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Research Article

Research on Intersection Signal Switching Model under Emergency Situation

Li Zongping, Bai Wei, and Gan Mi

School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

Correspondence should be addressed to Gan Mi, yyganmi@gmail.com

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The frequent occurrence of the city emergency leads to rapid development of emergency traffic management which is an important part in the Emergency Rescue System. In the intersection with heavy traffic, the emergency rescue vehicles often with increased delay, reduced safety, and sometimes even with a collision, which restrict the efficiency of the rescue. This paper established the intersection signal control optimization model based on detail analysis of emergency rescue vehicles traffic characteristics and traffic signal control. The models, on one hand, were able to guarantee the emergency vehicles through the intersection quickly and without delay; on the other hand, could ensure the minimum impact to other vehicles in the process of the emergency vehicles through the intersection. Finally, the model's practicality was verified by real cases.

1. Introduction

In modern life, the emergency events, natural disasters, and the non resistance events happen frequently. Moreover, these events are unpredictable and bring to several damages. Statistics show that every year our country has big loss because of the disasters (such as the natural disasters, accidents, the social and public events), and the loss caused by rescue that does not come in time increased year by year [1]. Therefore, the accurate and reliable traffic control measures are an effective way to reduce the response time of the emergency vehicle, improve the efficiency of the emergency rescue, and reduce the loss of lives and property. But in the process of the emergency response, the emergency vehicle often with increased delay, reduced safety, and even with a collision in intersections. According to the results of the emergency vehicle accident investigation in Virginia, about 31% accidents of the emergency vehicles' happened in the intersection. Moreover, the consequences are even more serious than happened in other places [2]. Therefore, the study on signal optimization control under emergency situations has an important significance in emergency rescue, traffic safety, and traffic management.

For the research on the right-of-way of the emergency vehicle, the scholars in transportation area in different countries focused on different aspects. Bachelder and Foster proposed the emergency vehicles preferred system based on the induction coils [3]. Mussa and Selekwa raised one conversion process of the traffic signal timing based on quadratic optimization method [4]. Nelson and Bullock pointed out that the signal control should back to normal operation rapid and safely after the emergency vehicles through the intersection [5], but the conversion mode of the signal control they proposed back to normal often used the ways of smooth, add only, or dwell, all of which are set according to the experience and are hard to adapt to the change of complex traffic condition.

In recent years, as the development of intelligent agent technology, many domestic scholars put forward the methods to solve the traffic problem based on this innovative, real-time and intelligent technology. Cao fulu (Chang′an University) proposed a kind of urban traffic signal optimization control system for the optimization of signal control through the coordination of the intelligence agents between adjacent intersections. Cheng Xiangjun (Beijing Jiaotong University) presented one distributed traffic signal coordination control method based on the multiagent technology, this method makes the vehicles through the intersection without delay under the higher utilization of the each phase in crossing traffic time.

We can conclude from the above analysis that the current study is mainly concentrated in the hardware and system design of the signal priority. The purpose of emergency signal optimization control can be expressed as one objective function, and this function subjects to some restrictions. We are able to obtain the optimal control strategy by the mathematical programming model and various kinds of optimization methods.

2. Signal Conversion Control

2.1. Control Process

This paper chooses the four phase signals cross-intersection as the research object. The signal optimization control measures under emergency situations are built according to the traffic conditions when the emergency vehicle's detector detects the request vehicles. The control process as in Figure 1.

2.2. Vehicle Detector Position Setting

2.2.1. General Vehicle Detector Position Setting

As shown in Figure 2, the position of the general vehicle detector can be expressed as

$$L_{\mathrm{VD}} = L_{\mathrm{QD}} + L_{\mathrm{DD}}, \tag{2.1}$$

where, L_{VD} is the setting distance of other vehicle's detector; L_{QD} is the length of the other queuing vehicles under peak traffic condition; L_{DD} is the length of the slowly moving vehicles under the peak traffic condition.

To ensure the emergency vehicle could pass through the intersection safely and without delay, we must make sure the other vehicles in front of the emergency vehicle dissipated in time. L_{QD} can be determined by the average value of multiple times

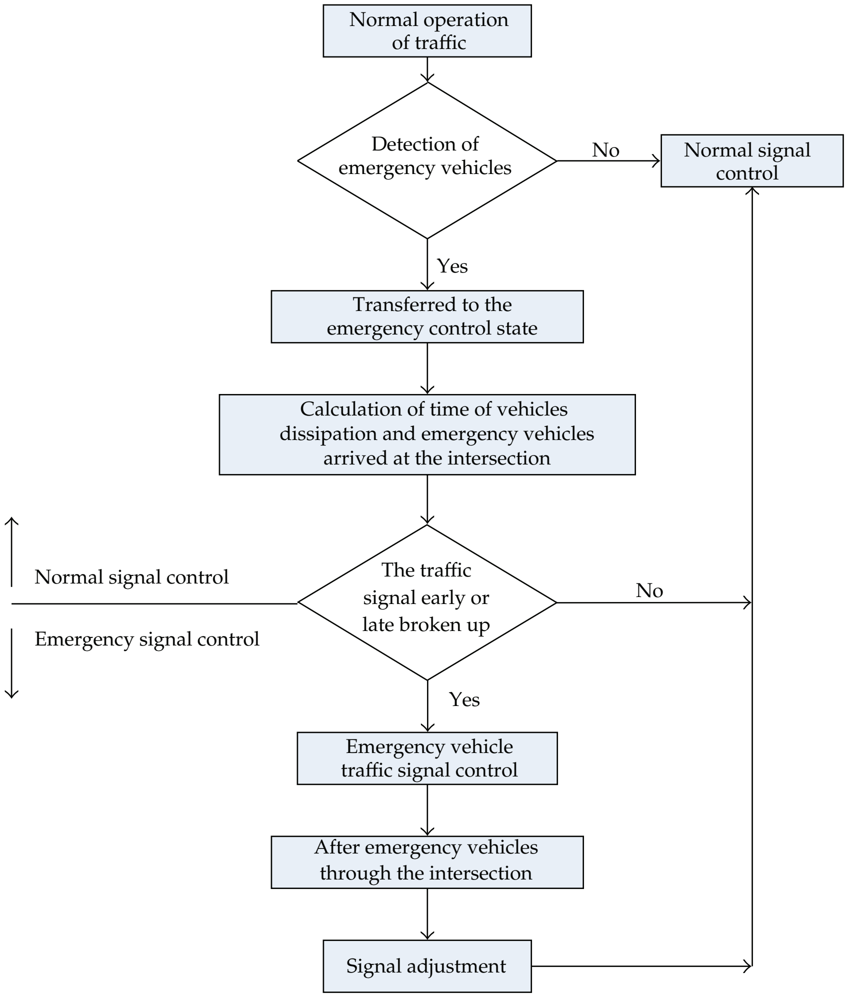

Figure 1: Intersection signal conversion control process under emergency conditions.

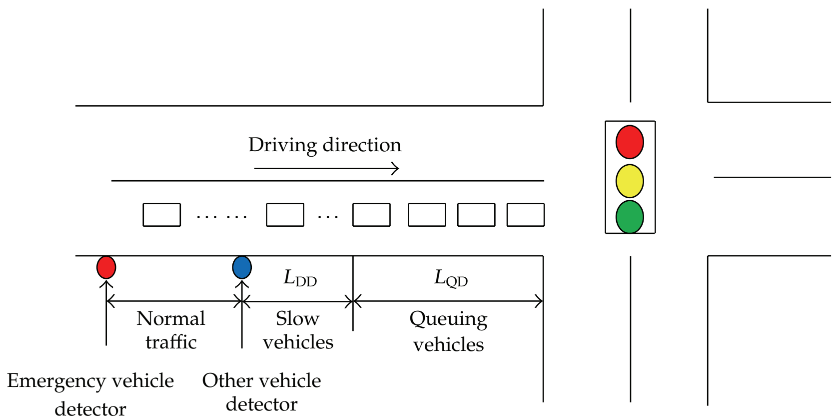

Figure 2: Classification of the traffic vehicle.

measurements. L_{DD} is difficult to detect, it can be replaced by the sum of the mean value and two times standard deviation of L_{QD} [6], as follows:

$$L_{\mathrm{QD}} = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad i = 1, 2, 3, \ldots n,$$
$$L_{\mathrm{DD}} = L_{\mathrm{QD}} + 2\sigma = \overline{X} + 2\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \overline{X}\right)}. \tag{2.2}$$

Then, x_i is the detected length of the other queuing vehicles under peak traffic condition; $\overline{X}$ is the average queue length of the other vehicles; σ is the standard deviation of the other vehicle queue length.

2.2.2. Emergency Vehicle Detector Position Setting

The setting distance of the emergency vehicle detector should be able to guarantee that it has enough time to dissipate the vehicles before the emergency vehicle arrived at the intersection. So, there exists

$$t_{\mathrm{ED}} = \frac{L}{v_{\mathrm{ED}}}, \tag{2.3}$$

where t_{ED} is the ideal travel time of emergency vehicle from the detected position to the intersection parking line; L is the distance between the emergency vehicle detector and intersection; v_{ED} is the ideal average speed of the emergency vehicle.

In actual situation, the emergency vehicle could reach the intersection in any time. Assume the driving direction is already known, according to the different signal phase condition when the signal control machine receives the detected information from the emergency vehicle, the location of the emergency vehicle's detector can be set as follows.

(1) The signal phase of the emergency vehicle's driving direction is green:

Then, the disappearing time of the other vehicles is:

$$t_{\mathrm{CL}} = \frac{(L_{\mathrm{QD}} + L_{\mathrm{DD}})}{v_{\mathrm{QD}}}, \tag{2.4}$$

where t_{CL} is the disappearing time of the other vehicles before the emergency vehicle appears; v_{QD} is the dissipation speed of the other vehicle's queue in front of the emergency vehicle.

There should be a certain safety time interval between the last dissipated vehicle and the emergency vehicle. The formula is as follows:

$$t_{\mathrm{ED}} - t_{\mathrm{CL}} \geq t_{\mathrm{SI}}, \tag{2.5}$$

where t_{SI} is the time interval between the last dissipated vehicle and the emergency vehicle.

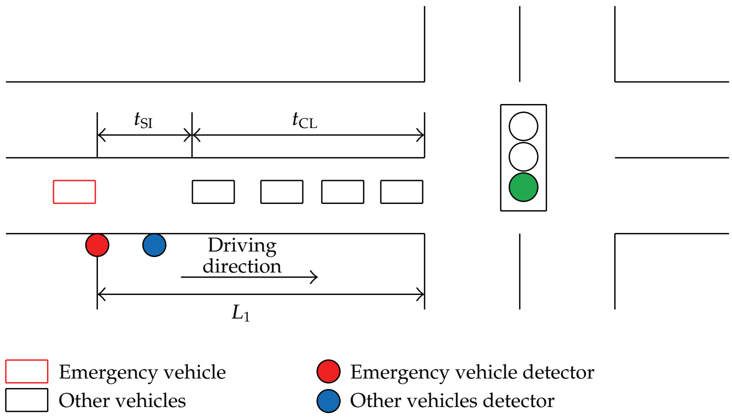

Figure 3: The location of emergency vehicle detector (green).

So the minimum distance of the emergency vehicle's detector in this condition is

$$L_1 \geq \left[t_{SI} + \frac{(L_{QD} + L_{DD})}{v_{QD}}\right] \times v_{ED}. \tag{2.6}$$

(2) The signal phase of the emergency vehicle's driving direction is yellow.

According to the conduct process we proposed above, the minimum distance of the emergency vehicle's detector in this condition is

$$L_2 \geq \left[t_{SI} + t_{SL} + \frac{(L_{QD} + L_{DD})}{v_{QD}}\right] \times v_{ED}, \tag{2.7}$$

where t_{SL} is the loss of the start time (see Figure 4).

(3) The signal phase of the emergency vehicle's driving direction is red.

The minimum distance of the emergency vehicle's detector in this condition is in Figure 3

$$L'_3 \geq \left[t_{SI} + t_{SL} + \frac{(L_{QD} + L_{DD})}{v_{QD}} + t_{AR} - t'_{AR}\right] \times v_{ED}, \tag{2.8}$$

where t_{AR} is the all red light duration of this phase; t'_{AR} is the faded signal time of this red phase.

In practical situations, it is not easy to ensure t'_{AR}, which could be resolved by use the "real position" and the "virtual position". The "real position" is the actual position of the emergency vehicle detector. The formula is as follows:

$$L_3 \geq \left[t_{SI} + t_{SL} + \frac{(L_{QD} + L_{DD})}{v_{QD}} + t_{AR}\right] \times v_{ED}. \tag{2.9}$$

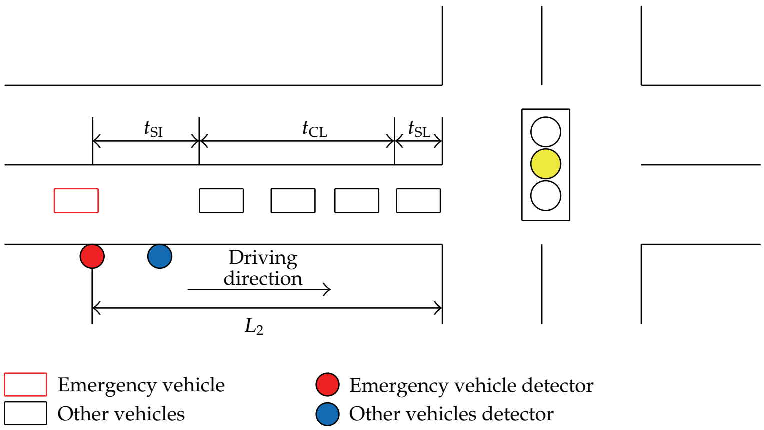

Figure 4: The location of emergency vehicle detector (yellow).

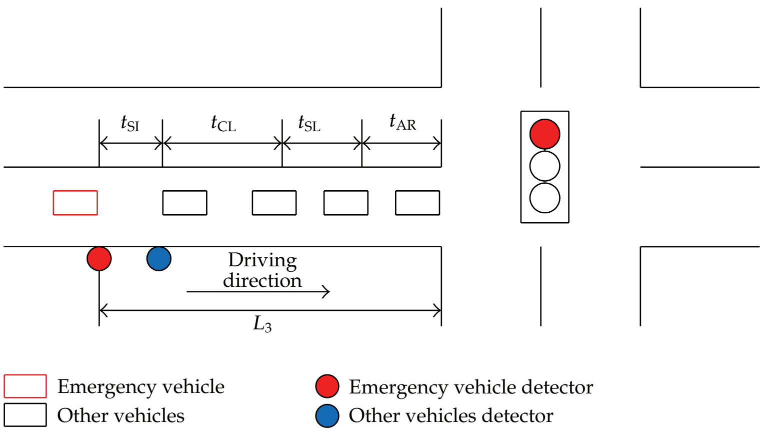

Figure 5: The location of emergency vehicle detector (red).

The "virtual position" is the position set by L_3'. In this condition, we should deduct the setting position of emergency rescue vehicle's detector during the red signal phase. So there exists: $L_3 \geq L_3'$ (see Figure 5).

Therefore, the minimum distance of the emergency vehicle detector is:

$$L = \max\{L_1, L_2, L_3\} = L_3. \tag{2.10}$$

2.3. *Optimal Control*

At first, divide the entire process into three periods: detection period, before, and after the intersection period.

2.3.1. Detection Period

After the distance of the emergency vehicle detector is determined, the information about emergency vehicle, such as the location, speed, and the direction can be determined. The formula as follows [7–9]:

$$\begin{gathered} t_{\mathrm{HG}} = t'_{\mathrm{ED}} - \left(t_{\mathrm{SW}} + t'_{\mathrm{CL}} + t_{\mathrm{SI}}\right), \\ t'_{\mathrm{ED}} = \frac{L}{v'_{\mathrm{ED}}}, \\ t'_{\mathrm{CL}} = t_{\mathrm{SL}} + \frac{\left(L'_{\mathrm{QD}} + L'_{\mathrm{DD}}\right)}{v_{\mathrm{QD}}}, \\ t'_{\mathrm{ED}} > t'_{\mathrm{CL}}, \end{gathered} \tag{2.11}$$

where t_{HG} is the green time that other phases obtained; t_{SW} is the loss time of conversion; t'_{CL} is the detected time of the dissipated vehicles in front of the emergency vehicle; t'_{ED} is the time from the position that emergency vehicle is detected to the stop line; v'_{ED} is the detected travel speed of the emergency vehicle; L'_{QD} is the actual queue length of other vehicles in emergency vehicle driving direction; L'_{DD} is the detected length of the slowly moving vehicles in emergency vehicle driving direction.

Once the control machine request received the request of the emergency vehicle, we could decide whether to carry out the signal priority control by the formulas we proposed above according to the signal phase and fixed signal timing cycle.

2.3.2. The Optimization before the Vehicles through the Intersection

The optimization purpose of this period is

(1) to guarantee the emergency vehicle safety and without delay;

(2) to minimize the influence to other vehicles.

According to the actual situation and with above optimization goals, we could implement optimization methods by different control measures, which can be specified as [10–13]

(1) The signal phase in emergency vehicle's driving direction is green when the detector detected emergency vehicle to ensure the safety when the emergency vehicles passes through the intersection. We do not consider the emergency vehicles through the intersection in the yellow signal phase.

(i) Assume $t_{\mathrm{GR}} > t'_{\mathrm{ED}} > t'_{\mathrm{CL}}$.

The signal control plan is still running as normal. t_{GR} is the remaining signal time of this green phase in emergency vehicle's driving direction when the detector detected emergency vehicle; t_{AG} is the full signal time of this green phase in emergency vehicle's driving direction.

(ii) Assume $t'_{\mathrm{ED}} \geq t_{\mathrm{GR}} > t'_{\mathrm{CL}}$.

The signal control plan is changed according to the difference between the surplus green time of this phase and the required time for emergency vehicles arrived.

(a) If $t'_{\mathrm{ED}} - t_{\mathrm{GR}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} \geq T$, the signal control will be switched to normal, and the next phase can get the time for green is $t_{\mathrm{HG}} = t'_{\mathrm{ED}} - t_{\mathrm{GR}} - t_{\mathrm{SW}} - t_{\mathrm{SI}}$. After t_{HG}, convert the green signal phase to the emergency vehicle's driving direction.

(b) If $t'_{\mathrm{ED}} - t_{\mathrm{GR}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} < T$, extend the show time of the green light phase, there exist $t_{\mathrm{DG}} = t'_{\mathrm{ED}} - t_{\mathrm{GR}} + T_{\mathrm{EI}}$. Where, T is the time of the static car needed to through the intersection as usual. t_{DG} is the extended time of the green signal phase in the emergency vehicle's driving direction. T_{EI} is the time of the emergency vehicle needed to through the intersection.

(iii) If $t'_{\mathrm{ED}} > t'_{\mathrm{CL}} > t_{\mathrm{GR}}$, the signal control plan is changed according to the difference between the surplus green time of this phase and the required time for emergency vehicles arrived also.

(a) If $t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} \geq T$, the signal control will be switched as normal, and the next phase can get the time for green is $t_{\mathrm{HG}} = t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}}$. After t_{HG}, convert the green signal phase to the emergency vehicle's driving direction.

(b) If $t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} < T$, extend the time of the green signal phase and the extended time is $t_{\mathrm{DG}} = t'_{\mathrm{ED}} - t_{\mathrm{GR}} + T_{\mathrm{EI}}$.

(2) The signal phase in emergency vehicle's driving direction is yellow when the detector detected emergency vehicle.

(i) Assume $t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} + t_{\mathrm{YR}} \geq T$.

The signal control machine will be switched as normal, and the next phase can get the time for green is $t_{\mathrm{HG}} = t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} - t_{\mathrm{YR}}$. Where, t_{YR} is the remaining signal time of this yellow phase in emergency vehicle's driving direction when the detector detected emergency vehicle; t_{AY} is the full signal time of this yellow phase in emergency vehicle's driving direction, there exists $0 \leq t_{\mathrm{YR}} \leq t_{\mathrm{AY}}$. After t_{HG}, convert the green signal phase to the emergency vehicle's driving direction until the emergency vehicle passed the intersection.

(ii) Assume $t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SW}} - t_{\mathrm{SI}} + t_{\mathrm{YR}} < T$.

In this case, convert the green signal phase to the emergency vehicle's driving direction until the emergency vehicle passed the intersection.

(3) The signal phase in emergency vehicle's driving direction is red when the detector detected emergency vehicle.

(i) Assume $t'_{\mathrm{CL}} < t'_{\mathrm{ED}} < t_{\mathrm{RR}}$.

The other phases can get the time for green is $t_{\mathrm{HG}} = t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SI}}$. After that, convert the green signal phase to the emergency vehicle's driving direction and the break time of the red light in the emergency vehicle's driving direction is $t_{\mathrm{DT}} = t_{\mathrm{RR}} - (t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SI}}) + t_{\mathrm{SW}}$. Where, t_{RR} is the remaining signal time of this red phase in emergency vehicle's driving direction when the detector detected emergency vehicle; t_{AR} is the full signal time of this red phase in emergency vehicle's driving direction.

(ii) Assume $t'_{\mathrm{ED}} \geq t_{\mathrm{RR}}$.

(a) If $t_{\mathrm{RR}} \leq t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t'_{\mathrm{CL}} \leq t_{\mathrm{RR}} + t_{\mathrm{AG}}$, the signal control machine will be switched as normal.

(b) If $t_{\mathrm{RR}} + t_{\mathrm{AG}} < t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t'_{\mathrm{CL}}$, extend the time of the green signal phase and the extended time is $t_{\mathrm{DG}} = t'_{\mathrm{ED}} - t_{\mathrm{RR}} - t_{\mathrm{AG}} + T_{\mathrm{EI}}$.

(c) If $t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SI}} < t_{\mathrm{RR}}$, convert the green signal phase to the emergency vehicle's driving direction and the break time of the red light in the emergency vehicle's driving direction is $t_{\mathrm{DT}} = t_{\mathrm{RR}} - (t'_{\mathrm{ED}} - t'_{\mathrm{CL}} - t_{\mathrm{SI}}) + t_{\mathrm{SW}}$.

(4) Pedestrians scheme under the emergency situation.

Convert the pedestrian traffic light in emergency vehicle's driving direction to red until the emergency vehicle passed the intersection and make speakers or tips to notice to the crowd in the meantime.

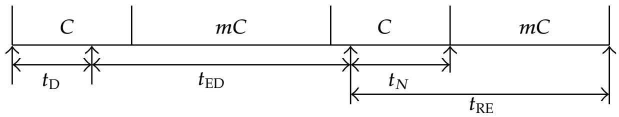

Figure 6: The priority control process of the emergency vehicle.

2.3.3. The Optimization after the Vehicles Passes through the Intersection

The control process of the emergency vehicle under the emergency situation can be described in Figure 6.

According to the Figure 6, the following relationships can be calculated:

$$t_N = C - \frac{(t_D + t_{ED})}{C},$$
$$t_{RE} = t_N + nC - t_{SI}, \tag{2.12}$$

where t_P is the time interval between the moment of the emergency vehicle detected and the beginning of next signal cycle; t_D is the time interval between the beginning of the signal cycle and the moment of the emergency vehicle detected; t_{RE} is the time length of the intersection signal optimization control after the emergency vehicles through the intersection; m, n is the signal cycle number.

In this period, establish the optimal model with the minimum delay of other vehicles' as the optimization target. Such that [14–18]

$$\min Z = \min \sum_{l=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{K} \max\left\{0, Q_{jl}^{i}(k-1) + \sum_{i=1}^{4}\left(q_{jl}^{i}(k) - \mu_{jl}^{i} \cdot \lambda_{jl}\right) \times g^{i}(k)\right\},$$
$$\text{s.t.:}\quad C(k) = \sum_{i=1}^{4} g^{i}(k),$$
$$g_{\min}^{i} \le g^{i}(k) \le g_{\max}^{i},$$
$$\sum_{k=1}^{K} C(k) = t_{RE} = t_N + n \cdot C - t_{SI},$$
$$Q(k) = \sum_{l=1}^{2}\sum_{j=1}^{4} Q_{jl}^{i}(k) \le Q_v,$$
$$Q_{jl}^{i}(k) = \max\left\{0, Q_{jl}^{i-1} + VA_{jl}^{i}(k) - VD_{jl}^{i}(k)\right\},$$
$$VA_{jl}^{i}(k) = q_{jl}^{i}(k) \cdot g^{i}(k),$$
$$VD_{jl}^{i} = \mu_{jl}^{i} \cdot \lambda_{jl} \cdot g^{i}(k),$$
$$Q_{jl}^{0}(k) = Q_{jl}^{4}(k-1), \tag{2.13}$$

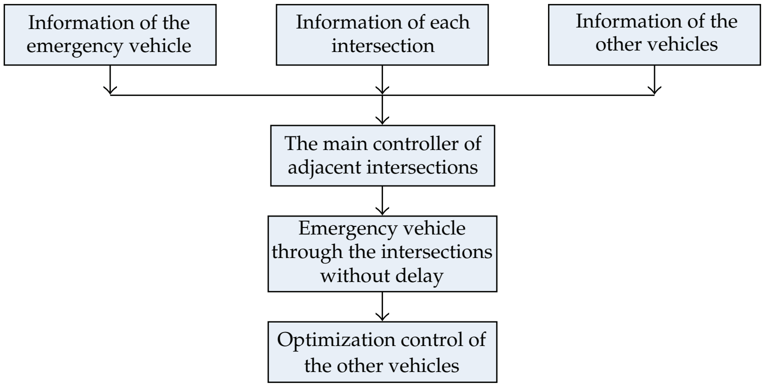

Figure 7: The process of the joint priority control.

where i is the number of the traffic signal phases, the maximum is 4; j is the driving direction of the intersection, 1, 2, 3, and 4 represent East, South, West and North; l is the direction of the lane, 1, 2 represent the direction of left and straight; k is the signal control cycle and K is the maximum number of it; $VA_{jl}^{i}(k)$ is the actual number of the reached vehicles in the i signal phase of k signal cycle and l lane of the j direction; $VD_{jl}^{i}(k)$ is the actual number of the past vehicles in the i signal phase of k signal cycle and l lane of the j direction; $Q_{jl}^{i}(k)$ is the number of queuing vehicles in the i signal phase of k signal cycle and l lane of the j direction; $q_{jl}^{i}(k)$ is the average arrival rate of the vehicles in the i signal phase of k signal cycle and l lane of the j direction; $g^{i}(k)$ is the duration of the effective green signal phase-in the i signal phase of k signal cycle; λ_{jl} is the saturated flow rate in the l lane of the j direction; T_{LS} is the loss time of each signal cycle; Q_v is the average queue length of each signal cycle under normal conditions; μ_{jl}^{i} is the traffic state of the l lane of the j direction in the i signal phase, if the car can move, $\mu_{jl}^{i} = 1$, else $\mu_{jl}^{i} = 0$.

The proposed optimization models could be solved with the genetic algorithm and the simulated annealing algorithm by applying the MATLAB tool.

2.3.4. The Control Strategy When through the Continuous Intersections

Take different control measures according to the traffic volume and the distance between the adjacent intersections.

If $L_N \geq L$, take the priority control independently for each intersection by the above method. Otherwise, take the joint priority control for the adjacent intersections. Where, L_N is the distance between the adjacent intersections. The process of the joint priority control is shown in Figure 7.

Set the controller of the largest vehicles' intersection as the main controller. The process of detection period and the optimization of the period before passed intersection are the same as analyzed in Section 2.3.2. After the emergency vehicle passed the intersections, take the optimization measures according to the sum of the vehicles in different directions in the adjacent intersections. Then, assign appropriate green signal time to the different directions of the adjacent intersections.

Table 1: Basic data of the experimental analysis.

DATA		Vehicles (vel/h)	Saturated flow rate per lane (vel/h)	Green time (s)
East	Straight	352	1450	31
	Left	228	1350	23
South	Straight	307	1400	28
	Left	231	1300	22
West	Straight	312	1450	31
	Left	219	1350	23
North	Straight	279	1400	28
	Left	201	1300	22

Table 2: The average length of the vehicles' queue.

		$\overline{X}$ (m)	α (m)	$\overline{X}+\alpha$ (m)
East	Straight	99	20	139
	Left	64	17	98
South	Straight	87	35	157
	Left	62	26	114
West	Straight	81	27	135
	Left	70	14	98
North	Straight	71	35	141
	Left	53	21	95

Table 3: The setting distance of the detectors.

	Other vehicle's detector (m)	Emergency vehicle's detector (m)
East	139	618
South	157	679
West	135	606
North	141	623

Table 4: The second simulation of the optimization control (low traffic).

Average length of the queue (m)								The obtained time of green light (s)	The moment enter the intersection (s)
North		West		South		East			
Left	Straight	Left	Straight	Left	Straight	Left	Straight		
82	87	101	7	128	107	13	29	47	27
16	171	9	72	0	88	22	37	43	52
72	77	64	126	58	41	0	134	30	98
51	73	65	15	58	50	7	23	43	113

Table 5: The second simulation of the optimization control (high traffic).

Average length of the queue (m)								The obtained time of green light (s)	The moment enter the intersection (s)
North		West		South		East			
Left	Straight	Left	Straight	Left	Straight	Left	Straight		
21	136	87	58	7	116	7	122	44	41
23	73	57	72	27	58	0	80	53	67
35	14	81	117	56	23	7	71	42	86
57	63	0	101	92	95	14	95	35	101

Table 6: The optimization of the green light duration.

Phases	Phase 1	Phase 2	Phase 3	Phase 4
Green time (s)	33	57	21	28

Table 7: The length of the other vehicles' queue.

Length of the other vehicles' queue (m)							
North		West		South		East	
Left	Straight	Left	Straight	Left	Straight	Left	Straight
25	65	43	64	60	71	92	67

Table 8: The average delay of the other vehicles.

Traffic	Low		High	
Emergency signal priority control	Yes	No	Yes	No
Emergency vehicles' delay	0	21.2	0	51.9
East				
Straight	63.4	43.9	71.9	55.7
Left	30.7	37.1	35.6	45.8
South				
Straight	51.2	40.6	75.9	48.1
Left	59.4	45.5	63.8	54.9
Average delay of other vehicles (m)				
West				
Straight	47.1	39.7	56.9	47.9
Left	37.8	45.1	48.1	53.2
North				
Straight	51.1	44.5	71.8	49.6
Left	42.6	39.1	50.1	43.4

3. Experimental Analysis

3.1. First Period

The selected experimental data and the average length of the vehicles' queue are shown in Tables 1 and 2.

The average speed of the dissipating vehicles is 3.3 m/s and the setting position of the detector are shown in Table 3.

3.2. Second Period

Select eight groups of data to simulate, as in Tables 4 and 5.

It is clearly shown in Tables 4 and 5 that all the emergency vehicles can pass through the intersection without delay and just cause little influence to other vehicles in most cases.

3.3. *Third Period*

Apply the first group data in Table 5 to calculate in MATLAB program, the results are shown in Table 6.

Apply the data in Table 6 to the simulation environment, the length of the other vehicles' queue are shown in Table 7.

Calculate the eight groups data, the average delay of emergency vehicle and other vehicles' are shown in Table 8.

4. Conclusion

This paper aims to establish the optimization model of the signal switching under emergency situations. On one hand, the models could guarantee the emergency vehicles are able to through the intersection safe and without delay; on the other hand, pass could ensure the minimum impact to other vehicles in the intersection during the processing of emergency vehicles pass through. Finally, real cases are employed to verify the practicality of the models. The models and algorithms can be also provided to some relevant management departments as the decision-making reference.

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