

A VANET-based Emergency Vehicle Warning System

Andreas Buchenscheit, Florian Schaub, Frank Kargl, and Michael Weber
Institute of Media Informatics, Ulm University, Germany

firstname.lastname@uni-ulm.de

Abstract—One often cited use case for vehicular networks are applications that relate to emergency vehicles. In addition to the traditional siren, they could use radio communication to warn other vehicles or to preempt traffic lights. Such an application can reduce accident risks during emergency response trips and also help save valuable time. We outline a comprehensive design of such an emergency vehicle warning system that makes full use of inter-vehicle communication, but also encompasses roadside infrastructure like traffic lights. In our system, other vehicles are not simply warned of an approaching emergency vehicle; they also receive detailed route information. Based on this information, timely and appropriate reaction of other drivers is possible. A prototype of our system has been tested in a traffic environment including emergency vehicles and traffic lights. To identify requirements and evaluate our system, we also conducted a detailed analysis of videos from emergency response trips and an expert survey among members of a local emergency response organization.

I. INTRODUCTION

Every driver knows the situation: you hear a siren of an emergency vehicle and struggle what to do next. It is often hard to locate the emergency vehicle, to decide where it is driving to, and what would be the best maneuver to give way. Therefore, drivers often react too late or in a wrong way, which can lead to severe accidents with exactly those vehicles that should bring help and relieve.

During emergency response trips, emergency vehicles have a much higher risk of being involved in accidents than other cars. With emergency vehicles, we mean all kinds of vehicles that are authorized to use emergency signaling equipment (e.g., blue lights and sirens) to be exempt from certain traffic regulations. Examples for emergency vehicles are police cars, ambulances, fire trucks, or vehicles of other emergency response organizations. The German Federal Highway Research Institute (BASt) [1] found out that such vehicles have an 8 times higher risk of being involved in traffic accidents with serious injuries and a 4 times higher risk with respect to lethal accidents compared to an average vehicle. The risk of involvement in accidents with high property damage is even 17 times higher.

Analysis in [2] reveals that in 60 percent of all cases, accidents are caused by errors of the driver of the emergency vehicle. In 30 percent, wrong behavior of other drivers is the root cause. 44 percent of such accidents happen at intersections where the traffic situation is often complex and unclear.

In addition to the high accident risk, wrong behavior of other drivers also slows down the emergency vehicle and prevents it from reaching the emergency scene earlier.

For example in traffic jams, confused drivers often do not know how and where to form a suitable corridor to let the emergency vehicle through. To support these findings, we have conducted a video survey in cooperation with a local emergency service organization. As presented in Section II, the video material highlights specific dangers and requirements of emergency trips.

By introducing vehicular networking technologies¹ either in its vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) form, stakeholders envision many eSafety applications that will enhance traffic safety. For example, applications can provide drivers earlier with additional information on traffic situations to help them react appropriately and timely to potential dangers.

Obviously, such information could be especially helpful in the case of emergency response operations. For example, an approaching emergency vehicle could send warning messages to neighboring vehicles periodically to inform them about its current position and speed. Similarly, such messages could be used for traffic light preemption where the traffic lights switch to green in the direction of the emergency vehicle while blocking crossing directions. When stopping at an accident site, an emergency vehicle can continue emitting warning messages to inform approaching vehicles of the accident.

Such emergency vehicle applications are often cited as a VANET use case, but only few projects and demonstrations have investigated these scenarios so far. sim TD² plans to implement emergency vehicle warning in its field operational trial, but details are not yet available. The most prominent example so far, might be the Rescue sub-project³ of the European GST project. GST Rescue designed a comprehensive telematics platform for rescue operations. One part of it were two VANET-based applications for creating a free corridor (“Blue Wave”) and for warning at an accident site (“Virtual Cone”). However, being one of the first projects in this direction, the VANET-specific aspects were rather limited and based only on one-hop communication. The Car-2-Car Communication Consortium held a large demonstration at the C2C-CC Forum 2008⁴ where they also demonstrated a police car sending warnings to surrounding vehicles. However, the scenario was only designed as a demonstration and rather limited.

¹We will use VANET to refer to any kind of V2V/V2I communication.

²sim TD: <http://www.simtd.org/>

³GST Rescue: <http://www.gstforum.org/en/subprojects/rescue/>

⁴C2C-CC Report: <http://www.car-to-car.org/index.php?id=89>



Fig. 1. Prepared emergency vehicle for video documentation.

In contrast, our system is based on more advanced multi-hop communications and features many aspects that provide a clear evolution of such earlier systems. In the rest of the paper, we will first present the results from our video analysis, in Section II. Sections III and IV describe design and prototype implementation of our system and highlight details that have not been addressed in earlier work. We have also demonstrated our system to experts – ambulance drivers – and conducted a survey to identify potential acceptance of and expectations for such a system. The results of the survey are discussed in Section V. Section VI concludes the paper.

II. VIDEO ANALYSIS

To better understand the issues that emergency vehicles face on emergency response trips, we equipped two emergency vehicles with digital video cameras in cooperation with the German Red Cross emergency response base in Ulm, Germany. One ambulance and one emergency doctor's vehicle were capturing the behavior of other road users during actual emergency response trips. We attached a video camera to the windscreen of each vehicle and used a GPS data logger to collect driving data, like speed and route information, over a period of 9 days. Fig. 1 depicts a prepared vehicle.

21 typical emergency response trips have been recorded and evaluated. On average, each trip is 7 minutes long and vehicle pass 4 red and 3 green traffic lights. Observation of specific intersections passed in many trips showed that each red traffic light causes additional 15-30s delay. On 50 % of the trips, there was at least one red light situation where forming a corridor for the emergency vehicle took over 30s (see Fig. 2). Wrong behavior of other road users creates additional delay. On average, 2.5 drivers reacted incorrectly, causing a total delay of about 1 min. per trip. Even more significant is the accident risk on emergency response trips. Per trip, we observed 2 dangerous situations and almost 1 near-accident (see Fig. 3).

Most of these situations and results can be attributed either to late perception of the approaching emergency vehicle by other road users – despite activated emergency lights and sirens – or to non-optimal switching of traffic lights.



Fig. 2. Very slow formation of a corridor at a red light.



Fig. 3. Near-accident, the other driver perceived the emergency vehicle too late.

III. SYSTEM DESIGN

Apparently, the current warning method of combined emergency lights and sirens draws attention to the emergency vehicle but is insufficient to prevent dangerous situations and slow-down of emergency vehicles. The warning is often recognized too late and drivers are confused about the position and direction of the emergency vehicle. This then leads to wrong reactions. In this section, we devise a warning system that disseminates warning messages in a geographic region ahead of the vehicle through the vehicular network. The aim is to complement the existing warning methods and extend the range of emergency warnings. Other road users can be warned earlier and are provided with detailed information about the route of the approaching emergency vehicle. This enables them to react timely and appropriately so that they do not block the emergency vehicle.

A. Requirements

Based on discussions in Sections I and II, we identified a set of requirements for a VANET-based emergency vehicle warning system:

- **Versatility.** The warning system should be versatile enough to support different potential applications. E.g., warn vehicles about an approaching or standing emergency vehicle, but also support controlled switching of traffic lights.
- **Timing.** Warning messages have to reach other nodes early enough for them to perform appropriate actions. E.g., a driver can move her vehicle aside in time or a traffic light can initiate a green phase after stopping the current light switching cycle.
- **Relevance.** Warnings should only be displayed to drivers or acted upon if relevant, e.g., when driving towards the

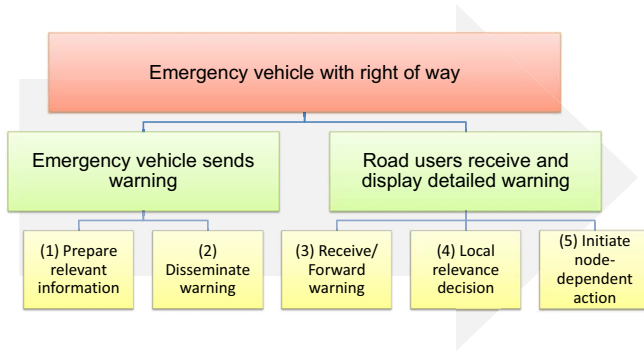


Fig. 4. Main system components and their tasks.

same intersection as the emergency vehicle but not when moving away from it.

- **Dependability.** The warning system must provide a warning to drivers when they expect one, e.g., when a siren can be heard. The system should also inform drivers if it is malfunctioning.
- **Security.** Warning messages have to be authenticated and integrity protected so that only authorized emergency vehicles can generate them. Otherwise, other vehicles could illegitimately send emergency vehicle warning messages to gain a driving advantage, e.g., clear a congested road ahead.
- **Privacy.** Personal information on involved individuals must not be disclosed, e.g., the final destination of an ambulance should not be included in warning messages to protect privacy of the patient.
- **Coordination.** The system has to coordinate and combine warnings from several emergency vehicles, e.g., when presenting a warning to other drivers. Autonomous coordination of traffic lights can also help to form green waves or clear roads from traffic.
- **Usability.** The system should be unobtrusive, intuitive, and easy to use, i.e., the interface should not induce stress but support drivers in a stressful situation.

B. System Overview

Our system takes the identified requirements into consideration. It consists of a sender component for deployment on emergency vehicles and a receiver component to be deployed on other nodes, e.g., other vehicles, traffic lights, or other road-side units. Fig. 4 gives an overview of the main system components and their tasks.

First, the sender component prepares relevant information to be included in the warning message (1). This includes information about the current position, speed, and heading of the emergency vehicle, but also information about the driving route. Based on this information, a warning message is generated. The warning is periodically disseminated (2) in a geographic area where mainly nodes are warned which are close to the route of the emergency vehicle.

The receiver component may forward received warnings (3), depending on the used dissemination scheme. A local relevance decision (4) is performed to determine how the

receiver should react to the warning. If the warning is deemed relevant, a node-dependent action is initiated (5). For example, a vehicle may display a warning message to the driver or provide audible feedback, traffic lights may initiate a specific switching procedure, and a *smart* road sign could display a warning with an estimated time of arrival. Including road side equipment as receivers in our system has the advantage that warnings also indirectly reach traffic participants not equipped with the system, e.g., older vehicles, pedestrians, or cyclists. In the following, we discuss the main aspects of our system in detail.

C. Relevant Data

For an effective warning, it has to be determined first what information is relevant to receivers and should be included in warning messages. The current position p_{EV} of the emergency vehicle (EV) is essential for receivers to assess if the EV is already in close proximity or still further away. Similarly, the Euclidean vector \vec{v}_{EV} (rooted in p_{EV} and defined by heading h_{EV} and velocity v_{EV}) enables a receiver to estimate whether the EV is approaching and when it may arrive. While this information may be sufficient on a highway, in urban scenarios the current heading of the EV may not correspond to its general direction due to the road layout. Thus, we also include information about the driving route of the EV. We assume that a destination is associated with the current emergency response assignment and that an optimal route can be calculated to it, e.g., by a navigation component. Obviously the driver of the EV can deviate from the calculated route to utilize known shortcuts or circumvent traffic. In such a case, the route has to be recalculated dynamically. Note that due to privacy and message size considerations, the complete route and especially the destination should not be part of the warning message. Instead, we use a partial route R_{EV} that spans only a certain length of the upcoming road. The length s of R_{EV} depends on the desired warning period t , i.e., how long in advance other nodes should be warned of the EV. For now, we assume an advance warning period of $t = 30s$ is reasonable to provide other drivers with enough time to notice the warning, process its information, and react to it in the correct way. The optimal value for t has to be determined at a later point through field tests and user studies. First results are given in Section V. The velocities v_{EV} and v_{RN} of the EV and a receiving node also influence s if a given t is to be met. Because only v_{EV} is known at the EV, we estimate the relative speed between both vehicles as $2 \cdot v_{EV}$. Then, the length s of R_{EV} can be calculated as

$$s = \max(2 \cdot v_{EV} \cdot t, s_{min}). \quad (1)$$

A minimum s is defined by s_{min} to ensure that R_{EV} is of useful length even when the EV is stopped or driving very slowly. Currently, we use $s_{min} = 700m$. Dissemination delay is expected to be negligible in comparison to the other parameters and is, therefore, not explicitly modeled in (1). Now, R_{EV} can be either encoded as a list of geographic waypoints or as a list of node ids, which refer to elements

of a specific map. The latter is more efficient but requires that the same road map material is available at all nodes. Additionally, a 4-digit code is included in warning messages that provides information on the organizational type of the EV (e.g., police, ambulance), the size of the EV (e.g., car, truck), and special properties (e.g., trailer). This EV code facilitates more accurate warnings that enable other drivers to identify the emergency vehicle easier and react properly.

D. Communication

Warning messages are disseminated using multi-hop inter-vehicle communication with the aim of reaching all nodes for which the warning may be relevant and providing them with a reaction window of $t = 30s$, on average. In terms of communication, we do not distinguish between vehicles and infrastructure nodes, but treat them equally. Nodes for which the warning is relevant are those that are either close enough to hear the siren (but may not see the EV) and those that are on the same route as the EV or are likely to cross it in the future. For dissemination we use geobroadcast which disseminates the warning messages in a pre-defined geographic area. In order to reach all relevant nodes, we designed a new specification for dissemination areas that better fits our needs than the traditional circle, rectangle, or polygon area specifications [3]. Our dissemination area consists of two parts (see Fig. 5): A circle with radius r around the vehicle is supposed to cover the area in which the siren can be heard. Additionally, a polygon is specified that envelopes the partial route R_{EV} of the EV with a fixed distance d and is defined by the road segments of R_{EV} . Thus, R_{EV} is reduced to a small number of significant waypoints S_i , which are differentially encoded relative to p_{EV} . This allows efficient forwarding decisions at receiving nodes, while R_{EV} , which is part of the message content, provides detailed information for the local relevance decision and warning presentation at receiving nodes. Future work will present a more detailed description and evaluation of this geocast mechanism.

The emergency vehicle now disseminates warning messages periodically with updated information. Two types of messages are used to reduce bandwidth requirements. A *full warning message* containing full R_{EV} is disseminated by geobroadcast in the whole specified region with a lower frequency of $\leq 1Hz$. A lightweight *immediate warning message* only containing id, EV code, p_{EV} , \vec{v}_{EV} , and no route information is broadcast single-hop with 5-10Hz frequency. Most nodes will receive full warning messages before immediate warnings are received, which then provide high resolution updates of the EV position and speed, when the EV is in close proximity. The immediate warning also contains enough information to provide a preliminary warning to nodes in the proximity of the EV that have not received a detailed warning before, e.g., a previously parked vehicle. In this case, the route details of the full warning refine the warning presentation when received. As mentioned above, the driver of the EV can deviate from the calculated route, in that case a full warning message is sent immediately without

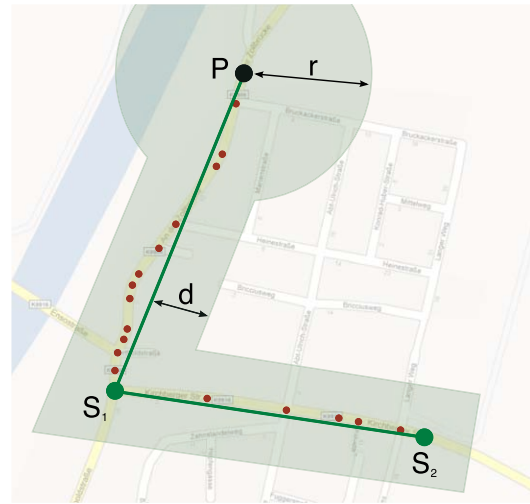


Fig. 5. Definition of an enhanced dissemination area specification for geobroadcast.

waiting for the next sending interval.

In the network, forwarding of emergency warning messages should have higher priority than non-safety applications. Priority classes [4] or dedicated channels can be used for this purpose. Messages also have to be authenticated to prevent abuse of the system. A viable approach [5] is digitally signing messages. The signature and a corresponding public key certificate issued by a trusted CA are attached to the message then. The attached certificate asserts the sender as an emergency vehicle. Receivers verify the signature before forwarding or processing the message and can ignore emergency warning messages from senders which lack the required emergency vehicle property.

E. Local Relevance Decision

When receiving a warning, a receiving node (RN) first has to decide locally how relevant this message is. This process has to take into consideration received information about the emergency vehicle and receiver-local information, i.e., current position p_{RN} , speed v_{RN} , heading h_{RN} , and available map data. From this information the distance d to the EV as well as an estimated time of arrival t_{ETA} are calculated. Additionally, potential crossings of mutual routes can be predicted. However, because the heading can arbitrarily change due to road layout, e.g., in a roundabout, the headings of the vehicles alone are not suitable to determine if EV and RN are driving in the same direction, are approaching each other, or are driving in opposite directions. Instead, the partial route R_{EV} is compared to the current route of RN, and the driving direction can be derived from the ordering of the waypoints or node ids in R_{EV} . We distinguish three relevance classes for warning messages:

- **Forwarding only.** RN and EV are moving in opposite directions or have divergent routes. Messages are forwarded but are ignored locally.
- **Information only.** RN and EV have divergent routes, but $d < r$, i.e., RN is in the range of EV and the

siren is audible. E.g., an information message should be presented to drivers to prevent confusion when hearing the siren.

- **Active warning.** RN and EV are on the same road or their routes will intersect with high probability. An appropriate action has to be initiated, e.g., a warning should be displayed to the driver with specific instructions for proper reaction.

Roadside units can evaluate the relevance of received messages similarly, taking $v_{RN} = 0$. The result of the local relevance definition determines the kind of action that will be initiated by the receiver component. In case a node receives warning messages from multiple emergency vehicles, an additional fusion step is required that merges the information from all warnings.

F. Warning Presentation

Once the relevance decision has been taken, an appropriate action can be initiated to present the warning. While our system has been independent of the type of a receiving node so far, presentation of warnings depends on it. Roadside units react only to messages that require active warnings. How they react is predetermined by their functionality. For example, a traffic light would initiate a green phase for the approaching emergency vehicle while a smart road sign could display the emergency vehicle's type and the estimated time of arrival.

Inside vehicles, the presentation of warnings is slightly more complex because warnings have to gain the driver's attention without distracting her from driving and the road. Effective warnings have to take into account the driver's cognitive processes and capacity, potential reactions of the driver, and other factors [6], [7].

We distinguish between two types of warnings corresponding to the relevance of the warning: information messages and active warnings. They are presented differently to reflect their relevance. When a warning is received that only has information value, the current position of the emergency vehicle and its route are displayed on the vehicle's driver information system beside the own route. For example, similarly to traffic message channel⁵ (TMC) icons that are displayed in modern navigation systems to provide real-time updates about traffic jams and roadworks. No further feedback is provided because the driver's attention is not required.

In contrast, the presentation of an active warning should help the driver to register and process the warning as quickly as possible and recommend a specific reaction. For this purpose, we combine visual and auditory warnings. The visual warning should be reduced in detail but also be unambiguous. Therefore, natural mappings [8] are used to facilitate quick orientation of the driver. For example, we only use abstract road outlines, leave out lane demarcations, and display the emergency vehicle in relation to the own vehicle. Based on the EV type encoded in the warning, a well-known symbol gives a cue for the kind of emergency vehicles approaching.

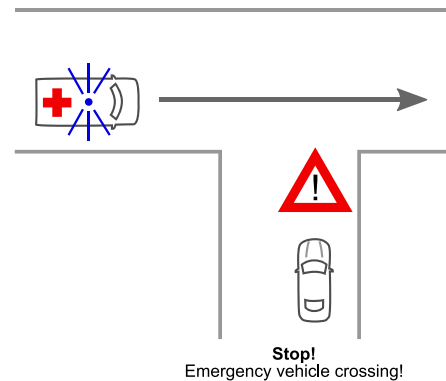


Fig. 6. Active warning when entering an intersection while emergency vehicle is crossing.

In the following, we use an approaching ambulance as an example for all warning displays. Recommended reactions are integrated as arrows in the visual warning. A textual representation of the recommended reaction is also provided, because Baber et al. [9] found that the combination of figurative and textual descriptions results in shorter reaction times.

What specific action is recommended to the driver depends on the local road context, i.e., if both vehicles are on the same road or meet at an intersection. At intersections, the driver is advised to stop and not enter the intersection, see Fig. 6. While EV and the own vehicle are on the same road, we distinguish if the EV is part of the oncoming traffic or if it is approaching from behind. In the former case, the driver is advised to remain on her side of the road and drive carefully, see Fig. 7. If the emergency vehicle is approaching from behind, the driver is advised to give way and let the EV overtake, see Fig. 8 left. Further context information can be used to provide more specific warnings. For example, in the latter case, if the vehicle is only moving slowly and a high traffic density is detected, the driver can be advised to form an emergency corridor, see Fig. 8 right. Note, that localization with lane accuracy would be required to decide whether the vehicle should move left or right.

The criticality of a warning is conveyed by varying the flashing frequency of the warning triangle symbol based on the ETA of the emergency vehicle. The closer the EV is, the faster the symbol is flashing. This is similar to parking assistants or distance warning systems [10] that use beeping and flashing frequency to convey distance.

Because humans are highly sensitive to sounds [11], additional auditory feedback is used to initially gain the driver's attention. The volume of radio and entertainment systems can also be automatically turned down to make sirens in range audible and focus the driver's attention to the warning message and recommended actions provided through speech output.

The presented examples of a potential warning interface are still of preliminary nature. The final refinement of the design of these warnings requires extensive user studies and usability tests. However, the outlined warning methods show

⁵TISA TMC: <http://www.tisa.org/en/technologies/>

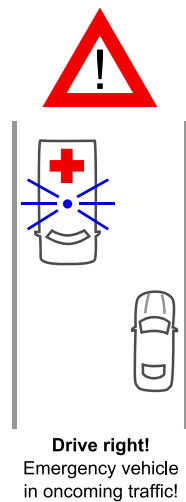


Fig. 7. Active warning when emergency vehicle in oncoming traffic.

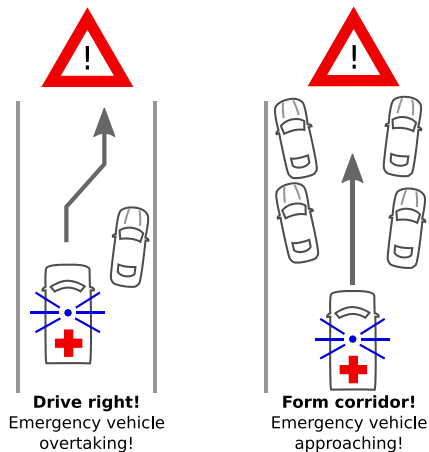


Fig. 8. Active warning when emergency vehicle is approaching from behind in normal (left) or dense traffic (right).

how such a warning system could work and interact with drivers.

IV. PROTOTYPE IMPLEMENTATION

We implemented our system as a prototype to demonstrate the functionality and the improvements of our warning assistant in real environments. The prototype implementation is based on U²VAS [12], a flexible and extensible research and experimentation platform for VANETs. All components, whether applications or core functions, are realized as plugins that can be configured at run-time. The core distribution already contains a rich set of communication mechanisms (IEEE 802.11 support, beaconing, geobroadcast, position-based routing), positioning mechanisms (GPS or trace playback), security components (PKI-based authentication, pseudonymity support), and demo applications (radar view of neighboring vehicles based on Google Earth, accident warning, attacker simulation). The whole stack is written in Java and uses the Java Plugin Framework (JFP) to provide an extensible architecture.

To transmit different types of data, the stack uses chained headers for flexible development. Each packet consists of any number of header-payload-combinations. The header indicates the type of the appropriate payload in each case. In our case, warning messages consists of the *SourceHeader*, which holds information about the sender (identification number, time stamp, current position, ...). Relevant data for our warning system is located in the *EmergencyVehicleHeader* (type, current direction vector and partial route of the emergency vehicle). The *DestinationHeader* defines the receiver area. Integrity and authentication is provided by the *SignatureHeader* and the *CertificateHeader*. The stack can support any physical interface if a corresponding translation plug-in is provided that (de-)serializes the headers into packets and back. Our prototype uses IEEE 802.11 wifi in the IBSS mode and directly broadcasts link-layer frames.

Our prototype consists of three application plugins. One sender component for the emergency vehicle to define the route to the emergency site and to activate the transmission of warning messages. The first receiver component is used by other vehicles to handle received messages and to display warnings to drivers. A second receiver component implements the control of traffic lights. In the following, the three plugins are described in detail.

A. EmergencyVehicle-Plugin

The sender component is responsible for collecting all relevant data. As described in Section III, the sender plugin knows the type of the emergency vehicle and determines the current Euclidean vector and partial route. In order to derive a partial route, a complete route to the destination has to be defined first through the user interface. Once the route has been defined, the dissemination of warning messages can be activated by a single button. On later systems, this functionality should be combined with the activation of the emergency lights and the siren. If navigation equipment already exists which can perform the calculation and definition of the route, fully transparent integration of the system is possible. Note that most of the functionality of the plug-in is not visible and remaining operation of the application is expected to be done by the co-driver.

Our prototype uses the OpenStreetMap (OSM) API⁶, which provides free geodata provided by community members. OSM data is used to render a detailed map with the EV's current position and clickable streets for interactive route definition (Fig. 9). Inquired map data is cached locally to enable usage without Internet access, e.g., when testing on the road.

B. EmergencyVehicleWarning-Plugin

Other vehicles and road users run the EmergencyVehicleWarning-Plugin. It also provides a map view with the current location to simulate a vehicle information system. If an emergency vehicle is close by, a relevance decision component handles the received warning

⁶OpenStreetMap-API: <http://www.openstreetmap.org/api/0.6/>

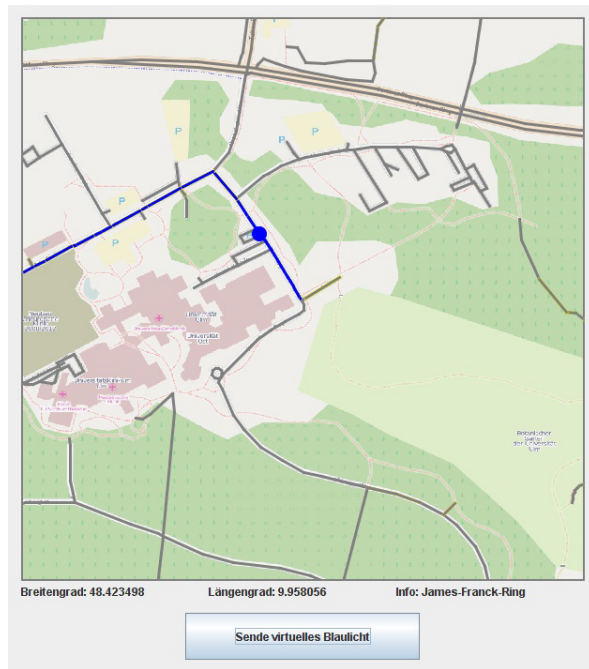


Fig. 9. User interface of the EmergencyVehicle-Plugin.

messages and decides which warning has to be displayed. As described, there are three different display modes. No warning (forwarding only), information only and active warning. No warning means that the user gets no additional information except the map view with its position. In case of information only, the current position of the emergency vehicle and its partial route are displayed in the map view. If an active warning should be displayed, the map view switches to active warning view where a warning message is displayed full screen. See Fig. 6 to 8 for examples of warning messages.

C. TrafficLight-Plugin

To demonstrate the control of traffic lights we implemented another application plugin as a specific receiver component for traffic lights. It simulates a static traffic light and shows how the sent warning messages could interrupt a cycle of operation for emergency vehicle preemption. As already mentioned we do not distinguish between roadside units and vehicles until the presentation of the warning, therefore, the EmergencyVehicleWarning-Plugin and the TrafficLight-Plugin only deviate in the actions they initiate. Thus, the traffic light does not require separate triggering.

D. Prototype Testing

To test and demonstrate the feasibility of our new system, an emergency doctor's vehicle and two more vehicles were equipped with our prototype running on conventional notebooks. Furthermore, we simulated a traffic light with another notebook running the corresponding plugin. On all test runs, the warning message was displayed in other vehicles before the EV was visible, especially on unclear and curvy roads.

Our successful test runs validate the operability of our prototype in real environments.

V. EXPERT SURVEY

To evaluate how experts judge the need for additional safety measures and how they would rate and accept our system, we also conducted a survey with 36 members of the German Red Cross in Ulm, Germany. All participants had at least 6 months of active experience with rescue trips, both as drivers and co-drivers in ambulances.

The survey was conducted in three steps. First, the participants filled out a questionnaire to assess the current safety situation without VANET support. Afterwards, we gave a detailed introduction to the concepts of VANETs and our warning system based on our prototype implementation and user interface. Then, participants were asked to assess the expected improvements from such a system with a second questionnaire. The questions also included a discussion on required warning periods to get a qualified estimation on how much in advance drivers would need to be alerted. In the following, we present an excerpt of the survey's results and findings.

The first questionnaire distinguished the current situation on straight roads and at intersections, in correspondence with our identified use cases. Asked about the perception and reaction by others, 56 % stated that emergency vehicles are often perceived too late and, thus, other drivers react too late (66 %). Furthermore, reactions of other traffic participants are hard to predict according to 84 % of the ambulance drivers, which results in often dangerous situations when overtaking on straight roads (61 %). However, the current situation at intersections is considered even more severe. 72 % of the ambulance drivers stated that the situation at an intersection is unclear even when the EV is approaching with activated emergency lights and siren. 73 % name insufficient perception of these warning measures as a reason for the unclear situation. 83 % state that the risk of collisions is the highest when driving over a red traffic light into an intersection. In contrast, the collision risk is significantly lower when the emergency vehicle has a green light (89 %). 78 % believe that the overall accident risk would be reduced if all traffic lights on a rescue trip would be green. Additionally, a green wave would also save time (78 %). These answers indicate that adaptive switching of traffic lights in favor of the emergency vehicle could improve the current situation.

After a demonstration of our system, the participants first answered questions concerning the general perception of the warning system. 78 % of the ambulance drivers think that the additional warnings are useful, because emergency lights and sirens are insufficient. Also 78 % believe that such a system could lower the overall risk during rescue trips. That severe accidents with involvement of emergency vehicles could be prevented by the system was only believed by 56 %. The remainder of the second questionnaire was again split into questions concerning situations on straight roads and at intersections, now with the goal of assessing the benefit of the demonstrated system. On straight roads, 84 % believe

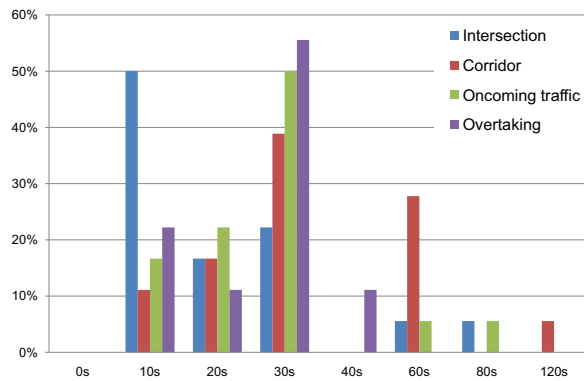


Fig. 10. Resulting estimates for the required warning period t in different situations.

that the system would improve the situation, because other drivers would know earlier how to react (67%) and have enough time to give way (72%). At intersections, 84% believe the system would improve the situation. Especially the integration of traffic lights is perceived as an improvement. 89% think that unclear situations at intersections would be made clearer and less dangerous if the emergency vehicle would not have to cross a red light. A green wave would also help to save sufficient time (83%).

Participants were also asked to estimate the warning period t (limited to 10s steps) required by other drivers to react properly in different situations. Fig. 10 presents the estimates for vehicles entering an intersection, when the emergency vehicle is approaching from behind in normal traffic and dense traffic (forming a corridor), and when the emergency vehicle is approaching from ahead. As can be seen, the expert participants confirm our initial assumption $t = 30s$, which was based on human reaction, orientation, and cognitive abilities. However, at intersections a 10s advance warning is deemed sufficient. An explanation could be that, drivers should not be unnecessarily warned before they are almost at the intersection. Obviously, extensive field tests and studies are required to obtain objective values for t . But $t = 30s$ seems like a reasonable initial assumption, considering that the participants of our survey are confronted daily with such situations as ambulance drivers as well as from the perspective of normal drivers.

VI. CONCLUSION

As shown in the motivation and video analysis, emergency response trips can pose a significant danger to traffic safety. Using VANET technology to deliver additional information about emergency vehicle positions, speeds, and routes to other traffic participants and infrastructure can help to make such operations safer and faster, and thus potentially save lives.

With our work we want to contribute directly to the development of such systems. Evaluations with experts have shown that we can expect a good acceptance once those systems are ready for deployment. Before this, some technical challenges have still to be solved, which will be the

focus of our on-going work. Field-trials and simulations are required to analyze the effectiveness and safety of such systems in larger networks. Additional questions to address are the system's security, privacy, and scalability.

We think that enabling emergency vehicle applications could also significantly contribute to the market introduction of VANET technology and needs further attention beyond the current level. Many discussions with stakeholders about VANET market introduction center around the fact that eSafety applications require a minimum market penetration before being attractive for vehicle customers. Usually, 10% equipment rate is seen as a minimum requirement. Before that, there is no incentive to pay extra for the eSafety equipment. While many suggest to focus on non-safety applications with a direct benefit for market introduction, we believe that eSafety applications should not be delayed.

Emergency vehicle scenarios provide the opportunity to circumvent this chicken-egg-problem. If public authorities would equip all emergency vehicles in a region with on-board units and all traffic lights with receivers and relays, every driver investing in an on-board unit for his car would immediately benefit from the applications outlined in this paper. And as we have shown, through the integration of traffic lights and other roadside equipment traffic participants and pedestrians not yet equipped with the technology can be warned implicitly and benefit as well.

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