confidence level determines the degree of system's emphasis on future events. Dealing with future serious incidents would be focused on prevention as the confidence level tends to one, while current incidents would be responded to with a priority as confidence level tends to zero.**

Keywords - Traffic engineering; emergency; vehicle scheduling; travel time

I. INTRODUCTION

The design and operation of emergency vehicle system are paid more widespread attention in the field of emergency response. The primary problem of the system is establishing and solving mathematical model to aid decision making. Goldberg [1] summarized predecessors' research results, and classified the research in the field into four categories: the vehicle's location; the vehicle scheduling; the vehicle number while different types of emergency units are combined together, the number of staff and the ancillary equipment level; the redistribution of resources under different system status. This article's research belongs to the vehicle scheduling. The selection of emergency vehicle routing under the condition of urgency has the characteristics of time urgency, uncertainty and limited resources, etc., the theory and the method of the vehicle routing problem under the normal status have certain limitations.

At present, in abroad the emergency research under uncertain conditions tends toward to the location model of emergency units[2], the experience formula of traveling time[3], the configuration method of finite scheduling resources [4], etc.. In the aspect of vehicle scheduling combines with uncertainty conditions, Pal [5] emphasized on the randomness of traffic conditions and events, using the simulation model to design the vehicle's patrol system on the highway; Ali Haghani [6] established the optimization model under the condition of the vehicle scheduling and route choice; Kaan Ozbay [7] studied the stochastic programming model for vehicle scheduling and resource allocation in event management system. In China the research in emergency vehicle scheduling model also started from certainty to uncertainty conditions. Xiao-guang Yang etc.[8] used the method of fuzzy evaluation to construct the evaluation model of rescue vehicle for traffic unblocked reliability; Yong Gu etc. [9] studied the vehicle scheduling model under the condition of stochastic travel time; Xiaokuan Yang [10] and Yang Liu[11,12] studied the emergency vehicles real-time calculation of travel time from different angles.

On the basis of literature research, with the research object of the emergency vehicle scheduling, according to the probability of current event information and future events, this paper establishes a city vehicle scheduling model under uncertainty.

II. PROBLEM ANALYSIS

The merit of the emergency vehicle dispatching decision-making is the key factor if it is a successful operation for the emergency system. The study purpose of the emergency vehicle scheduling model is to establish a mathematical formula to assist emergency decision-making. The authors in the literature [13] established the mathematical model function which takes the minimum whole loss as the objective function based on integer programming:

$$\begin{cases} Min\sum_i \sum_j (X_{ji}(t)T_{ji}(t)EP_i) \\ \sum_{j\in V} X_{ij}(t)=1 \\ \sum_{i\in W} X_{ji}(t)\le 1 \\ X_{ji}(t)T_{ji}(t)\le T_i \end{cases} \tag{1}$$

In the expression, $X_{ji}(t)$ is the 0-1decision variable; $T_{ji}(t)$ is the response time of emergency vehicle; EP_i is the event right.

The model focuses on multiple optimal operations of different kinds of events happening at the same time, in the model there does not consider the calculation of travel time. Shortening the travel time of emergency vehicles is very important to decrease the direct and indirect loss caused by emergencies. In the response process the emergency vehicle will alarm and have the right-of-way on the roads and intersections. Therefore, in the study of vehicle scheduling model, the research on travel time of emergency vehicles is less; usually the quotient value of distance and average speed is taken directly. However, in reality of urban environment, emergency vehicles will meet the road network with different congestion degree, which hinders the rapid response.

In addition, this model is only in view of the current incidents, not considering the prevention strategy of the events after the vehicles are scheduled again in the area. If a vehicle is scheduled to response a low priority event, at this time in the near site area the event occurs with the highest emergency priority level, which will cause the incident response time delay.

According to the above problem, this paper will consider the uncertainty factors such as random variation of travel time, the random location of the events happening in the future, and random types, etc., further perfecting emergency vehicle scheduling model.

III. MODEL BUILDING

A. Vehicle Scheduling Model

Based on the analysis of above problem, this part sets the overall response time cost of current events and future events as the mathematical programming model of the objective function. D is defined as the array for all emergency vehicles, D^n is the vehicle array where the emergency vehicles are stationed at the n-th site. r^n is the parked vehicle number at site n, N is the current emergency array that needs to deal with, F is the event array occurred in possible future. In order to reduce the loss caused by emergencies, different types of events should be given different response time requirements; serious incident should be responded in priority. W is defined as the weight array of response time, $EP(l)$ represents the l level of priority weight in W, EP_j is the response time weight for the current event j, EP_k is the response time weight value of future event k. t_{ij}, t_{ik} are defined respectively as the execution event of vehicle from the start to the event happening point, and the shortest travel time executing against future events. The decision variables are introduced into two 0-1variables x_{ij}, x_{ik}. When x_{ij} is equal to 1, which means vehicle i executes the task which responses to the event j, when it is equal to 0, which means there is no task to perform; when x_{ik} equals 0, which means the vehicle i executes the task to against future event k, if it is equal to 0, which represents there is no task. Emergency vehicle scheduling model is set up as follows:

$$Min\sum_{i\in D}\sum_{j\in N} x_{ij}EP_j t_{ij} + \sum_{i\in D}\sum_{k\in F} x_{ik}EP_k t_{ik} \tag{2}$$

$$\sum_{j\in N} x_{ij} + \sum_{k\in F} x_{ik} = 1, \ \forall i\in D \tag{3}$$

$$\sum_{i\in D^n} x_{ij} + \sum_{i\in D^n} x_{ik} \le r_n, \ \forall i\in N, \ \forall k\in F \tag{4}$$

$$\sum_{i\in D} x_{ij} = 1, \ \forall j\in N \tag{5}$$

$$\sum_{i\in D} x_{ik} = 1, \ \forall k\in F \tag{6}$$

$$\prod_{k\in F} P(\sum_{l\in W} EP_k(l)) \ge \alpha \tag{7}$$

Expression (2) shows that the objective function consists of two parts which are response time cost with current event's weight and the response time cost with future event's weight. Comparing with the expression (1), in the model the added next item is used to prevent the occurring of serious incident in the future. Each vehicle in expression (3) is restrained to only perform a task; expression (4) shows the vehicles number in the response event is limited by the vehicle number of the sites; expression (5) restrains that only one vehicle responses in the current event; expression (6) restrains in the future events only one vehicle responses; expression (7) shows that the ability of system against future events reaches a certain confidence level, which is defined as α.

In model (2), the three parameters of emergency vehicles travel time, events weights and confidence level α, show that the model is suitable for emergency demand in uncertainty conditions. The severity of the event is random, serious incident should be prioritized response.

The weight values of different types of events can adopt hierarchy analytic to determine. α represents that the events happened in the future can obtain the probability of satisfactory response, which is decided by the emergency event probability and severity probability in the region acquired by statistical history data. The follows focus on the determination of travel time.

B. Travel Time Model

The traveling time of emergency vehicles mainly affected by two factors: one is time period, the increase of peak travel time delay is obvious; another is spatial capacity, if road can provide enough space (including lane space), this determines whether the social traffic gives way to emergency vehicles. Therefore, the travel time of emergency vehicles can be calculated based on the point of view of time and space limit.

The travel time of emergency vehicles can be divided into two parts: the free flow phase and the delayed phase. When the road traffic reaches a critical level (which is defined as C_{ii}), social vehicles are not able to make way, emergency vehicles are driven only as follows, the travel time is as same as social vehicles.

T_{ij} is defined as the travel time of emergency vehicles from point i to point j with the free flow speed. T_{ij}^{d} represents the delay time of the emergency vehicle from point i to point j at moment d. L is the distance from i to j, Q_{ij}^{d} is the traffic flow at moment d, v_1 is the travel velocity of emergency vehicles in free stream, v_2 is the average traveling speed at moment d for the society vehicles. The emergency vehicle travel time (defined as t_{ij}) can be described as:

$$t_{ij} = T_{ij} + T_{ij}^{d}$$

$$= \frac{L(\frac{Q_{ij}^{d}}{C_{ij}})}{v_1} + \frac{L(\frac{(C_{ij} - Q_{ij}^{d}}{C_{ij}})}{v_2} \quad (8)$$

$$= \frac{L}{C_{ij}}(\frac{Q_{ij}^{d}}{v_1} + \frac{C_{ij} - Q_{ij}^{d}}{v_2})$$

The calculation problem of travel time is transformed into the decision of critical flow C_{ij} . For the road with different levels in different regions, the value of critical flow needs to be obtained through investigation.

IV. CASE ANALYSIS

In order to state the application of built model in emergency management decision-making, this article simulates an emergency case. As shown in figure 1, the road network consists of 16 nodes and 24 ligatures; node A and node B are on behalf of the emergency vehicle hosted sites, the equipped vehicle number are respectively 1 and 2; the emergency vehicles travel time among each nodes is the estimated time drawn from a certain time period based on traffic.

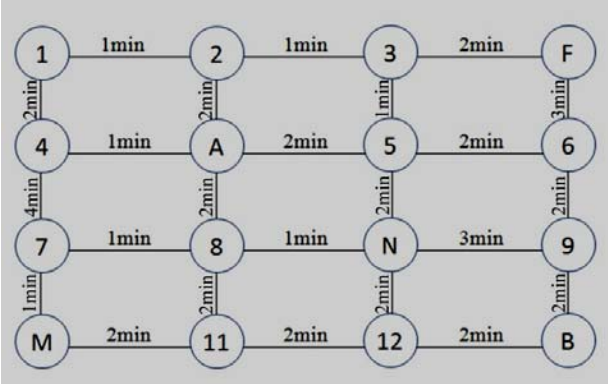

Figure 1. Schematic diagram of the road network.

Assume that the events waiting for response at the same time are located at point M and point N, its response time weights respectively are 0.1 and 0.4; future events may occur at point F, the probability of events occurring is shown in table 1, the weight 0 represents there is no events to occur. Scheduling department needs to determine the optimal vehicle dispatching strategy bases on above conditions.

TABLE I. PROBABILITY DISTRIBUTION OF EMERGENCY OCCURRED AT POINT F

The event weight	0	0.1	0.2	0.3	0.4
Probability of occurrence	0.5	0.2	0.1	0.1	0.1

Suppose the probability of future events by appropriate response is required to reach 90%, according to the probability distribution in table l, it is taken into expression (7) to obtain:

$$\prod_{h=1} (\sum P_h(w)) = 0.5 + 0.2 + 0.1 + 0.1 \geq \alpha = 0.9 .$$

if α is a higher value, future emergencies events are required to get higher response weights, the weight value of incident response time takes corresponding 0.3. If α is taken 0.7, the response time weight of future events takes 0.1. On the basis of travel time as shown in figure 1, the shortest travel time can be calculated from the location of emergency vehicle to each emergency event site, the results are shown in table 2. Respectively, the shortest distance method, model (1) and model (2) are adopted to select scheduling scheme aiming to the above case; the results are shown in table 3.

TABLE II. THE SHORTEST TRAVEL TIME OF RESPONSE VEHICLES

Vehicle site - event occurrence point	Route	The shortest travel time (minutes)
A-M	A-8-7-M	4
A-N	A-8-N	3
A-F	A-5-3-F	5
B-M	B-12-11-M	6
B-N	B-12-N	4
B-F	B-9-6-F	7

It is shown in Table 3, using different methods of scheduling may generate different scheduling schemes. If the future event becomes a reality (the weight is 0.3), the time cost with weight of the shortest distance scheduling is 4.1, in model (1) the weighted time cost is 3.9, in model (2) the weighted time cost is 2.7. Model (2) reduces the overall cost response of the current and future events.

The size of α value affects the scheduling result. If α takes 0, it means not to consider the occurrence of future events, model (2) will transform to model (1); if α take 1, it means which needs the optimal way to prevent the occurrence of future events, the future events and the occurred events are equally important; if α takes a value in (0, 1), it determines the weight of a future event response time, with the increase of α, the vehicle should be inclined to the area to prepare for the serious emergencies.

TABLE III. COMPARISON OF DIFFERENT SCHEDULING SCHEME

Scheduling method	Detailed scheduling method	Calculation result	Optimized method
The shortest distance scheduling	$A \rightarrow M$, $B \rightarrow N$ $A \rightarrow N$, $B \rightarrow M$	4, 4 3, 6	$A \rightarrow M$, $B \rightarrow N$
Scheduling according to model (1)	$A \rightarrow N$, $B \rightarrow M$	3*0.4+6*0.1=1.8	$A \rightarrow N$, $B \rightarrow M$
	$A \rightarrow M$, $B \rightarrow N$	4*0.1+4*0.4=2.0	
	$B \rightarrow M$, $B \rightarrow N$	6*0.1+4*0.4=2.2	
Scheduling according to model (2) ($\alpha = 90\%$)	$A \rightarrow N$, $B \rightarrow M$, $B \rightarrow F$	3*0.4+6*0.1+7*0.3=3.9	$B \rightarrow M$, $B \rightarrow N$, $B \rightarrow F$
	$A \rightarrow M$, $B \rightarrow N$, $B \rightarrow F$	4*0.1+4*0.4+7*0.3=4.1	
	$B \rightarrow M$, $B \rightarrow N$, $A \rightarrow F$	6*0.1+4*0.4+5*0.3=2.5	
Scheduling according to model (2) ($\alpha = 70\%$)	$A \rightarrow N$, $B \rightarrow M$, $B \rightarrow F$	3*0.4+6*0.1+7*0.1=2.5	$A \rightarrow N$, $B \rightarrow M$, $B \rightarrow F$
	$A \rightarrow M$, $B \rightarrow N$, $B \rightarrow F$	4*0.1+4*0.4+7*0.1=2.7	
	$B \rightarrow M$, $B \rightarrow N$, $A \rightarrow F$	6*0.1+4*0.4+5*0.1=2.7	

V. CONCLUSION

Considering that future emergencies have serious uncertainty in distribution probability and severity degree, this paper establishes the mathematical programming model of emergency vehicle scheduling to prevent response demand for emergencies. The created model takes reducing the overall response time cost of current and future events as the objective. Case study shows when the future emergency incident becomes a reality, the model can reduce the total response time cost. Comparing to the relevant research literature, the contribution of this paper mainly has two aspects: first, in the scheduling model the response time cost with the weight of the future emergency incident is introduced, which enriches the content of the emergency vehicle scheduling problem. Second, using the concept of confidence level α, reflects the service level that the whole regional emergency system may reach under different event types at different time, at the same time which reflects the distribution probability of emergencies at each position in the area.

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REFERENCES

[1] Goldberg J B. “Operations research models for the deployment of emergency services vehicles,” EMS Management Journal, 2004,vol.1,no.1, pp.20-39.

[2] Lei H, Cheu R L, and Aldoun R. “Optimal allocation of emergency response service units to cover critical infrastructures with time dependent service demand and travel time,” The 88th Annum Meeting of the Transportation Research Board, Washington, DC: National Research Council, 2009, pp. 74-84.

[3] Budge S, Ingolfsson A, and Zerom D, "Empirical analysis of ambulance travel times: the case of Calgary emergency medical services," Management Science, 2010, vol.56, no.4. pp.716-723.

[4] Huang Y, Fan Y, and Cheu R L, "Optimal allocation of multiple emergency service sources for critical transportation infrastructure protection," The TRB 86th Annual Meeting Compendium of Papers CD-ROM, Washington, DC: National Research Council, 2007:0028.

[5] Pal R and Sinha K, "Simulation model for evaluating and improving effectiveness of freeway service patrol programs," Journal of Transportation Engineering, 2002, vol.128, no. 4, pp.355-365.

[6] Haghani A, Huijun Hu, and Qiang Tian, "An optimization model for real time emergency vehicle dispatching and routing," The TRB 82nd Annual Meeting Compendium of Papers CD-ROM, Washington, DC: National Research Council, 2003: 0710.

[7] Ozbay K, Weihua Xiao, and Cem Iyigun, "Probabilistic programming models for response vehicle dispatching and resource allocation in traffic incident management," The TRB 83rd Annual Meeting Compendium of Papers CD-ROM, Washington, DC: National Research Council, 2004: 0014.

[8] Yang X G and Peng C L, "Travel reliability evaluation of emergency vehicles based on multilevel fuzzy synthesis judgment method," China Civil Engineering Journal, 2007, vol. 40, no.1, pp.79-84.

[9] Yong Gu and Xinping Yan, "A dispatch model of emergency vehicles based on stochastic travel time," The 8th International Conference of Chinese Logistics and Transportation Professionals-Logistics: The Emerging Frontiers of Transportation and Development in China, Chengdu, 2008, pp. 1565-1570.

[10] Yang X K, Gong J, and Cao J, "Dynamic link travel time for evacuation route in all emergency of Olympic Games," Journal of Beijing University of Technology, 2007, vol. 33, no.7, pp.702-706.

[11] Liu Y, Zheng L L, and Chang Y T, "Travel time model of emergency vehicles on urban road," Computer and Communications, 2008, vol. 26, no. 5, pp. 30-33.

[12] Liu Y, Shen H Z, and Peng G X, "Travel time model of emergency vehicle based on BP network," Journal of Wuhan University of Technology (Transportation Science＆Engineering), 2007, vol. 31no.6, pp. 973-975.

[13] Zhao H T, Wang Y P, and Wang J X, "Study on optimization model for freeway emergency vehicle dispatching," Journal of Jilin University (Engineering and Technology Edition), 2006, vol. 36, no.3, pp. 336-339.