ITS Solutions for Communicating Emergency Information in Road Tunnels
A state-of-the-art report

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PROJECT: Stockholm Bypass “ITS Solutions for Safe Tunnels”
DATE: 2013-11-06

Project Stockholm Bypass “ITS Solutions for Safe Tunnels” is initiated by the Swedish Road Administration and co-financed by the European Union’s Trans-European Transport Network (TEN-T) programme.
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Abstract

The Stockholm bypass link will be one of the longest road tunnels in the world. In this type of tunnel, road safety is a prioritized subject. Besides the type of technology that is used for these purposes today (e.g., variable road signs), new cooperative Intelligent Transportation System (ITS) solutions have showed potential of improving safety by allowing communication between vehicles and the tunnel infrastructure and enhance communication with other road users as well as the traffic management center.

As an important step in this work, the Stockholm bypass project has been granted co-funding for research from the European Union through the trans-European transport network (TEN-T). The overall aim of this part of the project is to give an overview of the relevant research in the field of cooperative ITS for communication of emergency information to road users in tunnels. More specifically, the project aims to explore which information needs to be provided to the road users and which technology could be used.

The literature reviewed suggests that the main goal of the information provided to the road users in emergency situations in tunnels should be: a) make road users aware of the danger, b) support road users in decision making, and c) guide road users in performing the evacuation. There are also clear indications that providing personalized emergency information, in addition to the conventional information in form of alarms and road signs, could make the evacuation process more efficient and fast. The literature surveyed emphasizes that information needs may differ significantly depending on the road user type and that multimodal information and training could have positive effects on the evacuation process.

There are no clear trends regarding the human machine interfaces (HMI) used to display emergency information. However, given that the number of smartphones and similar devices increases for every day it is likely that these may be a natural choice for communicating such information in future.

It is also difficult to draw any definite conclusions regarding the communication technologies that may be suitable for transmitting emergency information by 2024 (when the Stockholm Bypass will be deployed). This is an area that is in a continuous development and several stakeholders are trying to set the stage. Introducing standards related to 802.11p will accelerate the use of this technology and may make it more relevant for the application discussed in this report. Also, developments in cellular technology such as 4G/LTE and 5G may play an important roll as the coverage is expected to increase at the same time as the communication delays are expected to decrease.
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1 Introduction

Intelligent Transportation System (ITS) is a today a fundamental part of our society. In particular, ITS is important for emergency management, and its role is expected to grow with the future technology developments.

Emergency management in road tunnels is an area where the use of ITS could bring great benefits (ITS International, 2013). By using ITS, new traffic management strategies for tunnels can be developed based on new sensor technologies, traffic control devices, and information providing methods. In 2004, the European Parliament adopted the EU directive (2004/54/EC) highlighting the minimum safety requirements for tunnels in the Trans-European Road Network. According to the European Tunnel Assessment Programme (EuroTAP) that conducts evaluation of tunnel safety with respect to the directive (EuroTest, 2013), ITS related functions such as traffic surveillance and emergency management account for more than 50% of all points.

Emergency management and decision making in emergency situations in road tunnels is challenging because of the specific features of the tunnel environment. An important assumption for the evacuation in road tunnels is the internationally acknowledged self-rescue or self-evacuation principle. According to this principle, it must be possible for road users to rescue themselves in dangerous situations. A fast and efficient response by the road users and relevant organizations in emergency situations is thus key for tunnel safety. For this, it is required that dangerous situations are detected in an early stage and that the information about them is quickly transmitted to the road users. It is also important to take into account that the information must be correct and provide all details needed to stimulate an appropriate evacuation behavior. In addition, it must be considered that different groups of road users may have different needs.

The main promise in this study is that ITS can be used to provide such information to the road users. In particular, it is assumed that various wireless communication technologies can be used to inform road users about dangerous situations and thereby enlarge the time-window available for evacuation. Currently, a range of systems known as cooperative systems (i.e., systems that make use of wireless communication) are under development. The development is forced by both the industry and by society e.g., the European Commission.

The aim of this report is to give an overview of the existing digital strategies and corresponding technologies that can be used to inform road users about dangerous situations in road tunnels. A special attention is given to the future technologies since the results will in a later stage be used to suggest possible evacuation strategies for the Bypass Stockholm tunnel. Bypass Stockholm is a new tunnel project in Sweden that will be about 17 km in length and that is planned to be completed in 2024.
Based on a literature survey, the report describes a typical evacuation process including the information that should be provided to the road users in emergency situations. Next, a selection of relevant projects is given followed by an overview of the current communication technologies and trends. The report ends by summarizing the findings and identifying the implications for the Bypass Stockholm tunnel.

The Stockholm bypass project has been granted co-funding for research from the European Union through the trans-European transport network (TEN-T). The research project contains several parts and will be finalized by the end of 2014, although some parts will be reported earlier.

2 Evacuation process

2.1 Road user behavior in tunnels
In their study (Nilsson, Johansson, & Frantzich, 2009) explored how drivers behave when exposed to a fire emergency in a tunnel, how information and way-finding systems are perceived and whether green-flashing lights can influence exit choice. The study involved 29 participants who were told that they are participating in a study on driving behavior. The results show that participants had difficulties in figuring out what was said in the pre-recorded alarm. However, the acoustic signal made the drivers look for additional information (traffic signs). The results showed also that information signs were important for the decision to leave the vehicle. In addition, individual behavior was affected by the behavior of others regarding decision to leave the vehicle and choice of exit. The results also suggest that arousal level influences the amount of information noticed by motorists.

(Liao, Hu, & Ho, 2012) evaluated new traffic management strategies in the Hseuh-Shan Tunnel in Taiwan through computer simulation techniques. They simulated traffic control strategies and driver's response on these. The information to the road users in this tunnel is communicated via variable message signs as well as via loudspeakers.

(Tesson, Perrin, & Aurand, 2012) studied the effect of human (users, operators, rescue services) behavior on road tunnel safety as well as the factors that determine this behavior. In particular, they studied behavior in an emergency situation (fire) and used the findings to identify the actions for improving safety. The findings indicate that the users generally disbelieve the situation, lack knowledge and underestimate the actual risk, and have difficulties in making decisions on self-evacuation. The study shows also the importance of “leadership”, adequate communication means, and combining different means. The actions that were formulated based on these findings include: material for training of new drivers and training of professional drivers in order to enable them to adopt the adequate behavior.
As a part of the project SAFE TUNNEL, (Vashitz, Shinar, & Blum, 2008) evaluated the effect of in-vehicle displays on driving safety in road tunnels. They simulated tunnel driving in a STI-SIM fixed-based driving simulator implemented in a 1995 Rover Sedan. In the study, 15 participants tested two different displays: one highly informative and one less informative display. The results show that the drivers using the displays improved their speed control, but they had difficulties in maintaining lane control due to some distraction imposed by the displays. The drivers found the displays useful, in particular the highly informative ones. This and similar studies indicate that showing emergency information via displays in vehicles could be a way forward, as opposite to showing information via dynamic signs in the infrastructure. However, one must take into account the fact that this can cause distraction and that arousal level increases in emergency situations.

(Rudin-Brown, Young, Patten, Lenné, & Ceci, 2013) conducted a simulator study involving 24 participants to explore effects of driver distraction in a tunnel environment (Stockholm Bypass). The participants were asked to drive while reading and writing text messages using their own mobile phones. The results show that text messaging was associated with decrements in driving performance and visual scanning behavior, and increases in subjective workload. In particular, increases in lane deviation associated with the text-messaging task were more pronounced in the tunnel than on the freeway. On the other hand, the drivers reduced their speeds more when performing text-messaging while driving in the tunnel than in the freeway.

### 2.2 Effects of behavioral training

(Kinateder et al., 2013) investigated the effects of information with or without additional virtual reality (VR) behavioral training on self-evacuation in a simulated emergency situation in a road tunnel. The study involved 43 participants. The participants were divided into three groups: (a) a group that only filled in questionnaires, (b) a group that obtained information about road tunnel safety in form of an information brochure, and (c) a group that carried out a training session in a VR tunnel scenario. The evacuation capabilities of the participants in all groups were tested a week later in an emergency situation in a real road tunnel. The results show that the participants in group (c) were faster and evacuated themselves more reliably than the participants in the two other groups. Similarly, the performance by the participants in group (b) was better than the performance of the participants in group (a). These findings are also supported by the results from a one-year follow-up questionnaire. Based on this study, it can be concluded that information and VR training are promising methods to facilitate self-evacuation in emergency situations in tunnels.

### 2.3 Model for evacuation

(Kecklund, Petterson, Anderzén, Frantzich, & Nilsson, 2007) describe a model for evacuation from the road user perspective that is based on the previous work by (Enander, 2005) and (Mileti & Sorenson, 1988). According to this model, an evacuation process is divided into three steps: a) the road users becomes aware of the danger, b) the road user make decision to evacuate, and c) the road users performs the
evacuation. Each of these steps includes a number of sub-steps describing what is required to obtain an appropriate evacuation behavior and thereby to conduct a successful evacuation (Figure 1).

To become aware of a danger, the road user must *receive* a signal about the danger and *notice* it. Such a signal can be a sound or a speech message issued from a warning system, but it can also be that the road users see a fire, smoke, or other road users that are exiting their vehicles. Several studies (e.g., (Boer, 2002); (Nilsson et al., 2009)) have shown the importance of informing the road users about the need to evacuate; only informing the road users about a danger does not necessarily mean that they will start the evacuation.

To take the decision to evacuate, the road users need to *interpret* and *understand* the meaning of the signal, and to know *how to act*. Previous studies (e.g., (Boer, 2002)) indicate that there are significant difficulties in convincing people that they are in a dangerous situation and that they need to quickly take a decision to do something to save themselves. Generally, people are not likely to take initiative to evacuate, which can prolong the start of the evacuation process. However, people are likely to follow what others are doing and if someone takes a decision to evacuate, there is a chance that others will make the same decision (Frantzich, Nilsson, Kecklund, Anderzén, & Petterson, 2007). From this, it follows that the road users may benefit by knowing in advance how to act in dangerous situations.

To perform evacuation means that the road users *act, get feedback* on and evaluate their actions, and *continue* the evacuation. The feedback is important since the road user may become unsure if the decision was correct.
3 Communication technologies

Wireless communication technologies are changing faster than any other area of technology. The diversity of needs has stimulated a corresponding diversity of communication solutions and systems based on these. It is expected that beyond 2020, wireless communication systems will need to support more than 1.000 times today’s communication (Ericsson, 2013). Similarly to other domains, vehicle manufacturers and suppliers are looking to put functions based on wireless communication in their vehicles to enhance the experience of owning and driving a vehicle. According to Telematics Update (Telematics Update, 2013), in the time period 2023-2030 about 84% of vehicles are expected to have a connectivity solution.

This section provides an overview of the existing communication solutions that may have potential to be used for the transmission of emergency information related to road tunnels.

The main assumption here is that the transmission of emergency requires medium data rate, low latency, high message priority and reliability, and multicasting/geocasting transmission mode. These characteristic are typically required for safety applications related to incident management (e.g., emergency vehicle warning that provides a
warning to the driver to yield the right of way to an approaching emergency vehicle) (Dar, Bakhouya, Gaber, & Wack, 2010).

3.1 Dedicated Short Range Communication (DSRC)
Dedicated Short Range Communication (DSRC) is a communication service intended for fast and reliable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) information exchange at the frequency of 5.9 GHz (in Europe). The DSRC systems consist of Road Side Units (RSUs) and/or the On Board Units (OBUs) with transceivers and transponders. The DSRC standards specify the operational frequencies and system bandwidths, but also allow for optional frequencies which are covered (within Europe) by national regulations. In particular, IEEE 802.11p standard, which specifies medium access control and the physical layer for the future ITS, is developed. However, the fundamental characteristics of the physical layer are still an open question.

In Europe, 802.11p was used as a basis for the ITS-G5 standard, supporting the GeoNetworking protocol for vehicle-to-vehicle and vehicle-to-infrastructure communication. The ITS G5 and GeoNetworking is being standardized by the European Telecommunications Standards Institute group for Intelligent Transport Systems (ETSI). The DSRC systems are used in the majority of European Union countries, but these systems are currently not totally compatible. Therefore, standardization is essential in order to ensure pan-European interoperability. Standardization will also assist the provision and promotion of additional services using DSRC, and help ensure compatibility and interoperability within a multi-supplier environment. The work by standardization organization such as the ETSI, IEEE, and ISO is thus of utmost importance. According to (Telematics Update, 2013), by 2024, factory fit DSRC-equipped vehicles could rise to 30%, enabling widespread data communications services and a large national DSRC infrastructure. However, it is still unclear who will pay for such an infrastructure.

(Shivaldova et al., 2011) have explored performance (frame success ratio and goodput) of IEEE 802.11p physical layer (5.9 GHz) for a vehicle-to-vehicle scenario in a real-world road tunnel. The evaluation was carried out both with and without line-of-sight and in different traffic situations. The results show that connectivity is strongly degraded with loss of line-of-sight, especially when the occlusion occurs under a longer period of time. More specifically, when the vehicles were driving on different lanes (average separation 80 m) and the line-of-sight was blocked during the whole measurement by other vehicles, the frame success ratio dropped below 0.25 and average packet loss was 50% or more. These findings indicate that IEEE 802.11p should be used in tunnels with a great care.

3.2 Cellular Networks
Early generations of cellular networks (1G-3G) are mainly designed for voice data exchange, which makes them less appropriate for ITS applications that are time-critical.
and require high rate and broad bandwidth. For example, latency increases and reliability decreases for text data since voice data have higher priority.

The fourth generation network or long-term evolution (4G/LTE) is the current state-of-the-art terrestrial cellular broadband and addresses these drawbacks to some extent. It is adaptable to a wide range of radio bands and is recognized as a platform for communications requiring broadband data. That is, LTE can deliver infotainment types of applications far better than its precursors. IHS Automotive forecasts that the number of LTE-connected cars worldwide will grow from 1.2 million in 2015 to 16 million in 2017 (Gain, 2013). The fifth generation network (5G) is currently under development and there is for now no specified date for its deployment; some research communities and equipment manufacturers are aiming for 2020 (Ericsson, 2013) (Bleicher, 2013), while some others believe that the deployment will occur first around 2025 (Ghadialy, 2013).

Basically, 5G will be an integration of existing wireless communication technologies and complementary new technologies. The evolution of existing technologies such as LTE and Wi-Fi will thus be key enablers of 5G system (Ericsson, 2013). In comparison to the existing networks, Mobile and wireless communication Enablers for the Twenty-twenty Information Society (METIS) (METIS, 2013) defines requirements that 5G is expected to fulfill in the following way:

- 1000 times higher mobile data volume per area;
- 10 to 100 times higher number of connected devices;
- 10 to 100 times higher typical user data rate;
- 10 times longer battery life for low power MMC; and
- 5 times reduced end-to-end latency (maximum 1 ms latency).

The 5G system is, in other words, expected to provide efficient and high-performing communication that supports a range of different services, including cooperative ITS (Ericsson, 2013)(Bleicher, 2013). To accommodate all these requirements, Ericsson (Ericsson, 2013) and METIS (METIS, 2013) anticipate introduction of ultra-dense networks with nodes/base-stations operating with very wide transmission bandwidths (several 100 MHz) in higher-frequency bands (10-100 GHz). More specifically, these networks will consist of low-power access nodes being deployed with much higher density than the networks of today (e.g., at lamppost distance apart). These nodes could also be placed on vehicles. With these additions to the existing mobile network, data flows from the big base-stations are expected to become more effective at the same time as the distances to the users become shorter. Consequently, this will result in faster data traffic.

According to a report by GSMA (GSMA, 2012a) there are today three ways for enabling cellular connectivity between vehicles (Figure 2):
- Embedded solutions (all connectivity and intelligence is built into the vehicle);
- Tethered solutions (the driver must use their phones as a modem to enable connectivity)
- Integrated solutions (smartphones apps are integrated into the vehicle to enable the driver to safely access the features and services.

It should, however, be noted that these solutions are not necessarily mutually exclusive and that most vehicle manufacturers are today developing strategies that rely on a combination of these connectivity solutions.

![Figure 2. Three ways for enabling cellular connectivity within vehicles (GSMA, 2012a)](image)

### 4 Relevant projects

This section presents a selection of the projects that are considering relevant for communicating emergency information in road tunnels. The majority of the projects are European, but there is also a brief description of the related activities in Japan.

#### 4.1 SAFE TUNNEL

SAFE TUNNEL (SAFE TUNNEL, 2005) was a European project conducted in the time-period 2001-2005 as a part of the 5th RTD Framework Programme. Its objective was to
address road accidents and incidents by integrating on-board vehicle devices and ITS infrastructure using the public wireless network.

The project developed a system for heavy goods vehicles consisting of four different applications, including the one for distribution of emergency messages. An overview of the system is given in Figure 3 where it can be seen that the system includes three major parts: vehicle, infrastructure, and communication.

The main features of the vehicle system are: link to the standard onboard diagnostic system for checking the functionality of mechanical and electronic devices, a system that automatically control the vehicle speed and distance to other vehicles, a touch screen for the interaction with the driver, and a communication unit integrating a GSM/GPRS modem and a Bluetooth module that together enable information exchange between the vehicle and the control center.

The infrastructure part included mainly a control center that integrates the diagnostic information transmitted from the vehicles and the alarms provided by other existing ITS systems through a communication link. The control center is connected to the control network of the road operator that can interact with the system by means of a graphical interface. The operator can see information about the vehicles in the area of the interest, alarm description, location of the vehicles with anomalies, delivery of specific messages to vehicles with anomalies, and emergency messages to all vehicles in the area of interest.

The communication is based in a GSM/GPRS network. This is a module in the system that can be replaced with other technologies (e.g., 3G, 4G).

Emergency messages were displayed to the drivers by means of an in-vehicle HMI in order to obtain a safer operation and easier control of the traffic flow in case of an emergency.
4.2 COOPERS

The Co-Operative SystEms for Intelligent Road Safety (COOPERS) was an European IP project funded by EC FP6 (Mcdonald, 2008). The project started in 2006 and was ended in 2010. It involved 39 partners and was coordinated by AustriaTech.

The COOPERS focused on development and implementation of cooperative systems with aim to improve road traffic safety, predictability and controllability. More specifically, the COOPERS used infrastructure-to-vehicle (I2V) communication technology to provide infrastructure, vehicles and traffic control centers with technical intelligence making it possible to develop various measures to achieve safer and more efficient traffic flow on the existing road infrastructure. The vision of the project is illustrated in Figure 4 (Pfliegl, 2010).

The COOPERS architecture consists of three major parts: roadside data acquisition system, in-vehicle system, and traffic control center (TCC). The roadside data acquisition system includes roadside units (RSUs), cameras, and other sensors (weather, wind, temperature) that are connected to the TCC. The TCC processes the data sent by the roadside system together with relevant historical data and determines what type of traffic information needs to be communicated to vehicle drivers. It has also a graphical interface for interaction with the operators. The in-vehicle system consists of a display that is integrated with the standard human-machine interface (HMI) in the vehicle and positioned to the right of driver. All these parts are able to communicate with each other by means of wireless communication.
technologies.

The COOPERS evaluated the following communication technologies: DAB/DVB-H (digital audio/video broadcasting), GPRS/WIMAX (General Packet Radio Services/Worldwide Interoperability for Microwave Access), and CALM IR (Communications access for land mobiles based on infrared technology).

![Diagram of COOPERS vision](image)

**Figure 4. An illustration of the COOPERS vision** (Pfliegl, 2010).

The project developed and tested several services such as accident/incident warning, weather condition warning, in-vehicle variable speed limit information, road works, traffic congestion warning, and re-routing recommendation. Several of these services were tested in road tunnels since the interviews that the project conducted with different road operators and drivers showed a need to receive information about the situation in the tunnel that lays along the route of the driver (Mcdonald, 2008).

### 4.3 SAFESPOT

SAFESPOT was a European IP project founded by EC FP6 that was running from 2006 to 2009 and involved 51 partners (Brignolo, 2006).

The aim of the project was to understand how intelligent vehicles and intelligent infrastructure can cooperate to improve road safety. The project focused on developing applications based on vehicle-to-infrastructure and vehicle-to-vehicle communication that are able to detect potentially dangerous situations in advance and thereby extend
the time frame available for preventing the accident. The project developed a range of applications, including the one called Cooperative Tunnel Safety.

In the cooperative tunnel safety application the infrastructure informs drivers about recommended speed and safety distance. The Safety Margin is calculated on the basis of the state and typology of the vehicle.

Another relevant function that was developed within SAFESPO T is Hazard and Incident Warning. The function transmits warning messages to vehicles arriving on an area where a hazardous event (e.g., car accident) has occurred. The message is issued either from the infrastructure or from other vehicles. It contains the following information such as type of hazard, current location and previous positions, speed, and direction.

Due to safety reasons, these applications were not tested in tunnels.

4.4 SAVE ME
The System and Actions for VEhicles and transportation hubs to support Disaster Mitigation and Evacuation (SAVE ME) project was a European project that started in 2009 and was ended in 2012. The project was founded by EC FP7.

The aim of the SAVE ME project was to develop a system that detects natural disaster events (i.e. earthquake, fire) and man-made disasters events (i.e. terrorist attack) in public transport terminals, public transport vehicles and critical infrastructures including road tunnels (TRIP, 2013). More exactly, SAVE ME developed a common ontological framework for hazard recognition, classification and mitigation, innovative algorithms on human behavior (under stress, panic and strong emotions), standardized interface elements for intuitive human guidance, a holistic disaster mitigation strategy and intelligent agents algorithms for guidance personalization.

All road user groups were taken into consideration. However, vulnerable road user groups (elderly, disabled, children) were given a special attention. In order to design an appropriate decision support system and user interfaces, the project researched the influence of stress, panic, and other emotions on human behavior. The project developed the interfaces for operators, rescue teams (guidance through PDA), road users having mobile phones (personalized guidance through mobile phones), and road users without mobile phones (generic guidance through various displays and announcements). Also, the project developed some training actions for operators, rescue teams, and road users (TRIP, 2013). The mobile phone application that was developed supports all mobile phone platforms. In case of an emergency, it issues a warning with blue, green, or red background depending on the severity of the emergency. As Figure 5 shows, the SAVE ME mobile application includes also some functions where the user can get more information about the emergency and route guidance.
SAVE ME employed a wireless sensor network for emergency detection, environmental awareness and road users’ position and movements monitoring, as well as a fault tolerant communication network infrastructure. The traveller location-sensing system made use of standard mobile phones and Bluetooth. Regarding the telecommunication infrastructure, the model built is based on low cost ad-hoc Wi-Fi routers able to manage Bluetooth with pre-installed and automatic upgradable emergency software. These routers become active when an emergency is detected and have to be installed in vehicles and stations as black boxes. The main purpose of this sub-system is the deployment of an ad-hoc wireless network that can provide the required autonomy (power) to restore the communications among the critical components of the system.

4.5 SIRTAKI
The Safety Improvement in Road and rail Tunnels using Advanced ICT and Knowledge Intensive DSS (SIRTAKI) was a European project that started in 2001 and was ended in 2004 (SIRTAKI, 2001). The objective of the project was to improve tunnel safety by developing an advanced tunnel management system that addresses safety issues and emergencies as well as the integration within the overall network management. In particular, SIRTAKI developed and evaluated a real time decision support system to support crisis managers to take decisions in emergency situations and a tool to support training, decision taking and automation of actions by applying previous experiences in emergency management and simulation of emergency situations.
4.6 UPTUN and SafeT

UPgrading of existing TUNels (UPTUN) was a European project that started in 2002 (NordFoU, 2009). Its objective was to investigate how the safety in the existing tunnels could be improved, especially in emergency situations involving fires. One part of the project investigated road user behavior in case of a fire, both in a real-world tunnel and in a simulator. The results show that the road users did not react when a fire alarm was issued; they reacted first when some additional information was given. Another finding was that individuals usually followed the group, even if the group behavior was incorrect/inappropriate for the situation, and that people tend to escape the tunnel same way as they entered it.

Safety in Tunnels Thematic Network on development of European Guidelines for upgrading tunnel safety (SafeT) is a follow-on project (NordFoU, 2009).

4.7 HeERO

The Harmonized eCall European Pilot (HeEro) project started in 2011 and will last until the end of 2013. Its objective is to prepare the infrastructure necessary for a European in-vehicle emergency communication service (eCall) that will harmonize the disparate national services and ensure cross-border interoperability. The European Parliament has in 2012 adopted a resolution on eCall system requiring all new vehicles to be equipped with the system by 2015.

In the event of a serious automobile accident, the system will automatically notify emergency services (uses 112 emergency number). The system will transmit location information on the accident, as well as allow voice contact between operators and crash victims, see Figure 6 for more details (GSMA, 2012a)

The project will be extended to HeERO2 (2013-2015) with the objective to perform pre-deployment pilots and to encourage wider adaptation.
4.8 ITS in Japan

The vehicle information and communication system (VICS) provides real-time road traffic information on vehicle-navigation system. The system was introduced in 1996 in a few big cities. Today, the VICS is deployed in whole Japan and is used by approximately 35 million vehicles.

The system provides services to vehicle drivers such as road conditions, weather conditions, and dynamic route guidance. The information is collected in different ways including infrared light beacons, vehicle sensors, and road operators. The VICS information is edited and processed at the VICS Centre and is then transmitted to car navigation systems where it is displayed in written, audio, and graphic form. The communication is based mainly on 2.5 GHz two-way communication (Figure 7).

Ieda et al. (2013) describes a strategic plan developed by the VICS Center that covers the time period 2013-2030 and aims at realizing information services that make use of ICT to cope with both frequent and non-frequent disasters. This includes services that alert about upcoming disasters (e.g., earthquake, fire) as well as the services that inform about evacuation, risk avoidance and damage mitigation. The vision is to develop a common platform for the shared use of public and private sector information needed by drivers. The platform should build on the services and information that are currently
The information provided by the VICS. Ieda et al. (2013) do not provide any details on the information content that needs to be provided.

The Japanese Ministry of land, infrastructure, transport and tourism (MILT) has in 2012 introduced a new service that informs vehicle drivers about various emergency situations such as earthquakes, road elevations, and road closure (MILT, 2012). Another relevant service that is described in the same document is alerting drivers about oncoming dangers such as congestion behind a blind curve. These services present information to the drivers via in-vehicle navigation systems including a voice message, see Figure 8. In addition, a web-based interface that will make emergency information accessible via a map is under development.

These services, like many other similar services that exist in Japan, are a part of the MILT’s vision to make roads more safe by using cooperative systems. More specifically, the MILT has installed ITS Spot units at 1.600 location along expressways that are compatible with navigations systems from numerous manufacturers. These units and vehicles communicate with each other by means of two-way DSRC (5.8 GHz).

The information provided by ITS Spot is mainly generated by road administrators (Kawano et al., 2013).
5 Conclusions

The literature reviewed in this report suggests that the main goal of the information provided to the road users in emergency situations in road tunnels should:

1. make road users aware of the danger;
2. support road users in decision making; and
3. guide road users in performing the evacuation (or some other appropriate actions such as re-routing).

This means basically that providing just an alarm in an emergency situation is not enough, and that road users need more detailed information in order to obtain an appropriate behavior in such situations. There are also clear indications that providing personalized emergency information, in addition to the conventional information in form of alarms and road signs, could make the evacuation process more efficient and fast. However, the type and amount of information provided to the road users may be different depending on the situation urgency and the time-frame available for deciding on and conducting the evacuation, or some other appropriate action. To reduce anxiety that travelling in long road tunnels usually causes, the following information could be communicated to the drivers:

- Traffic conditions in the tunnel and on the approaching roads;
- Tunnel characteristics (entrances, exits, length, bends, gradients, emergency exits, emergency phones, etc.);
- Traffic regulations (speed limits, lane rules, etc.);
- Restrictions related to load, height, etc;
- Passage fees and their location;
- Estimated travel time;
- Ongoing maintenance.
- General evacuation strategy;
- Detailed evacuation plan;
Examples of information that could be provided to the drivers approaching or being in a tunnel where a dangerous situation has occurred include:

- The number and location of vehicles involved;
- If there are any dangerous goods involved;
- Access advice related to the congestion;
- Details on emergency exits, emergency phone location, etc.;
- Details on possible re-routing;
- Hose and hydrant locations;
- Ventilation and smoke door locations;
- Lighting and visibility level;
- Smoke or toxic levels;

It should also be noted that the literature surveyed emphasizes that information needs may differ significantly depending on the road user type (children, elderly, professional driver, etc.). The survey also highlights the importance of multimodal information and warnings. For people with sensory disabilities (e.g., blind, deaf), emergency notification systems may present messages in a form that may not be detected or understood. In order to effectively reach those with sensory disabilities, well-designed multimodal warnings can increase the likelihood that the message will be detected in at least one modality.

Furthermore, there are indications that behavioral training in emergency situations may have positive effects on how fast and efficiently the road users evacuate tunnels. Future studies should investigate if information and training give different results depending on the road user group (e.g., professional drivers vs. non-professional drivers). For example, if professional drivers are more likely to evacuate faster and more reliably than other road users, one could consider if their skills could be used to help evacuating other road users in case of emergency situations in tunnels. In that case, emergency training for professional drivers could be a part of their education, and thereby a part of the future strategies for improving safety in road tunnels.

The projects surveyed here do not show any clear trends regarding the human machine interfaces (HMI) used to display emergency information and warnings. However, given that the number of smartphones and similar devices increases for every day it is likely that these may be a natural choice for communicating such information and warnings in future. The reviewed literature suggests also that the behavior of road users is highly affected by stressful situations, which implies that the HMI needs to be tested under stressful conditions before it can be relied upon in a real tunnel emergency.

It is also difficult to draw any definite conclusions regarding the communication technologies that may be suitable for transmitting emergency information to and from road users by 2024 (when the Stockholm Bypass will be deployed). This is an area that
is in a continuous development and several stakeholders are trying to set the stage. Introducing standards related to 802.11p will accelerate the use of this technology and may make it more relevant for the application discussed in this report. Also, developments in cellular technology such as 4G/LTE and 5G may play an important roll as the coverage is expected to increase at the same time as the communication delays are expected to decrease.

6 References


SAFE TUNNEL. (2005). SAFE TUNNEL: Innovative systems and frameworks for enhancing of traffic safety in road tunnels (pp. 1–61).


7 Appendix: Examples of relevant technical solutions

7.1 Q-Free Traffic Surveillance
Q-Free has long experience in traffic surveillance in tunnels, inclusive dangerous goods detection and tracking. In addition, they have developed a cooperative solution (Road Side Equipment, RSE) that informs vehicle drivers about the access restrictions in tunnels (Soråsen, 2011). The RSE makes use of V2I communication to broadcast the service announcement and to enable vehicles to download information about restrictions that currently apply in the tunnel.

7.2 EvacTunnel
(Alvear, Abreu, Cuesta, & Alonso, 2013) have presented a decision support system (EvacTunnel) for emergency management in road tunnels. The system is made to guide operators providing dynamic decision recommendations. It uses predictive tools to estimate the severity of the accident/incident and rescue and evacuation times. This system is of special interest as it could be used as a starting point when defining conceptual ITS solutions for the Förbifart Stockholm tunnels.

7.3 Kapsch TrafficCom
Kapsch (Kapsch Group, n.d.) has developed an onboard unit called TS3306 that is designed for applications serving commercial vehicle operations and road tolling markets as well as for the USDOT's Connected Vehicle Safety Plot (conducted in Ann Arbor) based on the 5.9 GHz Dedicated Short Range Communication (DSRC). It supports WAVE standards including IEEE 802.11p. In addition, TS3306 supports over-the-air security including encrypted and digitally signed massages and has a GPS receiver that makes it aware of its own position.

7.4 Siemens Siveillance
Automatic incident detection using Siveillance from Siemens reliably identifies, monitors, and reports objects and situations that can lead to accidents and potentially fires (Maas, 2013). This universal video application platform generates alarms when defined safety rules are violated, e.g. slow or stopped traffic, wrong way drivers or lost loads. The system can be integrated with the traffic signaling system and automatic barriers, automatically alerting drivers to the incident before they enter the tunnel.

7.5 Navtech Radar
ClearWay is a radar-based Automatic Incident Detection (AID) system which provides unrivalled detection rates and situational awareness, proven in both tests and real-world deployments (Navtech Radar, 2013). It can enable events to be detected and resolved before they can escalate into major incidents. In the case of tunnels, there are particular issues relating to light and visibility. Video-based Automatic Incident Detection (AID) has set the standard for many years now and it is still considered by many to be the only practical solution.
7.6 MTA Drive Time
The MTA has launched an app called MTA Drive Time that enables users to check traffic on MTA bridges and tunnels from their smartphones (MTA, 2012). The app uses real-time data to show how many minutes it will take to cross each of the seven bridges and the two tunnels in New York. The information used to determine the time for cars to cross comes from EZ Pass data, which is updated every five minutes. The app also enable users to find out how long it would take to get to nearby places from whichever tunnel or bridge they select. The app is available for free.