Research Article

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Raising security of first responders with C-ITS?

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Abstract: This article recommends social science research-based recommendations for improving first responder safety and occupational health by assessing cooperative intelligent transport systems (C-ITS) for use by emergency services and law enforcement. This involves vehicles using digital technologies to inform each other or via objects such as roadworks signs about traffic situations and dangerous circumstances. The application of information and communication technologies to the road transport sector and its interfaces with other modes of transport shall make a significant contribution to improving environmental performance, efficiency, including energy efficiency, safety, and security of road transport. This article investigates which social science aspects must be considered when implementing C-ITS, so that emergency vehicles such as ambulances can be given automated priority. Since emergency vehicles can communicate with traffic signal systems or other vehicles, safety requirements play a particularly important role. This leads to the question of which challenges subjective safety and technology perceptions regarding first responders are essential for the introduction of C-ITS for first responder organizations and which factors can lead to rejection.

Keywords: C-ITS, first responder health, first responder organization, technology

1 Introduction

Cooperative intelligent transport systems (C-ITS) are a steadily growing sector that is becoming increasingly important in European countries. Countries and the European Union itself fund research into C-ITS technologies and implementation for several years [1]. One example is the Austrian project EVE – "Efficient Prioritization of Emergency Vehicles in Automated Road Traffic (EVE)" – on which this article is based [2].[1] The goal was to conduct multidisciplinary research on the automatic prioritization of traffic signals for first responders. With C-ITS, emergency vehicles can request priority at a traffic light intersection or warn other road users. This can save valuable time and nerves at a rescue operation and prevent traffic accidents involving emergency personnel. On the other hand, these forms of connected driving can also cause new safety problems. These lie in both technical and security challenges as well as the question of the integration of technological developments into the working reality of first responders [3]. This article focuses on the last point, the sociological aspects of implementing C-ITS into first responders' existing work environments and their openness to and trust in these new technologies.

To approach this challenge, expert interviews with the Vienna Professional Fire Brigade, the Vienna Professional Rescue Service, and the Austrian Red Cross and workshops with stakeholders with several feedback loops should approach their workflows and attitudes to this technology.

2 C-ITS

Due to the growing number of vehicles and selfish driving behavior, traffic accidents are a major societal problem that affects both public health and national economies. In addition to awareness and policy programs (e.g., speed reduction, seat belt use), C-IST are considered key technology for road safety and traffic efficiency [4]. These new technologies in vehicles enable direct short-range communication, e.g., vehicle-to-vehicle, vehicle-to-infrastructure,

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1 This article summarizes results from the research project "Efficient Prioritization of Emergency Vehicles in Automated Road Traffic" (EVE). EVE is supported and partially funded by the Austrian National Security Research Program KIRAS (Austrian Federal Ministry of Agriculture, Regions, and Tourism (BMLRT) and Austrian Research Promotion Agency (FFG) – Project Nr. 867024). https://www.kiras.at/gefoerderte-projekte/detail/eve

vehicle-to-pedestrian, and vehicle-to-something (V2X) [5,6]. Another distinction must be made here between autonomous and cooperative automation. Autonomous vehicles rely purely on sensors on board the vehicle. Cooperative automated vehicles incorporate information transmitted to them by the road infrastructure or other vehicles. In this way, crashes can be prevented even more efficiently – at least in theory – and for example, first responders can be given priority at traffic lights [7]. Selfish behavior in traffic is considered a major cause of congestion and stop-and-go waves, which in turn lead to accidents, stress, lane restrictions, increased exhaust emissions, and fuel consumption [8]. C-ITS can lead to smoothing in this regard by considering algorithms with altruistic agendas in technology development. This in turn benefits the efficiency and stress minimization of first responders [9–11].

The communication systems involved, called road-side units and on-board units, can be integrated into infrastructure or vehicles, respectively, and operated independently. Here, all participants must have the same expectations of the service. Interoperability at the technical level, agreed on trigger conditions, compliance with traffic regulations, a common understanding of expected driver behavior, etc., must therefore be considered in the necessary interdisciplinary development [12]. The technological potential here has been accompanied by standardization and research programs addressing radio channel modeling, data transmission protocols, wireless communications, network protocols, and security issues, as well as privacy and resource management [4]. However, concerns and research gaps remain regarding traffic safety, privacy, traffic flow, energy and environmental impacts, land use, vehicle industry economics, cybersecurity, and integration into work environments [7].

Therefore, ongoing research includes significant efforts to identify risks and define strategies. When it comes to prioritization from the emergency vehicle, V2X communication can be coupled semi-automatically to the manual use of emergency lights or a siren. This can mitigate any reservations that emergency vehicle drivers may have about purely automated operations.

3 First responder health

Accidents not only affect the health of the victims but can also significantly damage the (mental) health of first responders, which include police, fire, search and rescue personnel, and emergency and paramedic teams [5,6,13]. First responders are usually confronted with difficult, dangerous, and stressful situations. This in turn increases risks and consequences for their own health (e.g., PTSD, stress, and depression). Consequences subsume disorders as diverse as acute stress disorder, adjustment disorder, somatoform or dissociative pain disorder, affective disorder, and substance dependence, but also post-traumatic stress disorder [5,14]. The effects go from somatization and concentration disorders to depression, phobias, and paranoia to isolation and aggressiveness. This massively affects the health of individuals as well as their environment [15]. In addition, first responders are also exposed to a high risk of being involved in traffic accidents themselves [16,17].

Different studies show that the group of professional drivers behaves differently in traffic than private drivers [18–21]. Considering the daily context of emergency driving, first responders are more likely to be involved in dangerous situations and accidents and more likely to be injured. They are more prone to driving at higher speeds, not wearing their safety belts, and/or in an impaired condition [22]. Traffic-related death rates for police officers, firefighters and paramedics are 2.5–4.8 times higher than the US National average [16,23].

According to Symmons and Haworth [24], seven factors can be distinguished that have an influence on the driving safety of emergency vehicle drivers: awareness and assessment of the situation, stress level, distractions, pressure or increased workload, driving at high speed, driving at night, and adverse weather conditions [24]. But the emergency vehicles themselves are also a significant factor; for example, the size and mass of emergency vehicles can be protective of their occupants. At the same time, however, the vehicle is also difficult to maneuver [25]. The equipment, such as radio transmitters, warning devices, and map navigators, also requires different multitasking activities than private drivers. Because here it is often necessary to take your eyes off the road [16]. Despite the bright, sometimes garish colors, recognition of emergency vehicles often remains a challenge for other road users, depending on the ambient conditions (e.g., twilight and rain). Fluorescent materials offer little additional benefit during the day but at night, as they interact with ultraviolet radiation [26]. Warning lights and sirens, in turn, have a negative impact on vision and hearing as well as physical and physiological systems [27]. In addition, drivers experience an adrenaline rush, which promotes the feeling of invincibility and leads to more aggressive traffic behavior. Intersections in particular are a danger point here [27].

Connected vehicle technology and efficient prioritization of emergency vehicles can reduce risks [28]. But minimization of risks to the physical and mental health of first responders requires confidence in the technology. Studies show the importance of considering the impact of new technologies on existing processes and workflows. It is crucial to understand the processes and activities of potential users to involve them in technology development. Only in this way is there a possibility that the functions necessary for the users can be covered by these new technologies [3]. Technology is used when it is accepted [29]. This in turn is related to trust in the technology, and whether it can reliably fulfill the desired functions. The aim of the social scientists was to record possible positive as well as negative effects of implementing such a communication system to increase acceptance.

4 Materials and methods

To answer the research question on existing challenges of emergency drives as well as on opportunities of a technological communication system, the social scientists conducted qualitative expert-interviews as well as ongoing technology-assessment workshops. The aim of the social science part of this project was to intervene in the processes of technology design and innovation actively and constructively. Therefore, selected societal problems form the starting point of an interdisciplinary analysis and design process in which all relevant actors are to be involved. Particularly, qualitative, in-depth methods and feedback loops were used here to analyze the working realities to gather the existing knowledge about emergency drives of first responders.

Particular attention was paid to the challenges faced by emergency vehicle drivers, the context, and general conditions of first responder driving, and the existing wishes for improvement and expectations of the operators. To this end, an interview guide and a declaration of consent including data protection information were prepared, which was made available to the participants in advance and signed by all of them. Subsequently, five qualitative expert interviews were conducted between July 2019 and November 2019 with ten representatives of the following first responder organizations: professional fire brigade, police, and ambulance like Red Cross in Vienna [30]. These five semi-structured expert interviews [19] were conducted with one to two participants each to evaluate emotions, challenges, and needs of emergency driving. These were drawing on the qualitative content analysis according to Mayring [31].

In the second methodological phase, the results of the interviews were presented and discussed within the project consortium and subsequently presented to various stakeholders in workshops via group discussions [32]. The participants were selected to include both "insiders," developers and supporters, and "outsiders," users, and regulators [33]. The 21 participants represent the different actors that are affected by such a communication system. Representatives of infrastructure and road operators, as well as vehicle manufacturers, maintenance providers, and third-party service providers, were recruited, as well as representatives of emergency drivers, road users, authorities, and the public. The workshop was divided into two phases: the first was for brainstorming and assessing possible consequences of integrating C-ITS into the process of driving in emergencies, and the second phase was for brainstorming and discussing possible solutions. In the context of the workshops, the previous results were further developed in the sense of constructive technology assessment (CTA) [34]. Organized as an exploratory research and design process, CTA uses diverse, heterogeneous sources of information [35].

This method mix identifies opportunities as well as risks of a practical implementation of the new technical communication system. In addition, options for action and design can be derived that advance desirable opportunities and counteract undesirable risks.

A limitation of the study is an unbalanced gender distribution among the participants in the project. Despite the efforts to involve more non-males in the project, it was not possible to achieve a balance due to an over-representation of men in the different areas. For this reason, it must be considered that the male perspective on the topic could be overrepresented in the results. Among the interview partners, there was only one woman, and only three women participated in the workshops. At the same time, ten interviewed first responders automatically impose a certain limitation. In combination with the workshop with various stakeholders in the transport sector, however, important perspectives of the end users could be brought to the table in the sense of the CTA, and thus, new realistic approaches to solutions could be found through the mix of methods. The insights gained here have subsequently been used to define technical processes that can support emergency services in their tasks.

5 Findings and discussions

The findings of this article may be separated into two categories, according to the research question. First, the authors will present those challenges the emergency vehicle drivers put at the center of attention. Second, the article will outline the main opportunity of a car-to-car communication system that can contribute to first-responder occupational health, as well as some risks that come along with it.

5.1 Challenges of first responder driving

5.1.1 Definition and delimitation of the emergency drive

Although the focus of the expert interviews was on the practical procedures, i.e., on the processes and actions surrounding a drive, the interviewees repeatedly raised the issue of the delimitation of this kind of driving per se. The interviewees explained that, on the one hand, there is a legal definition that delimits an emergency drive as such. This is regulated in the Austrian Road Traffic Act 1960 §26 and linked to the use of emergency signals (light and horn). The legal regulation is inflexible and seems to prescribe a clear demarcation. However, the interviewees unanimously argued that the internal definition of an emergency drive depends on many more factors. Each organization has a clear understanding of what constitutes an emergency drive, but these differ between organizations and do not necessarily coincide with the legal definition. For example, one interviewee noted, *"It's not an emergency drive by law, but for our colleagues it is of course an emergency drive within the organization." (IP3_1)*

Basically, the following factors are mentioned that influence the delimitation of an emergency drive: decision of the emergency team, nature of the incident/condition of the patient, time of alerting/starting the journey, and use of emergency signals.

Particularly regarding emergency signals, controversies exist. While the prerogatives of an emergency vehicle are linked to the use of special signals such as lights and horns, their use often leads to greater challenges in the interaction with other road users. For this reason, the emergency signals are not always used by some organizations: *"Sometimes it is simply better to – I say it this way – sneak up on people. Because then the reactions of the road users are somehow not so hysterical. But as a rule, the special signal is used when it is appropriate." (IP1_1)*

5.1.2 Emergency drive and behavior on the road

Even though emergency drives are an everyday occurrence for drivers, they constitute an extreme situation, and the interviewees are aware of the potential dangers involved. The challenges addressed on the road can be divided into two types, situational and contextual challenges, and the challenges of interacting with other road users.

Situational and contextual challenges are those that depend on framework conditions such as the operational area or special traffic situations. An urban area, for example, poses completely different difficulties than a highway. The interviewees highlighted the Viennese urban area as particularly complex due to the high density of traffic, the narrowness of the streets, and some dangerous intersections. Special intersections or road sections are avoided wherever possible. Regarding the freeway, the emergency lane is perceived as a positive initiative, if it works: *"It's simply a completely different environment. If I'm lucky on the highway and an emergency lane is formed, it's easy. In the urban area, I have so many variables that have an impact there." (IP1_1)* However, emergency vehicle drivers are used to slowing down or even stopping due to lane constrictions or because common drivers did not form an emergency corridor, as required by law in Austria. Another challenge is the encounter of emergency vehicles at intersections. These situations occur mainly with emergency vehicles from other organizations but can also occur with emergency vehicles from the same organization in the event of a departure from different locations. In principle, there is a legal regulation between different first-responder organizations as to which vehicle has the right of way: First, the ambulance/paramedic may drive, then the fire truck, and only then the police. However, this regulation is very static, and there are also variations in practice, which the emergency vehicle drivers perceive as challenging in different ways. Accordingly, the decision is made situationally. The order in which vehicles approach the scene of the incident is also oriented toward the sensibility of the situation. If several first-responder organizations are alerted to an incident, the drivers try to position their vehicles to give the necessary space to the organization that acts first. The issue of access is also challenging on the highway, as the emergency corridor initially formed by road users is often closed by them after the first emergency vehicle has passed through. This then prevents other first-responder vehicles from passing through and thus from reaching the scene of the accident.

The interaction with other road users is highlighted as the greatest challenge regarding emergency driving safety. The perception of the emergency vehicle and the reactions to it play a key role here. According to the interviewees, emergency vehicles are often noticed too late by other road users. On the one hand, this is because the emergency signals may be audible or visible, but it is often difficult for road users in dense urban areas to locate where these signals are coming from. Furthermore, it depends on the situational conditions how well these signals can be recognized: While the light can be perceived more difficult in bright sunshine than at night, the sound of the followup horn is easily reflected by high buildings and gets lost. On the other hand, road users are often distracted or limited in their sensory perceptions by other activities. Some examples of this are the radio of car drivers, but also the headphones and the smartphones of pedestrians or cyclists: *"And what I personally notice is that when you are already driving 500 meters behind vehicles – with the horn blowing and the blue light on – that people only swerve in the last two meters, because they are distracted by cell phone calls, or by various other activities that they do, like they listen to the radio too loudly in the car." (IP3_1)*

Once the road users have recognized the emergency vehicle, many do not react as expected, as another interviewee pointed out: *"The classic challenges are once again the road users. Estimating how they react to the emergency drive, to the flashing blue light, to the horn. They very often react atypically." (IP3_1)* The impression of the interviewees is that many road users do not know how they should behave when encountering an emergency vehicle and are therefore overwhelmed by the situation. In many cases, car drivers react incorrectly and brake, which causes the most complications because the emergency vehicle is prevented from continuing its journey or is slowed down. Thus, the wrong reactions of other road users endanger not only themselves, but also the emergency vehicle drivers. The interviewees believe that driving schools have a responsibility here and would like them to practice the correct behavior in dealing with emergency vehicles with their students as early as possible.

5.1.3 Role and acceptance of technology

As different as the opinions of the various interviewees are about technology, so is its integration into the everyday processes of their emergency organization. Based on their attitudes toward technology, emergency organizations can be divided into three groups: (a) the traditionalists, (b) the interested, and (c) the innovators. This classification can and should provide information on the extent to which C-ITS can contribute to the (mental) health of first responders or how much an implementation can lead to rejection and uncertainty.

The (a) traditionalists rely on human expertise and avoid incorporating technology into their processes: *"My personal opinion is: as little technology as possible in a vehicle." (IP4_1)* Even common technologies, such as navigation devices and GPS trackers, are under ongoing negotiation and are only used when necessary. In principle, the first responder should be able to do everything that the technology can do. These organizations sometimes decide against the use of technology despite the wishes of their personnel. Their skepticism about technology is based on the fear that the use of technology leads first responders into a kind of dependency and that reliability is not given to the same extent as when an action is carried out by technology and not by an individual: *"We force them (*authors note: employees*) to know the city area well, so that they take alternative routes out of instinct and don't somehow wait for a system to suggest it to them. (IP2_1)* Furthermore, traditionalists assume that the use of a technology displaces the self-determination of the first responder, because they do not dare to take the responsibility to turn against a recommendation of the system.

The (b) interested organizations use common technologies and are interested in newer achievements such as C-ITS. However, it is important to them that technologies only supplement or support human activities, but do not replace them. Especially in dealing with emergencies and operations, humanity and a feeling for the situation are seen as the most important prerequisites for successful work. At the same time, however, this group points out how helpful certain technologies can be for employees who must cope with many demands on their person. The systems are excellent for supporting people, if the decision-making power lies with the person: *"Many things are suggested quite well by these systems and the fastest car, that's wonderful. But it just lacks that gut feeling, which is what matters sometimes, though." (IP1_1)*

The (c) innovators see technologies and automatisms as the essential components toward improvement and further development. They want to see all technical potential exploited and constantly come up with new ideas on how technical systems could support emergency response organizations. In doing so, they deal with new technologies from the international field as well as with their own creations. However, it is important to them that technologies are not implemented for their own sake, but that they should also provide meaningful support for employees. In addition, this group sees technologies as helpful, especially in dealing with emergencies and operations, since ethically challenging situations often must be solved quickly and based on neutral parameters. In this way, employees can be provided with neutral guidelines in the form of a system that can support them in such stressful situations. In order to do justice to the general welfare and the exhausted potential, representatives of this grouping would also consider new regulations for individual technology use: *"I could imagine, that the emergency vehicle transmits something where some system – that you are not allowed to switch off* *or cannot switch off at all – (…) that then these devices that are playing music on your phone play "Attention emergency vehicle"." (IP3_2)*

5.1.4 Requirements for emergency vehicle drivers

While some interviewees see technology as a restriction for employees, others see it as an opportunity to improve or further develop processes in general and to support their first responder drivers. This support is becoming an issue, especially in view of the diverse demands placed on emergency vehicle drivers. Competent first responder drivers should therefore have several years of experience in the specific field, excellent driving and local knowledge, and a good sense of direction. In addition, a feeling for the situation is necessary, as well as humanity in dealing with the people affected by the incidents. Furthermore, there is a need for specialist knowledge, which differs from one first-responder organization to the next, a quick grasp of the situation, the ability to work in a team, as well as the ability to work under pressure and spontaneity to react quickly in an emergency.

If technologies are now used to relieve first responders of the demands placed on them, three functionalities of a technology become apparent. First, it should be noted that a specific requirement for the emergency vehicle driver cannot be covered by a technical tool, i.e., the individual must master these skills despite the use of technologies. Thus, technologies are merely a supplement in the form of a backup. For example, the navigation device does not replace the local knowledge of the driver but only serves as a backup to be able to provide this ability in any case. Second, there are cases in which the technical tool provides information that the driver would not have been able to provide without its help (e.g., accident data memory), but even in these cases the technology does not replace the employee's ability but provides additional information. In this function, the technology can support the emergency driver with additional information beyond the basic requirements. Third, the technologies used have an active effect on the skills required of the employee. Thus, the requirements for the emergency driver in dealing with technical tools are additionally extended by the following skills: skills in dealing with technical tools, evaluation of technical information, as well as self-confidence and assertiveness.

Skills in handling technical equipment means being able to operate it properly, understand fault messages, and ensure cooperation. If the employee is given information from an accident data recorder, for example, these figures and instructions must be applied in practice and their effects and correlations with the emergency drives must be brought to bear. The evaluation of technical information means the reasonable integration of the additional information by technical devices. Finally, when interacting with technical devices, the emergency vehicle driver needs a certain self-confidence and assertiveness. As mentioned earlier, the interviewees agree that the decision of the human should always be above that of the technical device. However, this also means rejecting a recommendation and asserting oneself against it. It is the requirement of this ability that prevents some organizations from implementing certain technologies: *"We simply believe that if we were to prescribe routes or use navigation systems, everyone would stick to the navigation systems and would then hardly dare to drive differently than the navigation system suggested. (…) So to speak, (authors note: the willingness) to take responsibility, to go against an established system, is very low." (IP2_1)* This refers specifically to personal responsibility, which increases as a result. Without technical support, the driver must also decide for themselves, e.g., which route to take. But going against a recommendation leads to the assumption of responsibility on a new level, should problems arise. This illustrates the requirement for personal responsibility that is demanded of the emergency driver when dealing with technical devices. So far, the technical tool can only be understood as a tool that provides additional information. Whether this information is used or not and how it is incorporated into occupational safety and health behavior is the responsibility of the emergency vehicle driver.

5.2 A great opportunity and some risks of car-to-car communication

5.2.1 Increased physical safety and more efficient healthcare delivery

The greatest opportunity a car-to-car communication could bring with it is an increase in safety for all road users involved, but also more efficient health care for society. The participants of the interviews as well as of the workshops shared the hope for a reduction of accidents with emergency vehicles as well as time saving in the handling of operations. The reduction of accidents is based on the reduction of complexity, which affects both emergency drivers and other road users. For road users, the horn and blue light are ambivalent signals – they are normally aware of their alarming significance, but they do not receive any information on how they can best react to the situation in question. This circumstance makes the encounter with an emergency vehicle a complex situation for road users, which is associated with uncertainty. A clear message, send from the emergency vehicle to the driver's vehicle, could make a huge difference. Due to additional information linked with concrete instructions, such as e.g., a red light or the suggestion to move to a specific side, road users are relieved of the decision of the right behavior and the probability of an accident situation is lower. In this way, both the situational awareness and the handling of the situation of the road users are improved. This in turn reduces the complexity of the situation for the emergency vehicle drivers, who are more likely to be confronted with adequate reactions. This increases the safety of emergency drivers, as they run less risk of getting into dangerous situations. The instructions to the road users must be situation-related to correspond to concrete road and intersection conditions. Moreover, the adequate behavior of the road users leads to time savings for the emergency drivers, who have less trouble avoiding other road users. This means that they can reach the scene of an accident more quickly and can treat their patients more quickly. This enables more efficient deployment in critical situations, which has a positive impact on the health of those who are dependent on the rapid progress of the emergency vehicle – such as accident victims. Beyond the people already in care, the time saved helps to use the available resources more efficiently. This means both emergency vehicles, which are available again more quickly, and personnel, who can attend to other victims more quickly.

Like with any technology, there are certain risks that must be kept in mind, when thinking about the implementation of a C-ITS infrastructure for emergency vehicles. These are problems in the operation by the user, vulnerability of the system, and responsibility and liability.

5.2.2 Utilization problems for the end-user

First, the complexity of the mission increases for the drivers, who must operate and consider an additional technical tool and its effects. Accordingly, the emergency vehicle drivers need additional competencies to deal with these new developments. It is important that for the emergency vehicle drivers the additional effort in the situation is kept to a minimum so as not to overwhelm them and distract them from acting in traffic: *"It must be totally easy for the driver to make decisions, because the situation is difficult enough as it is. That is certainly a challenge for the HMI, the human-machine interface; it must support the emergency driver." (W1PM_FR, 1.49)* In any case, the use of the communication system requires a change in thinking on the part of the drivers.

5.2.3 Vulnerability of the system and unclear responsibility and liability

In addition to intentional interaction with the system, as with any technical interface, there can also be malicious interventions by unauthorized persons, i.e., cybercrime. Perpetrators can not only try to reduce the functionality of the system, but also to manipulate it: *"Every interface is a potential target of attack and then you must not forget that other communication than the intended one could also come in here." (W1PM_VO, 1.37)* However, it is not only the vulnerability of the systems that is crucial, but also how data are handled. This raises the questions of how openly the collected data should be handled, but also how it is communicated and stored.

Finally, it could be that the legal framework is not adapted quickly enough or sufficiently to the new technology. This could lead to drivers of emergency vehicles assuming other road users have more information or recommendations for action. In addition, special legal conditions must be clarified, such as how to deal with over-the-air updates. These can interfere with fundamental functions of the vehicle. This raises the question of how this responsibility for the vehicle can be clarified and how uniformity can be made possible in the interests of the driver: *"Somehow, the legislator will have to consider to what extent manufacturers can be given a free hand and in what areas the authorities have to look over it each time. Which changes in the software must be typified or accepted in some form." (W2PM_BR, 0.53.0)*

Even though at first glance these points have nothing to do with first responder health, they were mentioned by them as factors of insecurity toward the system, which can lead to inherent stress and rejection. Therefore, these higher-level factors must also be considered during implementation. In this way, approaches to solutions can also be addressed in subsequent end-user training sessions.

During the workshops, these risks, which could wantonly disrupt the safe and reliable operation of an emergency vehicle prioritization system, were discussed in detail. As possible solutions against cyber-attacks and acts of sabotage, the entire C-ITS life cycle of emergency vehicles and their on-board equipment from installation to decommissioning as well as relevant use cases were thus subjected to a security analysis. While the technical provisions foreseen by the relevant standards in general provide strong security, detailed security management processes need to be specified. The exact procedure was explained in detail and published in the study by Langer et al. [36].

5.2.4 Summary benefits and risks

The emergency drivers participating in this study see relief from other implications of automated systems and are generally positive about a technical system that makes recommendations. Benefits of a C-ITS-supported emergency vehicle, including savings in time, improved situational awareness, and increased safety for all involved.

The technology assessment also indicated several concerns from various stakeholders regarding the use cases studied. The following factors were identified as hazards: severity (amount of harm caused by the hazard), exposure (likelihood of being in a situation where an event could cause such a hazard), and controllability (ability of the driver to control the situation and avoid the hazard).

These systems are trusted more on highway than in complex urban traffic situations. Especially at urban intersections, the provision of information would hardly relieve the drivers of emergency vehicles. In contrast, automated decision-making by an emergency vehicle interacting with other automated vehicles would not provide a combination of technical and situational information, including human factors. Operational drivers believe that only the combination of the system's analytical "emotion-free" information on the one hand and the driver's situation assessment and "human feeling" on the other will produce the best decision. Thus, they see it as crucial that the decision as such is the responsibility of the human. There is a risk that the safety of the emergency drivers and other road users can be jeopardized by a possible inappropriate or uninformed interaction between C-ITS-drivers, priority systems at traffic lights, and other road users. This can be due to a lack of competence of first responders in using these systems as well as misuse. Some stakeholders are skeptical about automated priority systems due to the expectation of high costs for implementation and maintenance of all stakeholders involved (infrastructure, manufacturers, emergency services, and authorities). Without a comprehensive agreement, stakeholders might thus unconsciously or consciously set or omit actions, which hinder the implementation of the system. Finally, stakeholders are currently concerned about the unclear responsibility regarding liability. This aspect concerns prioritization systems in general and are not specific to C-ITS.

Based on the findings of this article, the authors came to the conclusions that an implementation must go hand in hand with three accompanying measures: education and training, certification and reliability tests, and disclosure of responsibilities.

6 Conclusions and outlook

The EVE project investigated the impact of an automatic warning and priority system for emergency vehicles. Such a system could be installed in the emergency vehicle and provide a priority request to traffic signals and other vehicles to inform them of the approaching emergency vehicle. This could improve safety for first responders and all road users involved by reducing the risk of crashes involving emergency vehicles and saving time during operations. The aim of further research in first responder health and the role of technology should be, to use knowledge from end-users to positively influence technology development. Therefore, such technical systems will have to be more open-minded in the future. This means to work on international solutions and a new concept of mobility that integrates goals and values such as safety and health. The topics of international politics, law, economy, and cross-border infrastructure play a dominant role. International cooperation in connection with national subsidies and amended legal framework conditions as well as certifications will be essential.

In addition to technological developments and the development of international guidelines, it is particularly important for the implementation to involve the first responder as a human being and expert in the respective processes. Further studies on gender and ethical aspects are also necessary as surveys already show differences in driving behavior and requirements in advanced driving assistance systems here [37]. While the technological solution of car-to-car communication holds a great potential of raising physical safety and thus occupational health of emergency drivers, there are several risks, which must be considered when discussing the implementation of such a system in daily practices. These risks show once more that a system is as good, as users can trust on its reliability, validity, and know how to run it properly.

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