Signal Priority Control for Emergency Vehicle Operation

Wei Huang*
Center for Industrial Management/Traffic & Infrastructure,
Department of Mechanical Engineering, Katholieke Universiteit Leuven, Belgium
Xiaoguang Yang, Wanjing Ma
Department of Transportation Engineering, Tongji University, Shanghai, China

ABSTRACT

Emergency Vehicle is one of the rescue resources in a city. It is important to ensure safe and rapid emergency operations in case of emergency calls. This paper presents a signal priority control strategy for emergency vehicle operations in urban roads. The preset plans are discussed first to provide an optimal route considering the one-way coordinated signal setting, which focuses on the green time and offset probability dispersion. A VISSIM simulation example explains the selection of routes. The simulation result shows the travel time improvement of the coordinated control. The on-line actuated signal control is then put forward in order to adjust the real time signal setting to deal with the perturbation of traffic conditions. The priority control strategy suggests a route selection and signal setting method in the context of emergency vehicle operation.

Keywords: Emergency Vehicle Priority, Preset route, One-way Coordinated Control, Actuated Control

INTRODUCTION

Emergency vehicles, such as ambulances, fire engines, police cars, engineering rescue vehicles, are one very important rescue resources in a city. The management and control strategy for emergency vehicle operations holds a significant position in the transportation management system, especially in a big city with complex traffic networks. The key issue is to clear or opportunistically manage the traffic on the route the emergency vehicle passes as soon as possible, thus ensuring that it safely and rapidly reach the destination.

Most of the relevant researches on emergency travelling focus on dispatching and routing models for the optimal route, signal settings and evaluation of priority strategies. Some research works are carried out on algorithms to determine the static shortest route under different scenarios like fire fighting, supply of aid materials [1, 2]. Some focus on developing flexible dispatching strategies under real-time traffic conditions, searching for the time-dependent shortest path [3, 4]. The dispatching strategies do not take into account the control settings explicitly.

Concerns on emergency priority signaling start from a single intersection base control that requires detection information to activate signal priority settings at each intersection [5, 6]. Such a local detection-based and intersection-by-intersection clearance strategy is still an attraction for many systems to date [7]. Due to the response time delay and the degrading performances under heavy traffic demand of the local strategy, route-based signal priority control is gaining more and more attentions [7, 8]. The route selection in these studies is executed using the developed shortest route algorithm such as the well-known Dijkstra’s algorithm, separating from the potential effect of signal plans. As for the assessments of the control strategies, most of the evaluations are performed via simulation analysis [9, 10].

Based on the route-based philosophy, this paper aims at presenting a signal priority control strategy for emergency vehicle operation in urban roads. It comprises a preset route coordinated control module and an on-line actuated signal adjustment. The preset route plan is determined accounting the potential effect of the one-way coordinated control. The on-line adjustment is implemented using a rule-based actuated control.

The main considerations of this paper are: 1) assign a route to the emergency vehicle, taking into account the effect of signal coordination and priority when selecting a route among the feasible routes; 2) the influence of the priority strategy on the cross-road traffic is taken into account. The assumptions apply to the situation that the non-emergency vehicles cannot yield due to the heavy flow thus the flow should be cleared first and/or the situation of a relative low level of emergency thus the impact on surrounding traffic is not neglected.

The remainder of this study is organized as follows. The operation procedure of the control strategy is explained at first. Next the one-way coordinated control is elaborated, focusing on the green time and offset probability dispersion. This is followed by the VISSIM simulation case, to explain the route selection. Then the decision rules with different switch patterns for on-line adjustment are discussed according to the real-time actuated information. The conclusion is drawn finally.

OPERATION PROCEDURE

The procedure of the emergency signal priority control is explained in Figure 1.
When the emergency request is activated, the origin and destination together with the traffic conditions determines the preset route and the corresponding coordinated control setting. Then the congestion vulnerability is checked and the queue clearance is performed for the potential point. The on-line actuated adjustment is implemented according to the detection of emergency vehicle. Finally the signal recovers the normal plans.

PRESET ROUTE COORDINATED CONTROL

The one-way coordinated control plan is determined off-line and preset in the database. When the emergency priority request is activated, the most efficient route clearance plan is selected according to the traffic scenario at that time.

1) Stage structure

First the protected stage structures are suggested to provide a conflict-free and safe travel for emergency vehicle. Figure 2 shows the combination of all the conflict-free stage structures.

2) Cycle time

A common cycle time is assumed for the coordinated intersections. The initial optimal cycle time is usually obtained from the optimization of a designated objective function.

$$ f = f(C, q) $$

Where C is the cycle time and q is the link flows. Here we take the delay formulation in the Highway Capacity Manual, (HCM2000, [11]) as the objective function in the simulation case.

3) Green time and offset

Offset is the most important parameter for a coordinated control. It is usually determined based on the average velocity in a Max-Band method. However the actual arrival pattern is not the same as that indicated by the ideal green wave because of the platoon dispersion. Thus it brings delays for the head vehicles blocked due to early arrival and the tail vehicles blocked due to late arrival, as shown in Figure 3.

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To provide an efficient clearance strategy, the ahead green time $\tau_a$ and the extension green time $\tau_e$ are suggested (see Figure 4). Given a confidence level $\alpha$, the green split and offset are calculated under the maximum green time and capacity constraints. The probability dispersion control model can be formulated as:

$$P(v_{tail} \leq v \leq v_{head}) \geq \alpha$$

Where $l$ is the distance between adjacent upstream and downstream stop line, $\bar{v}$ denotes average velocity, $v_{head}$ and $v_{tail}$ respectively represent velocity of head vehicle and tail vehicle in the platoon. The dispersion probability $\alpha$ indicates that vehicles can get through the intersection in a probability of $\alpha$. It could be adjusted according to the level of emergency.

**SIMULATION CASE**

We take the VISSIM simulation software program [12] for the priority control in the opening ceremony of Chinese National Game (organized in the city of Jinan in 2009) as an example. Priority control strategy is required for some special emergency vehicle traveling from A to B as marked in Figure 5. There are two available routes. Route 1 has six signalized intersections with a distance of 3,233 meters, while route 2 has three and a distance of 3,894 meters. The superiority of route clearance under the coordinated control is analyzed by comparing the travel times of the two routes.

**Fig. 4:** Increase the clearance probability by setting ahead and extension green time

**Fig. 5:** Two routes simulation in the city of Jinan in China

**Fig. 6:** Comparison of travel times under two traffic conditions between two routes (demand 1: 400 veh.h$^{-1}$-lane$^{-1}$, demand 2: 200 veh.h$^{-1}$-lane$^{-1}$)

**Fig. 7:** Improvement of travel time

Taken the effect of coordinated signal control into account, route 2 is recommended under both demand 1 and demand 2 (Figure 6). The comparison of travel time under different traffic conditions between the two routes also indicates the need of considering potential signal benefits when searching for an optimal route for emergency vehicle. Figure 7 shows the improvement (19% for route 1 and 24% for route 2) in travel time comparing the uncoordinated and coordinated plans.
ON LINE ACTUATED CONTROL

On-line actuated signal control is proposed in order to adjust the real time signal setting to deal with the perturbation of traffic conditions. We introduce four kinds of switch patterns:

- Green extension
- Red truncation
- Phase insertion
- Phase skipping

The decision-making rules according to the detection of emergency vehicle can be formulated as follows:

1) min green for the phase previous to emergency phase and then switch to emergency phase

\[ t_e \leq t_d < g_{s-min} - \frac{L}{V_E} \]

2) red truncation for the previous phase

\[ R_{s-min} - \frac{L}{V_E} \leq t_d < g_{s} - \frac{L}{V_E} \]

3) hold

\[ g_{s} - \frac{L}{V_E} \leq t_d < g_{s} - \frac{L}{V_E} \]

4) green extension for the emergency phase

\[ g_{s} - \frac{L}{V_E} < t_d \leq g_{s} \]

5) phase insertion or skipping

\[ t_d < t_{p} \quad \text{or} \quad t_d > g_{s} \]

We denote the decision-making time by \( t_d \), i.e. time when a decision is made. \( t_e \) is the startup time of the phase previous to emergency phase. \( R_{s-min} \) is min green time of the previous phase. \( L \) is the distance between detector and stop line. \( v_r \) is the average velocity of emergency vehicle. \( g_{s} \) is initial green time of the previous phase. \( g_{s} \) represents the initial green time of the emergency phase.

CONCLUSION

This paper presents a signal priority control strategy for emergency vehicle operation in urban roads, mainly comprising a preset route coordinated control module and a real time signal actuated control module. A probability dispersion coordinated control is introduced to increase the probability of route clearance. Simulation results indicate the need of considering signal control influence and the improvement of the coordinated control. In order to handle the perturbation, an on-line actuated adjustment is performed.

The study is carried out on the assumption of known flow patterns. Further research could take the exploration on control strategy in an equilibrium context.

Besides, the adaptive optimization instead of the preset plan is suggested for further attentions, taking advantage of the detailed traffic data benefit from the developed detection techniques.

REFERENCES