1 Cooperative Traffic Management for Emergency Vehicles in the City of Bologna

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1.1 Abstract

In case of an emergency the incident location must be reached by emergency vehicles as fast as possible. But driving an emergency vehicle is a dangerous task. The risk being involved in accidents, being insured or killed is much higher with an emergency vehicle than with a private vehicle. Cooperative traffic management strategies can support emergency vehicle drivers by switching the traffic lights on the way of the emergency vehicles accordingly to reach the incident location fast and safe. The approach was simulated in SUMO using the simulation scenario of the city of Bologna.

Keywords: Emergency vehicles, V2X Communication, Traffic Management

1.2 Introduction

One essential part of a working health system is that people who are seriously injured or sick receive professional assistance immediately. Therefore, emergency vehicles are allowed to use special rights e.g. having priority at intersections and violating red traffic lights etc. Driving an emergency vehicle is still a stressful situation. The driver is in a conflict situation not only to reach the incident location as fast as possible but also to avoid accidents and critical situations [5]. Furthermore, the drivers might mentally prepare for the following operation while they need to concentrate on the surrounding traffic. The aim of this study is to improve the operation drives of emergency vehicles considering traffic safety and travel time.

1.3 Traffic Safety of Emergency vehicles

Statistically, the risk for emergency vehicles having car accidents is much higher than that for other traffic participants [9]. A traffic safety study [15] indicates that the probability to have an accident for emergency vehicles is 8 times higher than that for other vehicles. Additionally, the study indicates that at least one person is killed per 272,000 emergency drives. This fact is dramatic, especially considering that emergency vehicles should help other people and prevent death instead of causing injuries and deaths. Other studies confirm also the higher risks for emergency vehicle drivers (e.g. [15], [14], [9], [7]).
To find out which supports emergency vehicles need to prevent accidents an internet research was performed and the results can be found in [2]. The description of 189 accidents with emergency vehicles in Germany in the years 2009 and 2015 were collected and evaluated. All accidents happened

while the vehicle were requesting special rights with blue flashing lights and siren. It can be assumed that emergency vehicles which were driving without special rights should have a similar traffic behavior and risk for accidents as normal vehicle and therefore are not considered in this study.
The reasons for the analyzed accidents are shown in figure 1.1. As a result, most of the recorded accidents happened at controlled and uncontrolled intersections (51%). 32% of the reported accidents were due to red light violation. It is not evaluated whether the accidents were the fault of the emergency vehicle driver. Legally, a emergency vehicle driver is obliged to make sure that other drivers have noticed the emergency vehicle and react accordingly and therefore will mostly be blamed for the respective accident at least partly.
Also other reasons are strongly related to the special rights of emergency vehicles e.g. overtaking (12%), abrupt breaking (4%), one way road (0.5%) and stop sign (0.5%).But there are also other reasons which could lead to an accident for every vehicle type for example the influence of alcohol (3%) and icy roads (5%).

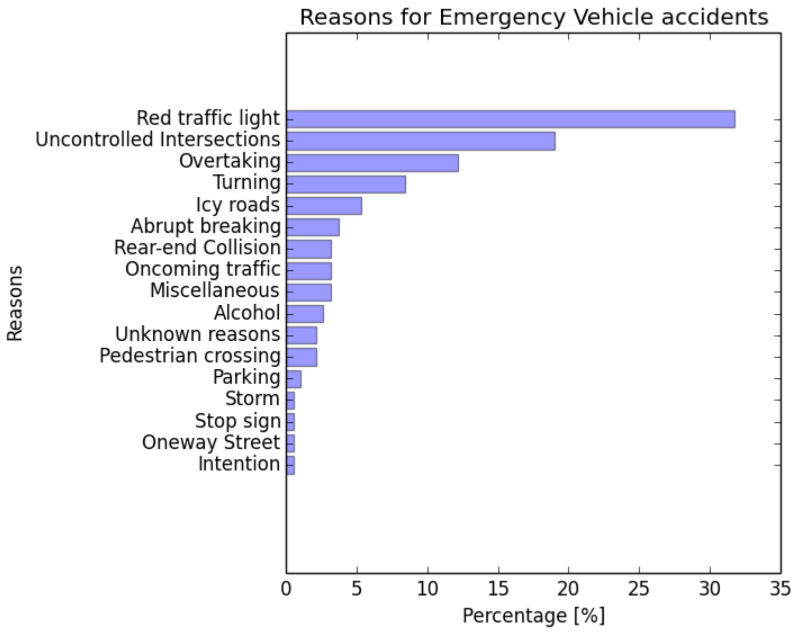


Figure 1.1: Reasons for Emergency Vehicle Accidents

Based on this emergency safety evaluation this study focuses on supporting emergency vehicles at controlled intersections. To reduce the accident risks emergency vehicles should get priority at intersections without violating red traffic lights.

1.4 Prioritization strategy via Vehicle-to-Infrastructure communication (V2I)

This research aims at adapting the traffic lights on the way of emergency vehicles and give the drivers priority at every intersection without violating red traffic lights. Other studies also investigated the impact of priority systems for emergency vehicles [11]. In the work of Nelson [11], the priority for emergency vehicles is given manually by a traffic controller. The main idea was to extend the green time durations for emergency vehicles.
Another way to support emergency vehicles is special routing adjusted to the needs on the characteristics of emergency vehicles and has been investigated in the work of Haghani et. al. [8]. Haghani et. al. inspect how the routing and dispatching of emergency vehicles could be optimized and therefore

lead to faster routes for emergency services. Furthermore, a special routing for emergency vehicles was introduced in [18] as well.

Vehicle-to-Vehicle and Infrastructure communication (V2X) has the potential to improve traffic conditions in several ways. On the one hand side V2X communication can be used to inform traffic participants about the current traffic state or dangerous road conditions (warnings about icy roads, construction sides or accidents). In the case of supporting emergency vehicles, V2X communication can provide warning messages to inform drivers about an approaching emergency vehicle [16] [6]. On the other hand V2X communication can support traffic management solutions with the current traffic state e.g. route recommendations according to the current traffic state or dynamic traffic light schedules. In [13], a navigation model using V2V communication for emergency vehicles was investigated.

The scope of this research is to get the information about an approaching emergency vehicle via V2X communication and adapt the traffic light state automatically on the route of the corresponding emergency vehicle accordingly. The basic approach was already investigated in [1] and is extended and evaluated in this paper. The traffic lights will be switched to green for the direction of the emergency vehicles while the red traffic lights are on to all other traffic participants. The procedure is described as follows: An emergency vehicle on its way to an incident location or the way back sends unicast messages to a road side unit (RSU), which include its expected route and current position. If an RSU receives such a message it will inform the traffic management center which sets the traffic lights on the way of the oncoming emergency vehicle to green while all other vehicles have to stop at a red light. The traffic light controller will continue its normal operation after the emergency vehicle has passed the intersection.

This basic approach has two problems. First, if drivers have to wait at a traffic light for a long time and they do not know why. They might assume that the traffic light is not working properly. Furthermore a long red phase might cause large traffic jams. And the second problem is how more than one emergency vehicle are handled. To overcome these problems the basic approach was extended.

To minimize the time the traffic light is set to red, the application calculates the best time when the traffic light phase should be adapted. The basic approach adapts the traffic light if the emergency vehicle is in communication range (300 meters) of the RSU of the traffic light and has reached the street in front of the traffic light. If there are more traffic information available e.g. loop detector data or V2X communication, the information can be used to calculate how long the traffic light should be set to green for the street of the emergency vehicle to free its way. For each vehicle which is waiting at the controlled intersection it was estimated that it needs 2 seconds for passing the traffic light plus 5 seconds for the emergency vehicle and reaction time for safety reasons:

$$T_{free} = \#waiting\_vehicles * 2sec + safety\_time$$

The distance from the emergency vehicle to the traffic light when the traffic light program should be adapted can be derived from T_{free} and the speed of the emergency vehicle:

$$distance = T_{free} * v_{emergency\_vehicle}$$

where: $v_{emergency\_vehicle}$ is velocity of the emergency vehicle (m/sec)

This allows the application to change the traffic light phase as long as necessary and as short as possible. The surrounding traffic have enough time to react to the emergency vehicle before they normally would notice the siren and the blue flashing light. Normally, the siren of an emergency vehicle can be perceived by the drivers only up to a distance of 25 meters according to [12]. The application extends this distance up to the communication range of 300 meters.

(a) Bologna traffic network (b) Position of the RSUs in SUMO

Figure 1.2: Region of Bologna which was used for the simulation

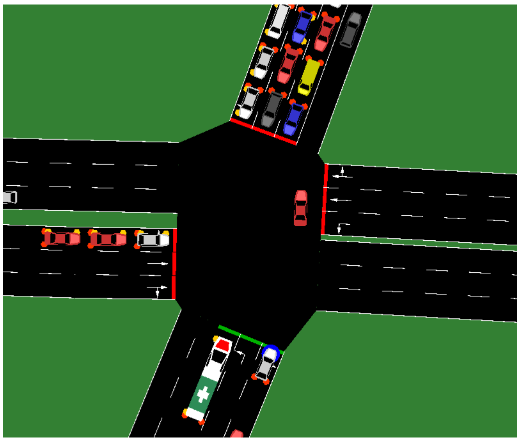
Another important issue is how to handle multiple emergency vehicles at the same time. If two or more emergency vehicles are driving at the same time the algorithm checks first whether the routes of them are having an intersection in common. If not the traffic management center can set the traffic lights two green for both routes without having any conflict. Otherwise, the application calculates the estimated time slot of the emergency vehicles at the conflicting intersections. The emergency vehicle which will probably reach the intersection first will get the priority at this intersection and after the emergency vehicle has left the intersection the second emergency vehicle will get priority. If the estimated arrival of both emergency vehicles are in the same interval, the emergency vehicle gets priority with the highest priority class. Ambulances have the highest priority class, second fire brigades and third police cars. If both vehicles have also the same priority class then the vehicle which sent the request first will receive priority and both vehicles will receive a warning message that another emergency vehicle is approaching at the same intersection.

1.5 Simulation

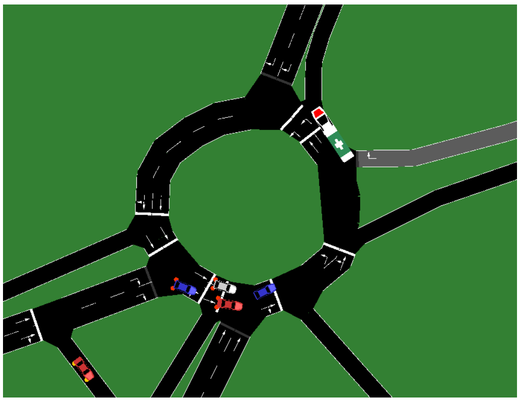
For this research the traffic of the city of Bologna was simulated with SUMO version 0.28 [10] and the used scenario was described in detail in [3]. The communication model which was used for the message transmission is described in [4]. Bologna has many traffic problems because of crowded and narrow streets. The scenario includes the area of a hospital and the football stadium of Bologna. When football games are taking place the area is extremely crowded. Therefore some lanes are restricted for buses which emergency vehicles are also allowed to use. The road network and the simulated area in SUMO are illustrated in Figure 1.2. In the simulation every traffic light was equipped with an RSU to receive the messages from the emergency vehicles. Every emergency vehicle sends Cooperative Awareness Messages (CAMs) with the current route and the vehicle type information. CAMs are periodically updated and sent and include the current information of the sender. For the message transmission of the V2X communication the standard of the IEEE 802.11p standard is used.

The vehicle type indicates that the emergency vehicle requests priority at the downstream intersections. The RSU triggers the traffic light to switch to green for the direction of the emergency vehicle and to red for all other directions. After the emergency vehicle has passed the intersection, determined again by using the position information from a CAM, the traffic lights continue their normal operations.

Currently there is no model for simulating an emergency vehicle available. This aspect should therefore be the focus of further research. Some aspects like building an emergency lane have been modeled and evaluated in [17]. While the application modifies the traffic light program in a way that



(a) Emergency vehicle receives priority at intersection



(b) Emergency vehicle gets priority at an round about

Figure 1.3: Emergency vehicle on its route in Bologna

there is no need for the emergency vehicle to violate red lights, the simulation needs only two small modifications to simulate the behavior of an emergency vehicle for the purpose of this application: having right to use bus lanes and getting priority at roundabouts, see Figure 1.3b.

1.6 Results

The simulation was performed 40 times with the same simulation scenario. For comparison 3 different scenarios have been simulated and analyzed. The baseline scenario is an emergency vehicle without surrounding traffic: the emergency vehicle was simulated in an empty traffic net. The second scenario is the simulation of the scenario with the emergency vehicle as a normal vehicle. And the last scenario is the simulation with the application for the emergency vehicle. The result of the average travel time, the waiting time and time loss of the emergency vehicle in the 3 different scenarios can be seen in Table 1.1.

Table 1.1: Simulation Results

Scenario	Travel time (seconds)	Waiting time (seconds)	Time loss (seconds)
EV without traffic	216.25	12.325	32.548
EV with traffic	229.567	19.15	46.0655
EV with Application	210.6	1.7	27.086

As expected the travel time of the emergency vehicles with the application is lower than without the application. It also can be seen that the emergency vehicle is even faster with the application than without any traffic, because of the normal program of the traffic lights. In real life of cause the emergency vehicle would not wait at the red traffic light. But still the results show that the application could support the travel time of emergency vehicles and could reduce the number of stops on its route.

1.7 Conclusions

The simulation results indicate that V2I can support the routes of emergency vehicle regarding the aspect of travel time. It was not possible to evaluate the safeness of the routes limited to the fact that it is not possible to simulate accidents in SUMO or other safety criteria. According to the literature [15] and the traffic safety evaluation [2] it is expected that emergency vehicle driving will be much safer if there is no need to violate red traffic lights.

Many V2X applications have the problem that they need a specific amount of equipped vehicles to work properly. The advantage of this applications is that only the emergency vehicles and the traffic infrastructure have to be equipped with the communication technology.

But it also has to be considered that for more reliable investigations of emergency vehicle routes a better model of emergency vehicles and their special driving behavior is needed. In reality the emergency vehicle is expected to reach its destination faster than in the simulation because of its special rights. Also another interesting aspect will be how and when other traffic participants will react to the emergency vehicle.

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