

## Deep characteristics analysis on travel time of emergency traffic

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**DOI**

[10.1504/IJCSE.2020.107271](https://doi.org/10.1504/IJCSE.2020.107271)

**Publication date**

2020

**Document Version**

Accepted author manuscript

**Published in**

International Journal of Computational Science and Engineering

**Citation (APA)**

Yao, J., Dai, Y., Ni, Y., Wang, J., & Zhao, J. (2020). Deep characteristics analysis on travel time of emergency traffic. *International Journal of Computational Science and Engineering*, 22(1), 162-169. <https://doi.org/10.1504/IJCSE.2020.107271>

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1           **Deep characteristics analysis on travel time of**  
2           **emergency traffic**

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

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

33          **Reference** to this paper should be made as follows: Yao, J., Dai, Y., Ni, Y.,  
34          Wang, J., and Zhao, J. (2019) ‘Deep characteristics analysis on travel time of  
35

1 emergency traffic’ , Int. J.Computational Science and Engineering, Vol. \*\*,  
2 No. \*\*, pp.\*\* - \*\*\*.

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30 This paper is a revised and expanded version of a paper entitled ‘Deep characteristics  
31 analysis on travel time of emergency traffic’ presented at 5th International Conference  
32 on Artificial Intelligence and Security (ICAIS 2019), New York, USA, 26 - 28 July  
33 2019.

## 34 1 Introduction

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

40 In the actual emergency response process, these vehicles cannot make a  
41 reasonable judgment on the optimal path selection because the traffic information  
42 along the line cannot be grasped in real time (Wang et al., 2018). In addition, there is  
43 no special driving route in the city road, and the space limitation of the traditional  
44 traffic information collection method, the signal priority control strategy along the  
45 intersection cannot respond to it in time. Especially for the congested roads, the

1 emergency rescue vehicles are even submerged in the traffic jams, which makes the  
2 rescue response work cannot be performed in time (Zhu et al., 2008).

3 For the emergency department, the choice of the best route and the travel time of  
4 the emergency vehicle play a very important role. How to accurately predict the travel  
5 time of emergency vehicles has become a very important issue. Some foreign scholars  
6 have done some research on the calculation method of emergency vehicle travel time.  
7 Based on the observations on the spot, Louisell (2005) establishes a method for  
8 predicting the travel time of emergency vehicles based on the emergency priority  
9 signal. Rice (2001) combines the previous data to predict the travel time of the  
10 expressway section. After obtaining relevant traffic information, he uses the linear  
11 correlation of the travel time data of the emergency rescue vehicle to predict the  
12 current travel time in the past time series. Jenelius (2015) uses low permeability to  
13 detect vehicle data for vehicle travel time estimation. Cebecauer (2018) proposes a  
14 method for real-time network traffic management, vehicle routing and information  
15 provision and using low-frequency detection vehicle data for comprehensive urban  
16 road network travel time prediction. Westgate (2016) proposes a regression method to  
17 estimate the ambulance travel time distribution between any two locations in the road  
18 network by modeling the travel level and considering the dependencies between travel  
19 times of the various road segments. Trab's (2018) negotiation mechanism and its  
20 dynamic calculation of availability and compatibility constraints are well suited to the  
21 decision of the shortest route. Haghani (2004) proposes a model that uses real-time  
22 travel time information and helps emergency vehicle dispatchers assign responsive  
23 vehicles and pass non-congested routes. Zhang's (2016) emergency rescue system  
24 uses the travel time data of emergency rescue vehicles for nearly 4 years and proposes  
25 a utility-based model to quantify the travel time performance of emergency vehicles.  
26 Peter (2017) proposed an algorithm that identifies the vehicle's acceleration and  
27 position data to predict traffic conditions and better provide the best path for the  
28 vehicle to travel. Wang (2013) establishes a travel time estimation model for  
29 emergency vehicles under preemption control conditions, which including path  
30 preemption, intersection preemption, and section preemption. The results show that  
31 the model can accurately estimate the travel time of emergency vehicles. Musolino  
32 (2013) proposes a framework for dynamically designing emergency vehicle routes,  
33 whose modelling components forecast the short-term travel time. Now there is a  
34 method based on VANET algorithm to improve the accuracy of location information  
35 and ensure driving safety (Prado et al., 2018; Zhou et al., 2018). The model proposed  
36 by Jordan (2015) uses vehicles to send messages to infrastructure communications  
37 and uses shockwave theory to determine when each crosspoint signal preemption  
38 should be preempted. This allows emergency vehicles to pass through closely spaced  
39 signalized intersections as quickly as possible, reducing the travel time of emergency  
40 vehicles. The RFID IoT system proposed by Sourour (2018) is able to find the  
41 shortest path among them.

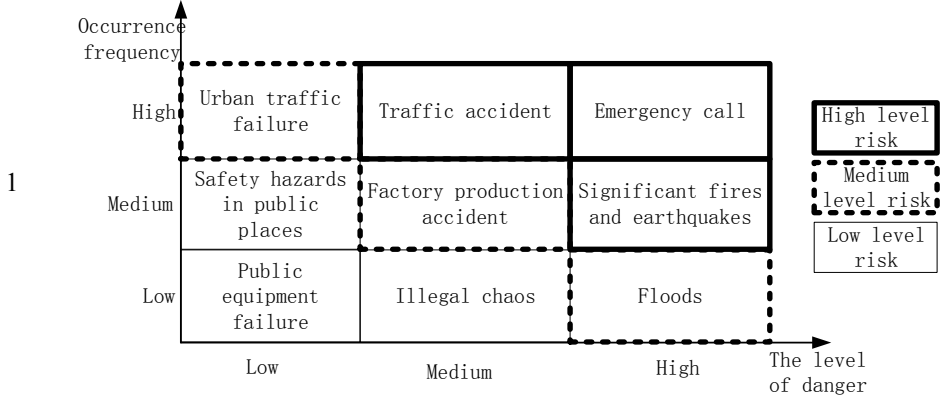
42 Domestic scholars have also spared no effort in this area. Yang (2001) mainly  
43 analyzes the travel time of emergency rescue vehicles from the perspective of traffic  
44 flow density, and divides the forecast of the travel time of emergency rescue vehicles  
45 into two parts: the normal travel time and the delay time of emergency rescue vehicles.  
46 Guo (2005) divides the travel time into three parts: free travel time, queuing time and  
47 time through the intersection, and established the corresponding road travel time

1 prediction model. Based on the driving characteristics of the emergency rescue  
2 vehicle and the influencing factors of the travel time, Shen (2007) uses the wave  
3 theory to establish the real-time section travel time prediction model of the emergency  
4 rescue vehicle and gives the calibration method of the model, combining the actual  
5 data calibration model parameters and the test model accuracy. Xiang (2018)  
6 proposes an algorithm that enables high-capacity embedding. Yang (2006) introduces  
7 the concept of reliability to the model of urban road emergency rescue vehicle travel  
8 time, and established a meta-cell transmission model to analyze the traffic conditions  
9 of emergency vehicles under non-signal priority conditions. Many researchers focus  
10 on using neural networks to conduct research, which inevitably brings the noise of  
11 artificial class into classification process. Zeng (2018) proposes a new algorithm  
12 based on neural network. The framework of the global positioning system proposed  
13 by Zhu (2018) can effectively cut the trajectory of the vehicle, and it has important  
14 reference significance for the vehicle to select the shortest path to reach the  
15 intersection. Liu (2008) applies the BP neural network model to select the two key  
16 factors of driving length and departure time to solve the problem of the travel time of  
17 the emergency rescue vehicle and establish the calculation model of the emergency  
18 vehicle travel time. In order to solve the problem of relying on a large amount of data,  
19 Sun (2018) proposes a thought that semi-supervised and active learning of big data is  
20 used to complete the domain adaptation task, and achieve the performance equivalent  
21 to using all data points. On the basis of analyzing the characteristics of the mixed  
22 traffic flow of emergency vehicles, Zhao (2015) adds the vehicle type and introduced  
23 two parameters: the emergency vehicle impact area and the general vehicle yield  
24 probability. He establishes a two-lane traffic flow cellular automaton model by  
25 modifying the vehicle lane change and speed update rules. Finally, MATLAB is used  
26 for numerical simulation to generate emergency vehicle travel time under different  
27 traffic density conditions.

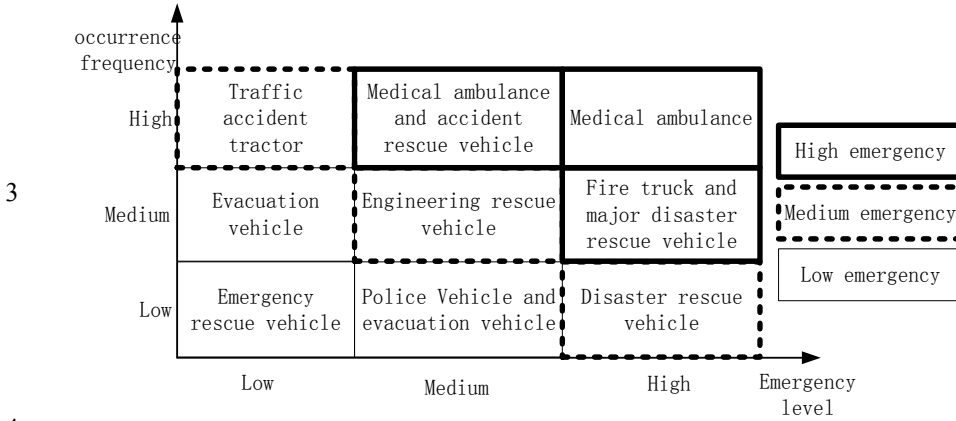
## 28 **2 Analysis of emergency rescue traffic characteristics**

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

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



2 **Figure 1** Emergency risk assessment matrix



4 **Figure 2** Emergency vehicle priority map

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

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

19 
$$P = \left[ \alpha F - \beta T + \gamma t + \lambda D + (1 - \alpha - \beta - \gamma - \lambda) G \right] \quad (1)$$

1           Where: F is the priority index of different types of emergency rescue vehicles,  
 2 and T is the ratio of the target travel time of the emergency rescue vehicle to the  
 3 estimated time passing through the intersection, t is the green light duration residual  
 4 rate of the phase, D is the ratio of the driving speed to the free flow speed under  
 5 different road grades, and G is the relative value of the fleet size,  $\alpha$ 、 $\beta$ 、 $\gamma$ 、 $\lambda$  are  
 6 weights in different aspects, the values are between 0 and 1, and the sum of the values  
 7 is 1.

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

11           **Table 1** Priority index of different emergency vehicles

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

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

14           **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        |

### 15   **3 Travel time model of emergency rescue traffic in 3 scenarios**

16           After receiving the distress signal, the emergency rescue vehicle may have  
 17 multiple paths between its location and the rescue location. The impedance values  
 18 (delay) of the different paths are different, and these paths constitute a path set. The  
 19 path selection is now analyzed by the model of travel time of the travel about  
 20 emergency rescue vehicle. The travel time of an emergency rescue vehicle includes  
 21 the travel time of the road and the passing time of the intersection, and the passing

1 time at the intersection is a key factor affecting the travel time of the emergency  
 2 rescue vehicle. The model about time passing through the intersection of emergency  
 3 rescue vehicle mainly considering the following three situations: 1 Emergency rescue  
 4 vehicles do not encounter queues; 2 encountered queues but available lanes (right turn  
 5 lane or opposite lane); 3 encountered queues with no available lanes.

### 6 3.1 Emergency rescue vehicles no encountering queues

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

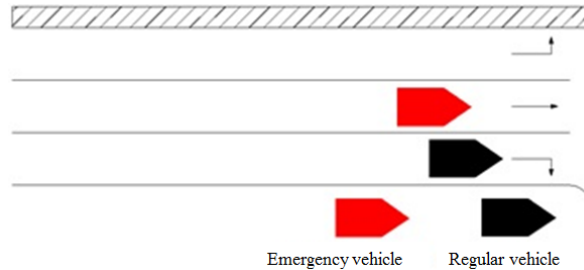
$$10 \quad t_c = a \times \frac{L}{v \left( 1 - \frac{k_t}{k_j} \right)} \quad (2)$$

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

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

$$17 \quad k_t = \frac{N - N_w}{L - L_w} \quad (3)$$

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



20  
 21 **Figure 3** Emergency rescue vehicles no encountering queues

### 22 3.2 Encountered queues but lanes available

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



1

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

2

3

4

5

6

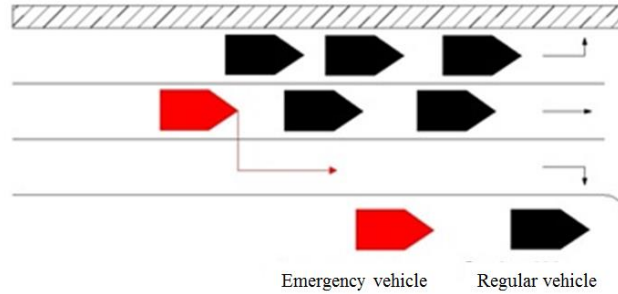
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8

9

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.



10

11

**Figure 4** Encountered queues but lanes available

12

### 3.3 Encountered queues with no available lanes

13

14

15

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:

16

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

17

18

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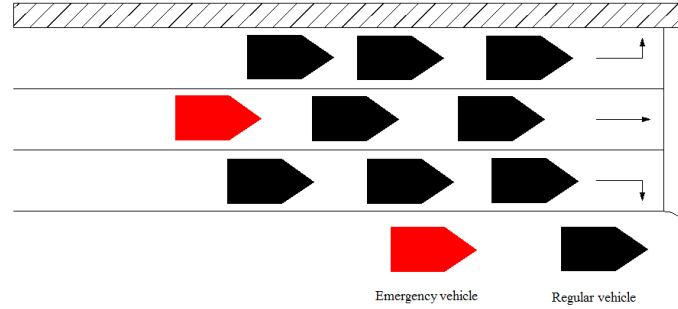
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27

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,  $\tau$  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

1 3 can be used to calculate the time that the emergency rescue vehicle passes through  
 2 the intersection if it encounters a queue and has no available lanes.



3  
4

**Figure 5** Encountered queues and no available lanes

### 5 3.4 Travel time of emergency rescue path

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

$$14 \quad v = v_{min} + (v_f - v_{min}) \left[ 1 - \left( \frac{k_t}{k_j} \right)^\alpha \right]^\beta \quad (6)$$

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

$$22 \quad t = \frac{L}{v} = \frac{L}{v_{min} + (v_f - v_{min}) \left[ 1 - \left( \frac{k_t}{k_j} \right)^\alpha \right]^\beta} \quad (7)$$

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

26 Therefore, when the emergency rescue vehicle path is selected with the shortest  
 27 travel time, we should use the model to analyze the path in the optimal path according

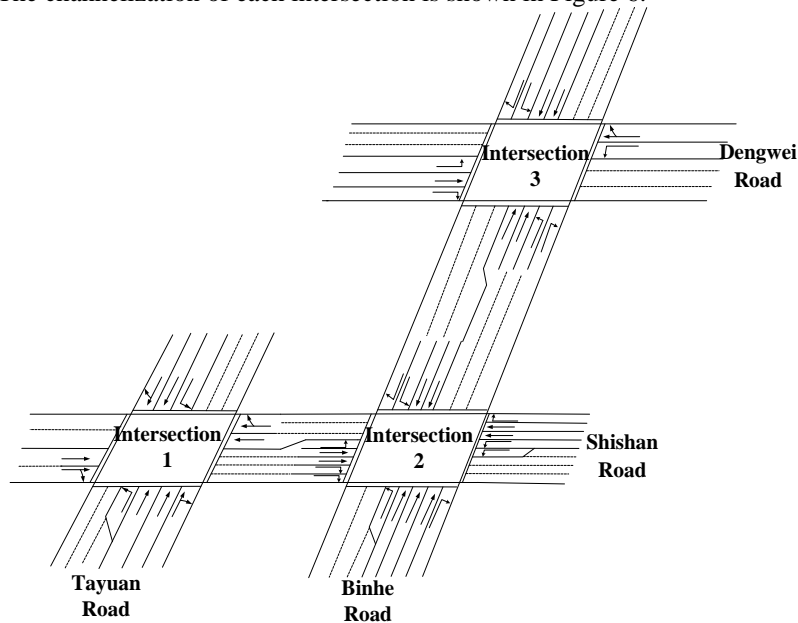
1 to the real-time road traffic conditions and the influence of the background traffic  
 2 flow. Thus, the optimal path with the shortest travel time is selected for the  
 3 emergency rescue vehicle to ensure the traffic efficiency.

#### 4 4 Case study

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

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

13 The channelization of each intersection is shown in Figure 6.



14  
 15 **Figure 6** Channelization map of cases

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

20 **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                       |

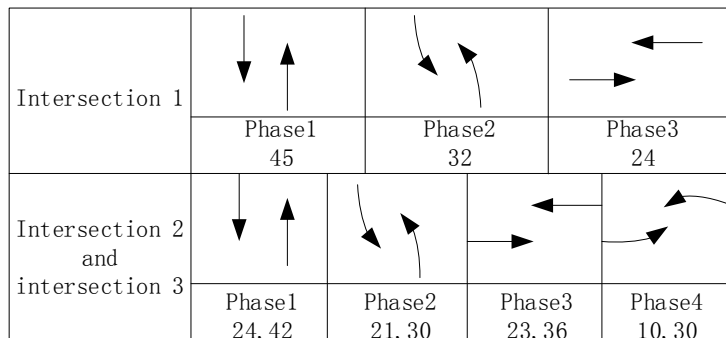
|                 |      |      |      |      |                              |    |
|-----------------|------|------|------|------|------------------------------|----|
| Intersections 2 | 1355 | 1027 | 1868 | 961  | Turn left in east approach   | 50 |
| Intersections 3 | 1264 | 1190 | 1960 | 1440 | Go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

1  
2

**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                     |

3



4  
5

**Figure 7** Map of signal timing scheme

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

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

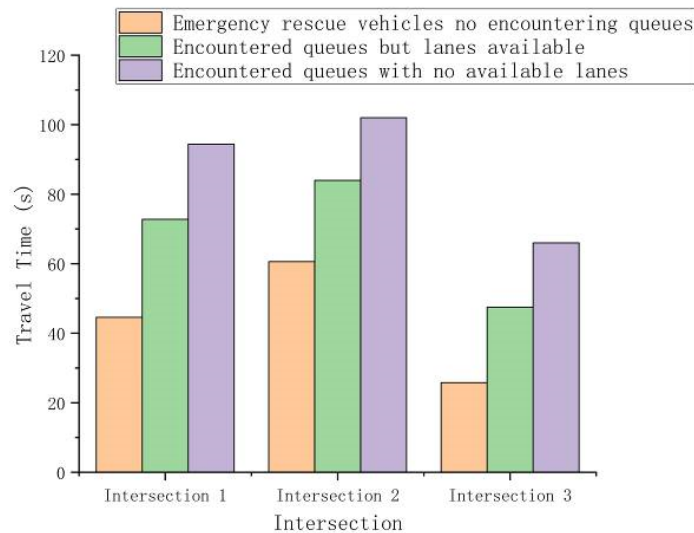
3 **Table 5** Simulation evaluation results

| 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            |

#### 4 **5 Conclusion**

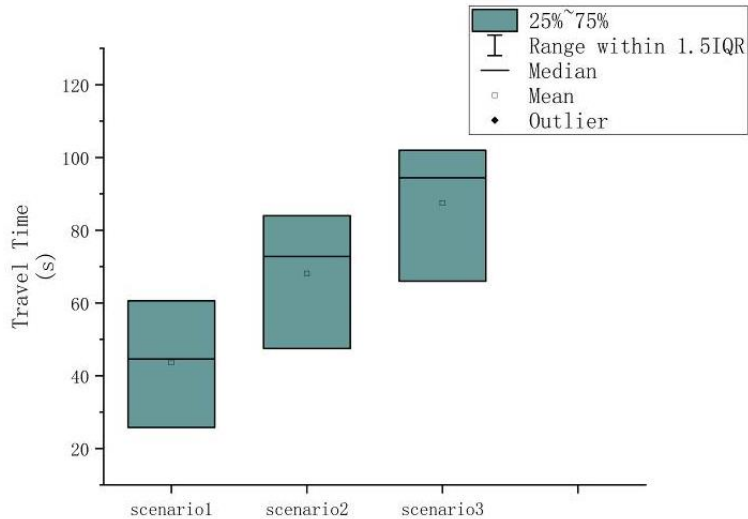
5 By analyzing the simulation evaluation results obtained above, the distribution  
 6 time of the emergency rescue vehicles in the three scenarios can be obtained, as  
 7 shown in Figure 8. Also, through the above data, the box plot of the travel time in  
 8 three scenarios is drawn, which is shown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

9



10

11 **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.

## Acknowledgments

This study was funded by MOE (Ministry of Education in China) Project of Humanities and Social Sciences (Project No. 17YJCZH225), Climbing Program of University of Shanghai for Science and Technology in Humanistic and Social Science

1 Research (SK18PB03), the Humanistic and Social Science Research Funding of  
2 University of Shanghai for Science and Technology (SK17YB05).

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