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Abstract: Owing to the rapid development of emergency rescue transportation cities and the frequent emergencies, demand for emergency rescue is increasing drastically. How to select an emergency rescue route quickly and shorten the rescue travel time under the condition of limited urban road resources is of great significance. Based on the characteristics analysis of emergency rescue, this paper classified priority levels of different emergency traffic, moreover, its travel time were also analyzed with three scenarios: (1) emergency rescue vehicles no encountering queues, (2) encountered queues but lanes available, (3) Encountered queues with no available lanes. Related case study shows that model in this paper can effectively shorten travel time of emergency traffic in the route and improve its efficiency.

Keywords: Emergency rescue traffic; Frequent emergencies; Limited urban road resources; Priority levels; Deep characteristics analysis; Travel time

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1 Introduction

Emergency rescue traffic mainly includes medical ambulances, natural disaster rescue vehicles, fire trucks, police vehicles, engineering rescue vehicles, municipal repair vehicles (electricity, water supply and transportation), traffic accident tractors, evacuation vehicles, emergency rescue vehicles and other vehicles that are performing special emergency rescue missions in the cities (Huang et al., 2018).

In the actual emergency response process, these vehicles cannot make a reasonable judgment on the optimal path selection because the traffic information along the line cannot be grasped in real time (Wang et al., 2018). In addition, there is no special driving route in the city road, and the space limitation of the traditional traffic information collection method, the signal priority control strategy along the intersection cannot respond to it in time. Especially for the congested roads, the emergency rescue vehicles are even submerged in the traffic jams, which makes the rescue response work cannot be performed in time (Zhu et al., 2008).

For the emergency department, the choice of the best route and the travel time of the emergency vehicle play a very important role. How to accurately predict the travel time of emergency vehicles has become a very important issue. Some foreign scholars have done some research on the calculation method of emergency vehicle travel time. Based on the observations on the spot, Louisell (2005) establishes a method for predicting the travel time of emergency vehicles based on the emergency priority signal. Rice (2001) combines the previous data to predict the travel time of the expressway section. After obtaining relevant traffic information, he uses the linear correlation of the travel time data of the emergency rescue vehicle to predict the current travel time in the past time series.Jenelius (2015) uses low permeability to detect vehicle data for vehicle travel time estimation. Cebecauer (2018) proposes a method for real-time network traffic management, vehicle routing and information provision and using low-frequency detection vehicle data for comprehensive urban road network travel time prediction. Westgate (2016) proposes a regression method to estimate the ambulance travel time distribution between any two locations in the road network by modeling the travel level and considering the dependencies between travel times of the various road segments. Trab's (2018) negotiation mechanism and its dynamic calculation of availability and compatibility constraints are well suited to the decision of the shortest route. Haghani (2004) proposes a model that uses real-time travel time information and helps emergency vehicle dispatchers assign responsive vehicles and pass non-congested routes. Zhang's (2016) emergency rescue system uses the travel time data of emergency rescue vehicles for nearly 4 years and proposes a utility-based model to quantify the travel time performance of emergency vehicles. Peter (2017) proposed an algorithm that identifies the vehicle's acceleration and position data to predict traffic conditions and better provide the best path for the vehicle to travel. Wang (2013) establishes a travel time estimation model for emergency vehicles under preemption control conditions, which including path preemption, intersection preemption, and section preemption. The results show that the model can accurately estimate the travel time of emergency vehicles. Musolino (2013) proposes a framework for dynamically designing emergency vehicle routes, whose modelling components forecast the short-term travel time. Now there is a method based on VANET algorithm to improve the accuracy of location information and ensure driving safety (Prado et al., 2018; Zhou et al., 2018). The model proposed by Jordan (2015) uses vehicles to send messages to infrastructure communications and uses shockwave theory to determine when each crosspoint signal preemption should be preempted. This allows emergency vehicles to pass through closely spaced signalized intersections as quickly as possible, reducing the travel time of emergency vehicles. The RFID IoT system proposed by Sourour (2018) is able to find the shortest path among them.

Domestic scholars have also spared no effort in this area. Yang (2001) mainly analyzes the travel time of emergency rescue vehicles from the perspective of traffic flow density, and divides the forecast of the travel time of emergency rescue vehicles into two parts: the normal travel time and the delay time of emergency rescue vehicles. Guo (2005) divides the travel time into three parts: free travel time, queuing time and time through the intersection, and established the corresponding road travel time prediction model. Based on the driving characteristics of the emergency rescue vehicle and the influencing factors of the travel time, Shen (2007) uses the wave theory to establish the real-time section travel time prediction model of the emergency rescue vehicle and gives the calibration method of the model, combining the actual data calibration model parameters and the test model accuracy. Xiang (2018) proposes an algorithm that enables high-capacity embedding. Yang (2006) introduces the concept of reliability to the model of urban road emergency rescue vehicle travel time, and established a meta-cell transmission model to analyze the traffic conditions of emergency vehicles under non-signal priority conditions. Many researchers focus on using neural networks to conduct research, which inevitably brings the noise of artificial class into classification process. Zeng (2018) proposes a new algorithm based on neural network. The framework of the global positioning system proposed by Zhu (2018) can effectively cut the trajectory of the vehicle, and it has important reference significance for the vehicle to select the shortest path to reach the intersection. Liu (2008) applies the BP neural network model to select the two key factors of driving length and departure time to solve the problem of the travel time of the emergency rescue vehicle and establish the calculation model of the emergency vehicle travel time. In order to solve the problem of relying on a large amount of data, Sun (2018) proposes a thought that semi-supervised and active learning of big data is used to complete the domain adaptation task, and achieve the performance equivalent to using all data points. On the basis of analyzing the characteristics of the mixed traffic flow of emergency vehicles, Zhao (2015) adds the vehicle type and introduced two parameters: the emergency vehicle impact area and the general vehicle yield probability. He establishes a two-lane traffic flow cellular automaton model by modifying the vehicle lane change and speed update rules. Finally, MATLAB is used for numerical simulation to generate emergency vehicle travel time under different traffic density conditions.

2 Analysis of emergency rescue traffic characteristics

For different types of emergencies, emergency vehicles are divided into medical ambulances, natural disaster rescue vehicles, fire trucks, police vehicles, engineering rescue vehicles, traffic accident tractors, evacuation vehicles, and emergency rescue vehicles.

Based on a comprehensive analysis of the frequency and the degree of damage of the emergencies, the risk matrix of the risk assessment method is used to indicate the relationship between the frequency and the degree of damage of the emergencies, as shown in Figure 1. The matrix of the emergency rescue vehicle priority level can be obtained through the emergency assessment matrix and the types of emergency rescue vehicles corresponding to the emergencies, as shown in Figure 2.

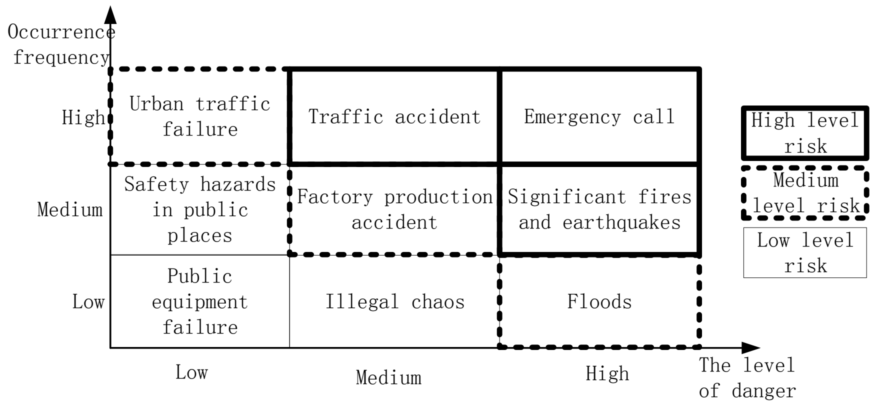

Figure 1 Emergency risk assessment matrix

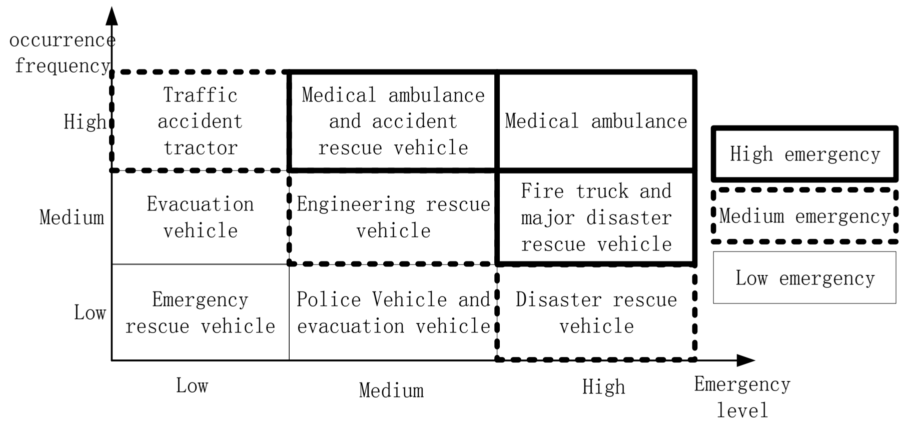

Figure 2 Emergency vehicle priority map

Considering the frequency and urgency of emergency vehicle attendance, the above eight types of emergency rescue vehicles are divided into three categories according to the emergency priority level. The first category is the highest priority, including medical ambulances, natural disaster rescue vehicles, and fire trucks. The second category is medium priority, including police vehicles, engineering rescue vehicles, and traffic accident tractors. The third category is low-level priority, including evacuation vehicles and emergency rescue vehicles (Zhu et al., 2002).

For different types of emergency vehicles, based on the emergency priority level of the emergency rescue vehicles, the emergency factors are calculated based on the road factors (Liu et al., 2009). Considering the types of emergency rescue vehicles, signal timing of intersections, road grades, and fleet size, the priority is determined. The priority of the emergency rescue vehicle is converted into a unified dimension, and the normalization process is converted into a priority value, which is between 0 and 1 [78], as shown in equation (1).

$$P=\left[\alpha F\text{-}\beta T+\gamma t+\lambda D+\left(1\text{-}\alpha\text{-}\beta\text{-}\gamma\text{-}\lambda\right)G\right] \qquad (1)$$

Where: F is the priority index of different types of emergency rescue vehicles, and T is the ratio of the target travel time of the emergency rescue vehicle to the estimated time passing through the intersection, t is the green light duration residual rate of the phase, D is the ratio of the driving speed to the free flow speed under different road grades, and G is the relative value of the fleet size, α、β、γ、λ are weights in different aspects, the values are between 0 and 1, and the sum of the values is 1.

According to the classification of emergency priority levels of emergency rescue vehicles, the priority types and priority indexes of emergency vehicles are summarized as shown in Table 1.

Table 1 Priority index of different emergency vehicles

Emergency vehicle type	Medical ambulance Natural disaster rescue vehicle Fire truck	Police vehicle Engineering rescue vehicle Traffic accident tractor	Evacuation vehicle Emergency rescue vehicle
Priority	1	2	3
Priority index (F)	0.8~1	0.5~0.7	0.1~0.4

According to the road grade, the types of emergency rescue vehicles priority are shown in Table 2.

Table 2 Priority levels for different road grades

Road grade	Express road	Main trunk road	Minor trunk road	Branch road
Travel speed interval value （km/h）	60- 100	40 -60	30 - 50	20-40
Priority	1	2	3	4
Ratio of travel speed to free flow speed (D)	0.80	0.67	0.60	0.50

3 Travel time model of emergency rescue traffic in 3 scenarios

After receiving the distress signal, the emergency rescue vehicle may have multiple paths between its location and the rescue location. The impedance values (delay) of the different paths are different, and these paths constitute a path set. The path selection is now analyzed by the model of travel time of the travel about emergency rescue vehicle. The travel time of an emergency rescue vehicle includes the travel time of the road and the passing time of the intersection, and the passing time at the intersection is a key factor affecting the travel time of the emergency rescue vehicle. The model about time passing through the intersection of emergency rescue vehicle mainly considering the following three situations: 1 Emergency rescue vehicles do not encounter queues; 2 encountered queues but available lanes (right turn lane or opposite lane); 3 encountered queues with no available lanes.

3.1 Emergency rescue vehicles no encountering queues

The situation that the emergency rescue vehicle do not encounter the queue is shown in Figure 3. At this time, the model about travel time of the emergency rescue vehicle passing through the intersection is:

$$t_c = a \times \frac{L}{v\left(1-\frac{k_t}{k_j}\right)} \quad (2)$$

Where: t_c is the travel time of emergency vehicles passing through intersections, L is the length of intersection, v is the speed of emergency vehicles passing through intersections, k_t is the traffic density function at the intersection, k_j is the blocking density at the intersection, a is the model correction factor (least squares calibration).

Through Equation 3.15, it is possible to calculate the time when the emergency rescue vehicle passes through the intersection without being queued.

$$k_t = \frac{N - N_w}{L - L_w} \quad (3)$$

Where: L_w is the queue length at the intersection and $L_w = \frac{N_w}{k_j}$, N_w is the number of vehicles queued at the intersection.

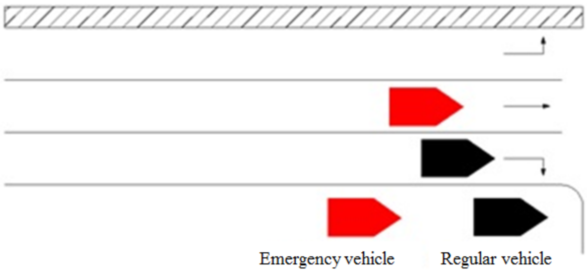

Figure 3 Emergency rescue vehicles no encountering queues

3.2 Encountered queues but lanes available

The situation that encountered queues but available lanes is shown in figure 4. At this time, the model about travel time of the emergency rescue vehicle passing through the intersection is:

$$t_c = b_1 \times \frac{L - L_w}{v\left(1 - \frac{k_t}{k_j}\right)} + b_2 \times \frac{L_w}{v} \quad (4)$$

Where: t_c is the travel time of emergency vehicles passing through intersections, L is the length of intersection, L_w is the queue length at the intersection, v is the speed of emergency vehicles passing through intersections, k_t is the traffic density function at the intersection, k_j is the blocking density at the intersection, b_1、b_2 are the model correction factor (least squares calibration).

Through Equation 2, it is possible to calculate the time when the emergency rescue vehicle encounters the queue but has access to the lane and k_t is the traffic density function the intersection.

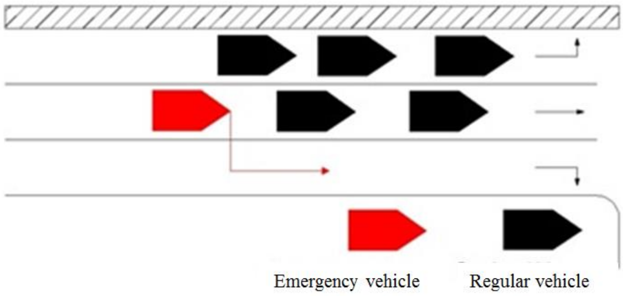

Figure 4 Encountered queues but lanes available

3.3 Encountered queues with no available lanes

The situation that Encountered queues with no available lanes is shown in figure 5. At this time, the model about travel time of the emergency rescue vehicle passing through the intersection is:

$$t_c = c_1 \times \frac{L - L_w}{v\left(1 - \frac{k_t}{k_j}\right)} + c_2 \times \frac{L_w}{s} + \tau \quad (5)$$

Where: t_c is the travel time of emergency vehicles passing through intersections, L is the length of intersection, L_w is the queue length at the intersection, v is the speed of emergency vehicles passing through intersections, k_t is the traffic density function at the intersection, k_j is the blocking density at the intersection, s is the rate of saturated flow at the intersection, τ is the duration of waiting for the green light, c_1、c_2 are the model correction factor (least squares calibration).

The rate of saturated flow s is a converted saturated flow rate, that is, an hourly maximum flow rate converted according to the duration of a specific maximum flow rate (generally 15 minutes). The duration of waiting for the green light refers to the time when emergency rescue vehicles are waiting in line to wait for the right of this entrance (green light) and k_t is the traffic density function the intersection. Equation

3 can be used to calculate the time that the emergency rescue vehicle passes through the intersection if it encounters a queue and has no available lanes.

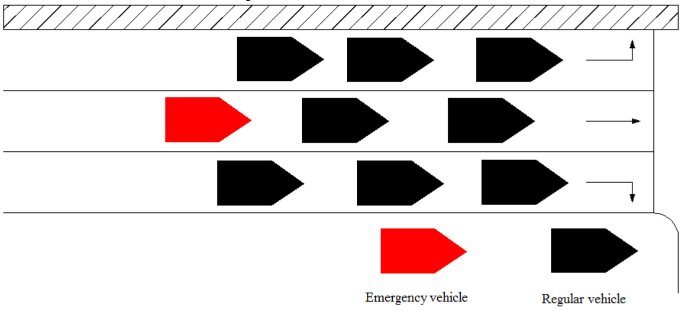

Figure 5 Encountered queues and no available lanes

3.4 Travel time of emergency rescue path

In the path between starting point and ending point, the main factors affecting the travel time of emergency rescue vehicles are the flow, speed and density of the background traffic flow and the flow, speed, density and other factors of the traffic flow have a certain impact on the travel time of the emergency rescue vehicle. The increase in density and traffic volume will result in a decrease in the speed of emergency rescue vehicles, resulting in an increase in travel time. Assume that the relationship of volume and density is consistent with the Greenshileds model. Here, the model is modified to obtain the relationship of speed and density as follows.

$$v = v_{min} + \left(v_f - v_{min}\right)\left[1 - \left(\frac{k_t}{k_j}\right)^{\alpha}\right]^{\beta} \quad (6)$$

Where: v is the driving speed, v_f is the expedite speed (speed of free flow), v_{min} is the minimum speed, k_t is the traffic density function at the intersection, k_j is the blocking density at the intersection, α、β are the model correction factor (least squares calibration). The minimum speed v_{min} introduced in the model is to limit the situation in which the vehicle is occupied by the lane when the emergency rescue vehicle travels. The model about travel time of the emergency rescue vehicle based on Equation 4 is as follows:

$$t = \frac{L}{v} = \frac{L}{v_{min} + \left(v_f - v_{min}\right)\left[1 - \left(\frac{k_t}{k_j}\right)^{\alpha}\right]^{\beta}} \quad (7)$$

Where: L is the length of intersection and the rest of the symbols are the same as above. According to the real-time data brought into the model, the travel time of the emergency rescue vehicle on the road can be obtained.

Therefore, when the emergency rescue vehicle path is selected with the shortest travel time, we should use the model to analyze the path in the optimal path according to the real-time road traffic conditions and the influence of the background traffic flow. Thus, the optimal path with the shortest travel time is selected for the emergency rescue vehicle to ensure the traffic efficiency.

4 Case study

This paper focuses on some of the arterial roads of Shizishan Regional Road Network in Suzhou City, Jiangsu Province. The path composed of three intersections of Tayuan Road-Shishan Road, Shishan Road-Binhe Road and Binhe Road-Dengwei Road was selected as a case to simulate the rescue route of emergency rescue traffic.

The road network selected in the case is located in Huqiu District, Suzhou City. The geographical position is superior and the traffic is prosperous. The selected intersection is also located in the central part of the area. Therefore, it has a certain representativeness and has certain reference significance for other studies.

The channelization of each intersection is shown in Figure 6.

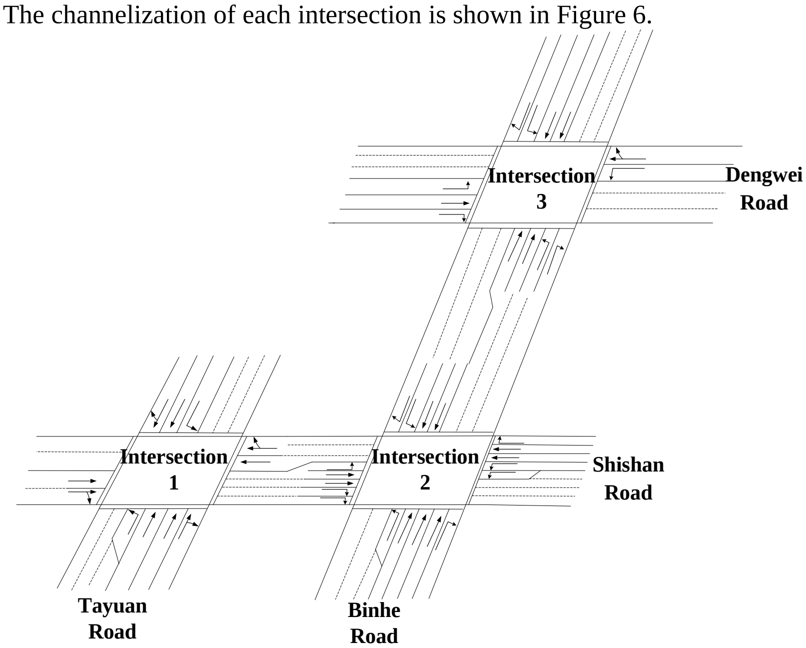

Figure 6 Channelization map of cases

The traffic volume used in the case is the peak hourly traffic from 17:00-18:00 at night, and is converted to the standard vehicle equivalent, so the corresponding path traffic is the evening peak traffic (pcu/h) data. Emergency rescue path, traffic data and signal timing scheme are shown in Table 3, Table 4 and Figure 7.

Table 3 Traffic volume data of evening peak (pcu/h)

	East	West	South	North	Emergency path	Emergency traffic volume
Intersections 1	762	828	2167	2288	Turn right in south approach	50

Intersections 2	1355	1027	1868	961	Turn left in east approach	50
Intersections 3	1264	1190	1960	1440	Go through in south approach	50

Table 4 Traffic volume data of case study intersections (pcu/h)

Intersections	Entrance lane	Volume of turning left	Volume of going straight	Volume of turning right
Tayuan Road-Shishan Road	North	556	1220	512
	East	0	604	158
	South	542	1126	499
	West	0	620	208
Shishan Road-Binhe Road	North	221	480	260
	East	156	843	356
	South	456	1050	362
	West	123	668	236
Binhe Road-Dengwei Road	North	330	720	390
	East	516	548	200
	South	595	961	404
	West	412	385	393

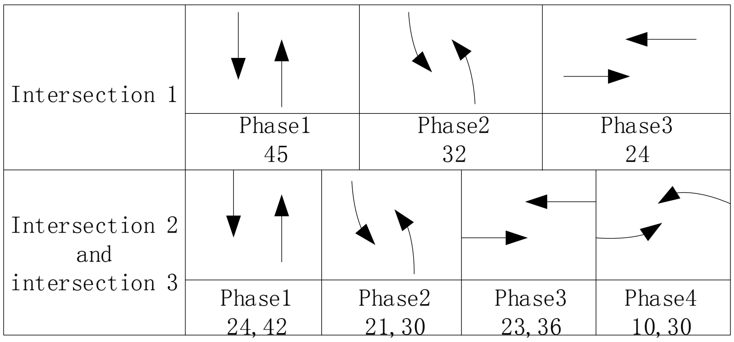

Figure 7 Map of signal timing scheme

In the example simulation, 10 sets of OD pairs are randomly selected for simulation analysis. The simulation is under the scenario of emergency rescue traffic no encountering queues, encountering queues with available lanes, and encountering queued with unavailable lanes. The emergency rescue path will turn right to Tayuan Road-Shishan Road, drive along Shishan Road, turn left into Binhe Road, and then go straight along Binhe Road to Dengyu Road. The travel time detectors are set in the emergency rescue lanes and the total path, and the length detectors are queued to collect emergency rescue related parameters. In the case of the same traffic volume, the simulation time is set to 3600 seconds, and the simulation run is 10 times. The simulation analysis is carried out for three scenarios of emergency rescue traffic no encountering queues, encountering queues with available lanes, and encountering queued with unavailable lanes.

Through the analysis of the statistical results of the simulation of the three scenarios, the emergency travel time of the entire path is shown in Table 5.

Table 5 Simulation evaluation results

Control scheme / **Evaluation results**		**Travel time（s）**
Emergency rescue vehicles no encountering queues	Intersection 1	44.6
	Intersection 2	60.6
	Intersection 3	25.8
	Average	43.7
Encountered queues but lanes available	Intersection 1	72.8
	Intersection 2	84.0
	Intersection 3	47.5
	Average	68.1
Encountered queues with no available lanes	Intersection 1	94.4
	Intersection 2	102.0
	Intersection 3	66.0
	Average	87.5

5 Conclusion

By analyzing the simulation evaluation results obtained above, the distribution time of the emergency rescue vehicles in the three scenarios can be obtained, as shown in Figure 8.Also, through the above data, the box plot of the travel time in three scenarios is drawn, which is shown in Figure 9.

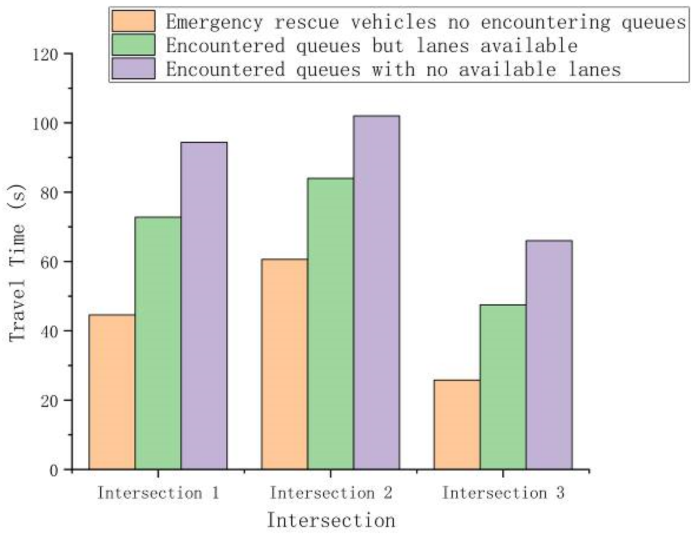

Figure 8 Travel time distribution of emergency rescue vehicles in three scenarios

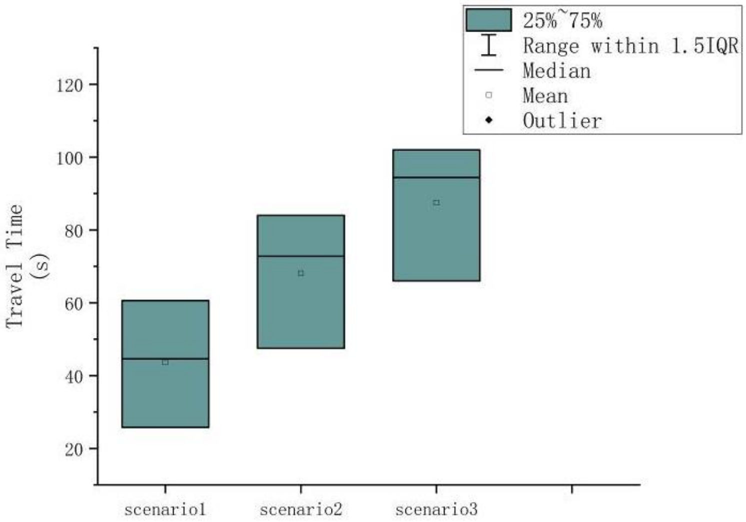

Figure 9 Box plot of travel time in three scenarios

It can be seen that:

(1) The travel time of emergency vehicles is increased in the following order: Emergency rescue vehicles no encountering queues, Encountered queues but lanes available, Encountered queues with no available lanes.

(2) When the emergency rescue vehicles no encountering queues, the travel time of the emergency rescue vehicle is significantly less than the other two cases, which is 35.8% less than the average of scenes that encountered queues but lanes available, which is 50.1% less than the average of scenes that Encountered queues with no available lanes.

(3) For the analysis of the latter two scenarios, it can be found that the average travel time of the former can be reduced by 22.2%, the maximum can be reduced by 53.4%, and the minimum can be reduced by 17.6%.Therefore, from this study, we found that when an emergency vehicle travels, if it does not meet the queue, it can reach the destination as soon as possible, and gain valuable time for emergency rescue. We can conclude that the implementation of priority signal control for emergency rescue vehicles can shorten the delay of emergency rescue vehicles, reduce travel time, and significantly improve rescue efficiency. In addition, for the selection of emergency rescue paths, the main trunk roads and minor trunk roads with large space available for road resources should be selected as much as possible, and the travel time can be greatly reduced.

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