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Deliverable D5.2

Standards for communication and data interoperability

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Consortium - List of partners

Partner No	Short name	Name	Country
1	UIC	International Union of Railways	France
2	VTT	Teknologian tutkimuskeskus VTT Oy	Finland
3	NTNU	Norwegian University of Science and Technology	Norway
4	IFSTTAR	French institute of science and technology for transport, development and networks	France
5	FFE	Fundación Ferrocarriles Españoles	Spain
6	CERTH-HIT	Centre for Research and Technology Hellas - Hellenic Institute of Transport	Greece
7	TRAINOSE	Trainose Transport – Passenger and Freight Transportation Services SA	Greece
8	INTADER	Intermodal Transportation and Logistics Research Association	Turkey
9	CEREMA	Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning	France
10	GLS	NeoGLS	France
11	RWTH	Rheinisch-Westfaelische Technische Hochschule Aachen University	Germany
12	UNIROMA3	University of Roma Tre	Italy
13	COMM	Commsignia Ltd	Hungary
14	IRU	International Road Transport Union - Projects ASBL	Belgium
15	SNCF	SNCF	France
16	DLR	German Aerospace Center	Germany
17	UTBM	University of Technology of Belfort-Montbéliard	France

Executive summary

The purpose of deliverable D5.2 is to present all communication standards used in the Safer-LC tests and to give some recommendations regarding some scenarios, while taking into account the format of data that need to be exchanged in the framework of the developed solutions.

Namely, various wireless communication systems and positioning standards are used and evaluated in two pilot sites: Thessaloniki and RWTH Aachen.

In this deliverable, the recommendations are given for three scenarios. These recommendations can be taken into account for future deployment in rail and road in order to improve the safety at LCs.

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1. INTRODUCTION

1.1. Objectives of SAFER-LC project

The main objective of the SAFER-LC project (Safer level crossing by integrating and optimizing road-rail infrastructure management and design) is to improve safety and minimise risks at and around level crossings (LCs) by developing a fully integrated cross-modal set of innovative solutions and tools for the proactive management and new design of level-crossing infrastructure. These tools will enable:

- Road and rail decision makers to achieve better coherence between both modes,
- Effective ways to detect potentially dangerous situations leading to collisions at LCs as early as possible,
- Prevention of incidents at level crossings through innovative design and predictive maintenance methods, and
- Mitigation of consequences of incidents/disruptions due to accidents or other critical events. The main output of the SAFER-LC project is a toolbox which will be accessible through a user-friendly interface integrating all the project results and solutions to help both rail and road stakeholders improve safety at level crossings.

The project focuses both on technical solutions and on human processes to adapt infrastructure designs to road user needs and to enhance coordination and cooperation between different stakeholders from different land transportation modes. The challenge is also to demonstrate the acceptance of the proposed solutions by both rail and road users and to implement the solutions cost-efficiently.

Within the project, the objective of Work Package 5 is to perform a cost benefit analysis and to present all standards used in the SAFER-LC project. The WP5 provides also final recommendations for future use by these standards in Rail and road environment, according in the scenarios defined by safer-LC project.

The goal behind Deliverable D5.2 is to discuss the required communication standards deployed in the technological solutions (smart detection and smart communication systems: LTE, ITS-G5) developed in the SAFER-LC project to improve safety at level crossings as well as at working zones. The information exchange allows for sharing the LC status among various actors involved in the LC, such as trains/vehicle drivers approaching/arriving the level crossing to workers at or near the crossing zone, etc.

In the last section, some recommendations regarding the use of existing standards as well as some aspects regarding future communication standards will be given in view of the scenarios defined in the framework of safer-LC project.

1.2. Purpose of this deliverable

In this deliverable, in the one hand we give the description of standards communication systems (LTE, ITS-G5) and positioning solution used at two pilot sites (Aachen, Thessaloniki). We also discuss the new Collective Perception Messages (CPM) of ITS G5 technology used in this task and some indicators for the future communication standards. On the other hand, recommendations of some scenarios are given. In the end of this document, a table summarizes all standards, realized tests and recommendations in SAFER-LC context is done.

2. DESCRIPTION OF ALL DEPLOYED STANDARDS AND SYSTEMS

2.1. V2X communication ITS-G5

In recent years, various communication standards have been developed across the globe to enable vehicular communication, either dedicated standards (ITS-G5) or cellular (LTE) based ones. Whatever the choice is, standardization bodies keep in mind that vehicular communication has stringent requirements. In fact, vehicular networks need to offer a secure communication in a highly mobile environment for time-critical messages from a large number of mobile stations [6]. Hence, the end-to-end latency, reliability, communication range, data rate, mobility, network density and security all should be taken into consideration to choose the appropriate wireless solution.

The V2X technology, to be thought of in SAFER-LC project, is the microwave radio technology being developed under the standard IEEE 802.11 on automotive focus with operation OCB (outside the context of a Basic Service Set (BSS)) [18]. Based on this technology, Intelligent Transportation Systems (ITS) standardizations have been investigated in the U.S and Europe in parallel, leading to the definition of two different protocol stacks. ETSI has defined the ITS stack covering PHY and MAC layers as ITS-G5. The G5 term indicates that it operates in the 5 GHz frequency band. It is based on the IEEE 802.11p U.S standard, with specific spectrum allocation to meet some requirements in Europe. The ITS-G5 operates in 5 subbands from A to D, with different 10 MHz channels each. The ITS-G5A, is the primary frequency band. With 30 MHz bandwidth, it is dedicated to safety and traffic efficiency applications. ITS-G5B has 20 MHz, allocated to non-safety application. The ITS-G5C is shared with the RLAN/WLAN/BRAN band, while the ITS-G5D band is set aside for future usage of ITS road traffic applications. A specific requirement in Europe is that the ITS-G5 spectrum must limit interferences to the 5.8 GHz CEN- system, which is used for electronic road tolling.

As we have seen through this brief description, overall, ITS-G5 is a mature technology designed to convey road safety messages. This is the reason why such a technology was adapted for several technological solutions developed in our project.

The key medium access features of IEEE 802.11p and ITS-G5 are the same. Both rely on OFDM on the PHY layer, where the subcarrier spacing is set to Δf = 152.25KHz. The number of used subcarriers is Nc = 64, 52 of which are useful and 12 are guards. The useful subcarriers are divided into 48 for data and 4 for pilots. As concern the MAC layer, the ITS-G5 relies on the, with Carrier Aggregation (CA) based protocol where Quality of Service (QoS) has been included, in order to prioritize data traffic. The ITS-G5 based deployment of ITS services has been an evolutionary process in Europe.

On top of the access layers, ITS standards define further layers, among which the Facilities layer. The later specifies requirements and functions supporting applications, communication, and information maintenance. Its most relevant standards cover messaging for ITS applications, such as CAM and DENM, which have been defined in EN 302 637.

Cooperative Awareness Message (CAM) is a periodic message exchanged between ITS stations to maintain awareness of each other and support cooperative performance of vehicles. It is composed of several containers, thus ensuring a flexible message format, easily adapted to the needs of the target application. The basic container conveys the station type and its position. Moreover, other relevant information, such as, for instance, vehicle heading, speed, and acceleration, can be added in other containers if needed.

Decentralized Environmental Notification Message (DENM) is an event-driven safety information, exchanged in a specific geographical area surrounding the event. When an ITS station detects a dangerous situation, a DENM message is generated defining the specific event, its detecting ITS station, its lifetime and relevance area, among many other information. DENM has several mechanisms to keep disseminating the event information in its relevant area during its lifetime. For instance, the detecting ITS station can repeat the DENM message during some time interval, to ensure that the vehicles entering the relevant area are informed.

In addition to the facilities layer, ITS standards define mechanisms for security and privacy protection, including private key infrastructure (PKI) enrollment and authorization management protocols, confidentiality, and data integrity.

2.2. Cellular communication system LTE

The LC safety measure tested in Thessaloniki is called ‘LC and train proximity in-car alert’. It provides auditory and visual warnings to road users. Those warnings are issued through a mobile application when a vehicle is approaching a level crossing. The warning also includes an estimated time of arrival for the case of an incoming train.

In the heart of this safety measure lie mechanisms and algorithms leveraging Information and Communication Technologies. They continuously generate, process and transmit data mainly concerning the location of road vehicles and trains.

In our project we also tested the communication systems via cellular communication LTE and the Internet. In fact, in order to accommodate the increasing mobile data usage and the new multimedia applications, LTE technologies have been specified by the 3GPP as the best mobile communication technologies [18]. The LTE system is designed to be a packet-based system containing less network elements, which improves the system capacity and coverage, and provides high performance in terms of high data rates, low access latency, as well as flexible bandwidth.

The test vehicles of the Thessaloniki pilot were taxis that had installed the application on the onboard tablet they use for navigation and dispatching. The application monitors the location of the vehicle and uses a cellular communication network to transmit the exact location of the vehicle whenever it enters a predefined area in close proximity to a LC. The trains are monitored by the train association TRAINOSE. Most of its fleet are equipped with tracking devices that transmit data to TRAINOSE’s systems using similar communication channel. The safety system’s backend server retrieves the train location data in real time via a stable Internet connection with the database. Several tests were implemented during the development of the system and the safety application.

Initially, artificial data for moving trains and vehicles were used to technically validate the system's components. The next testing phase took place in actual level crossing environment, using pre-release version of the mobile application and the backend data logging system.

Those tests revealed minimal system latency of around one second, meaning that whenever a vehicle enters the predefined area around the LC, the warning was typically issued within one second. This latency is definitely considered acceptable for this safety system, as it aims to inform drivers of the LC well in advance before they reach the crossing zone. However, in order for the system to operate as designed, it has to be foreseen that cellular communication is available in the area around the LC, to enable the components to communicate stably.

2.3. Positioning system

The locations of road vehicles and trains are monitored utilizing Global Navigation Satellite System (GNSS). Those systems use satellites to achieve geo-spatial positioning by determining the location of the sensor with high precision, typically within some centimeters to a few meters. Several GNSS exist, with the most well-known being the Global Positioning System (GPS) which is developed and operated by the United States. Other GNSS are Russia's Global Navigation Satellite System (GLONASS), China's BeiDou and EU's Galileo. More satellite navigation systems mainly providing regional coverage also exist. GPS and GLONASS have global coverage, while Galileo and BeiDou are expected to achieve this within the year 2021.

GNSS receivers determine the location by triangulation, a method that calculates and compares their relative distances from at least four GNSS satellites. The tracking accuracy of GNSS in known to reduce under certain circumstances and/or environments. The most significant errors are known to be caused by the "multi-path" effect in urban environments, when satellite signals reach the receiver following indirect trajectories, causing distance over-estimations. A typical example of multi-pathing occurs when the signal bounces on large buildings before it reaches the receiver. In general, tracking accuracy has been improving in recent years. To put this into perspective, it is foreseen that satellite navigation will be one of the enabling technologies of autonomous driving, with high-precision tracking in the order of a few centimeters [19].

The LCs at which the system was tested in Thessaloniki are located in open air environments with generally high GNSS accuracy. There are no tunnels either for the trains or vehicles approaching these LCs. It is recommended that satellite navigation tracking accuracy is validated on-site in case this LC safety solution is considered for implementation in other LC environments. It is considered more important to validate the positioning for road users, as the warning system is triggered by the entrance of a vehicle in the area close to a LC. It is worth noticing that even in the scenario of an undetected train, the driver will receive the warning about the LC proximity, however, the estimated time of train arrival will not be provided.

3. SYSTEM ARCHITECTURES DEPLOYED IN THE PILOT SITES.

3.1. Specificities of rail-road cross-modal communication

Enhancing LC safety by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is one of the dedicated goals of the SAFER-LC project. That means the use and integration of advanced wireless communications to provide both road and rail traffic participants as well as road and railway operators with a means to detect hazardous events as well as control and manage the traffic on their networks. The application of vehicular communication methods and technologies in the rail and road domains has relatively long history. One curiosity of the development is that rail and road systems have developed communication methods independent from each other because of the different safety, security and efficiency requirements of the two modes of transportation.

Road-rail level crossings represent very specific operating conditions for traffic automation and communication. LCs are the geographic areas where two different technology domains are met, used and affected in a common environment in an attempt to make the train and road traffic safer and more sustainable in the future. Rail traffic is characterized by poor braking capabilities of trains and rail vehicles in general, the fixed traveling path, and the inability to avoid obstacles. This property generally prioritizes train traffic over road traffic in all places where they interact with each other, such as, for e.g., in LCs.

The need for cross modal communication services between road and rail systems, therefore, is growing apace in the past few years due to the necessity of the application of novel communication technologies aimed to detect the presence and/or share data between road and rail vehicles and other traffic participants such as vulnerable road users (VRUs), i.e., pedestrians, cyclists, motorcycles, agricultural machinery etc. The involvement of not V2X enabled traffic participants (beyond VRUs) into the frame of safety technologies, such as vehicles not equipped with communication, is an ever-important safety issue as well.

The common requirements of interoperability have led to the development of communication methods and technologies conformant to the common requirements of the two different technological domains and also to the development and adjustment of current standards to be suitable for the more challenging and varying conditions of LCs.

The primary objective of the application of railway communication systems is to provide railway operators with a means to control and manage the train traffic on their networks. Railway control systems aim to prevent trains from colliding with each other and with obstacles, and prevent derailing based on various train and hazard detection technologies. Rail communication solutions traditionally do not treat with methods trying to avoid incidents caused by the road traffic nearby or other hazards originated in the connecting road systems.

From the one hand, rail connectivity solutions are basically using GSM, IEEE 802.11 and other proprietary technologies and solutions. While GSM-R (GSM for railways) and LTE-R (Long Term Evolution - Railway) are built on the cellular network infrastructure, the 802.11 microwave (WiFi) solutions make use of the private network of wayside units. Both technology groups ensure connectivity of the trains with the control center in order to send and receive control information.

From the other hand, road ITS communication systems (either based on the 802.11 OCB, or cellular-based C-V2X solutions) are increasingly relied on the use of the 5.9 GHz safety spectrum (for specification see Section 2a above).

Recognizing the need for cross-modal solutions and facilitate communications between rail and road systems, in the recent years, the rail community has proposed and pushed to use the spectrum allocated to the road ITS systems in the band 5.9 GHz for the use of their systems as well. The deployed communication systems became isolated with using mostly proprietary solutions and mainly based on the 802.11a standard. They do not follow any harmonized specification and are based on a set of specific requirements derived from the rail application in question, and as such, they are inappropriate for harmonized use with the advanced road technologies. A sharing between these systems and the existing ETSI Road ITS technologies (Intelligent Transport Systems operating in the 5 GHz frequency band, ITS-G5) can only be reached by means of complex mitigation and sharing techniques [1].

Considering rail communication, there is a well-defined technology separation between systems that are being used in mass transit networks (metros and urban rail lines in general) and the ones being used for mainline (or long-haul lines). Both urban rail (UR) lines and mainline networks generally involve LCs and, therefore, interfere with roadway traffic. Because of the higher traffic density, however, LCs of UR lines represent more challenging safety situations.

Mass transit and mainline communication systems evolved along two separate trajectories resulting in ecosystem approaches which are most often not compatible with each other.

In Europe, where cross-border interoperability is particularly important, the International Union of Railways (UIC) and the European Rail Research Institute (ERRI) began the search for a common European operation management platform for railways, titled European Rail Traffic Management System (ERTMS). ERTMS is a European harmonized action to achieve rail interoperability on the mainlines throughout Europe, which relies fundamentally on GSM-R communication (LTE-R is an updated action of ERTMS). Technically speaking, ERTMS is the system of standards for management and interoperation of communication and signaling for railways in the EU. The larger part of the related work is performed under a standardization project (led by UIC) called FRMCS (Future Railway Mobile Communication Systems), aimed at replacing the existing cellular communication technologies (i.e., GSM, LTE) that is expected to be phased out by 2030.

Mass transit and UR lines depend on the use of the Communication Based Train Control (CBTC) system solutions almost exclusively that are considered distinct from ERTMS. While mainline railway operations make use of wide area network technologies (GSM-R), CBTCs are based on short and medium range communications solutions.

CBTC is an enveloping technology term used for train automation in segregated local urban areas. Normally these systems are well separated, they do not interact with each other which did not help to use harmonized solutions. There has been a general lack of standardization for CBTC. There are more than one hundred isolated CBTC installations world-wide with nearly all systems incompatible with each other.

It has been recognized early that the convergence of CBTC and ERTMS solutions would be highly beneficial which is a primary focus of the harmonized development of both fields. Newly deployed advanced CBTC systems, therefore, tend to use harmonized solutions and are employing IEEE 802.11 communications operating in the 5 GHz range which facilitates the shared use of the C-ITS spectrum.

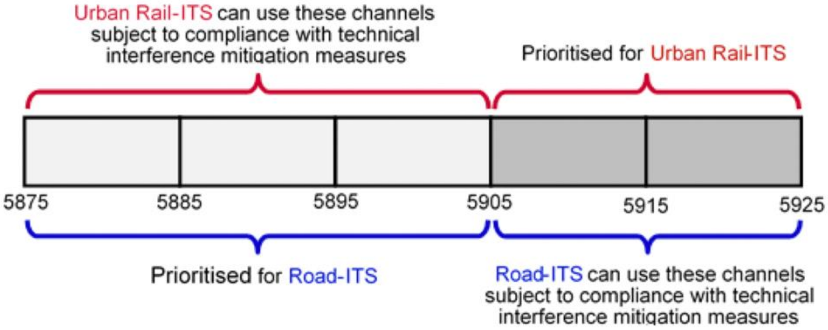
One of the key differences between rail (CBTC) and road applications (ITS-G5) of the base technology IEEE 802.11 is that rail favors connection based (unicast) methods while road systems are broadcast-based solutions, which further complicates the situation. The recent proposals [1] and [2] describe a technical solution to the above discrepancies which is fully compliant with EN 302 571 [4], [16] [17].

The urgent need for harmonization of CBTC in the framework of ERTMS is evident and the integration of rail systems with other modes of transportation such as with road transportation systems is being considered in various technology forums recently. As the harmonized European CBTC solutions will be part of final ERTMS specification, the technical work on closing the gap between the road and rail technology domain is an urgent harmonization task as well. A first effort in this direction is described in [1] and [2].

Further difficulties lie in the spectrum sharing which became a hot topic in recent discussions. As it was discussed in another section of this document, the 5 GHz ITS-G5 road technology uses the spectral

- ITS-G5A : 5.875 GHz to 5.905 GHz – ITS safety (not limited to road safety)
- ITS-G5B : 5.855 GHz to 5.875 GHz – ITS non-safety
- ITS-G5D : 5.905 GHz to 5.925 GHz – other future ITS applications which is to be shared with rail systems.

In 2017 ECC/CEPT proposed revision of ECC Recommendation 08(01), see [6] and instructed ETSI to find an agreement [5]. Joint taskforce between TC RT (rail technology) and TC ITS (road technology) TC RT JTFIR was created, which proposed a new spectrum allocation in acc. with the following scheme:



It has been agreed between the communities that the Urban Rail application will have a certain prioritisation in the upper 20 MHz of the ITS band (5905 MHz to 5925 MHz) as long as the planned ITS application can still use the bands with limited restrictions.

Note that this prioritisation is limited to the area where it is required (operational area of an Urban Rail and LCs) and to the time frame where a prioritisation is needed. This prioritization information is controlled by the train by transmitting a dynamic beacon (CAM messaging) which is only active where and when sharing is required (e.g., LC environments).

Another issue is the additional spectrum request of the rising C-V2X technology and the introduction of other unlicensed users into the 5.9 GHz safety spectrum at the expense of the standardized C-ITS applications. This, however, takes us too far from the context, is outside the scope and, therefore, not discussed in this document.

SAFER-LC contributes to this harmonization activity and intends to give an initial evaluation of novel safety enhancement methods applicable in LCs, such as event and incident detection methods, as well as cross-modal information sharing techniques based on C-ITS communication and V2X technology in general, in order to support technology validation and harmonization and facilitate future deployment of these methods in the field of rail systems.

The specific idea of the shared use of C-ITS technology between road and rail users is presented by SAFER-LC. Some project actions are related to the elaboration of basic research ideas that need further considerations regarding their applicability, some are more mature and in accordance with the recent harmonization and standardization activities.

4. SYSTEM DEPLOYED IN THE PILOT SITE AACHEN

4.1. System deployed in the Pilot site Aachen

Aachen test site was used to pilot several safety measures. Four of them were linked together and could be called as Smart detection and communication system. This system covers a real level crossing (a scale one mock-up representing an active LC) that is interfaced with a roadside unit (RSU) which can send information to cars, control room and trains. The system includes three main functionalities (Figure 1):

- Detection of potentially dangerous situations (obstacles, vehicle stopped at LC, approaching train, etc.) by cameras and/or vehicle to everything (V2X) communication. The objective of the **Smart Detection System** (SDS), developed within this task is to set up a warning system based on intelligent detection of potentially dangerous situations that may occur at LCs and some hazard situations in the larger surrounding of the LC. An optimized Automatic Incident Detection dedicated to level crossings is specified, implemented and evaluated. The SDS allows for the accurate detection of hazardous events and localization of obstacles which are motionless or in motion at the LC, which could jeopardize the safety of LC users, especially vulnerable users. Possible events to detect include vehicles stopped on the tracks, objects left on the tracks, trespassing and pedestrians stopping or crossing the LC**.**
- Wired communication between the cameras and the level crossing (LC) unit.
- The ITS-G5 communication between the roadside units (RSUs) and the LC unit and ITS- G5 communication between the LC unit and vehicles (road vehicles and/or train).

These functionalities are used for the following safety purposes:

- to close the barriers based on the estimated actual time of arrival (ETA) of the approaching train
- to deliver in-vehicle messages and alerts to the control room about a dangerous situation using decentralized environmental notification messages (DENM) and collective perception messages (CPM) to cars equipped via a specific on-board unit.

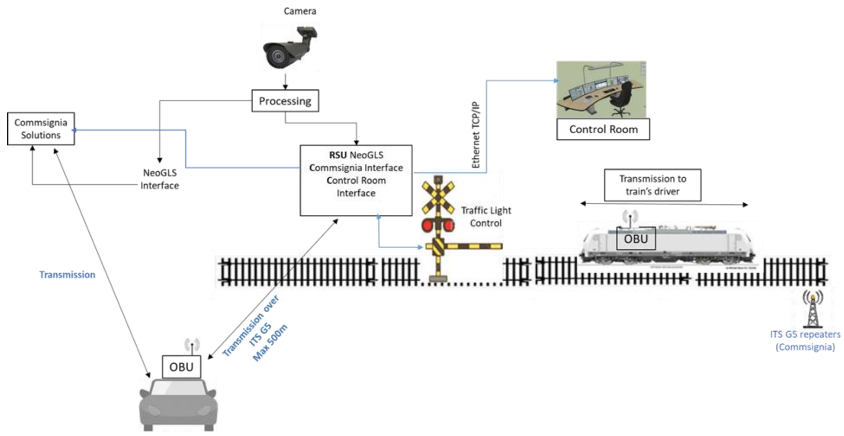


Figure 1 : *Main structure of various V2X communications scenarios*

The smart detection system is connected to the smart Roadside Unit with the NeoGLS interface which is able to send information to the cars in the LC vicinity, or to the train. The NeoGLS interface is connected also to IFSTTAR communication system:

- The SDS is implemented on a personal computer with Linux as operating system connected to an IP camera. The SDS processes data flows coming from the video sensor in order to detect events occurring in the field of view of the camera.
- The video flow is stored in a videodataset.
- The events detected by the SDS are registered using Linux Syslog standard process. This process is configured for using documents-oriented dataset, mongolb.
- The process (Event Proxy process) developed allows for sending events stored in the database, via NeoGLS Roadside Unit (RSU) network.
- The process (Video Proxy process) allows for sending video flows stored in the video database via NeoGLS RSU network.

The NeoGLS system receives all the information: events detected by the SDS, the corresponding video flow, the state of the lights, the state of the barriers. Then the principle is the following: According to the status of the lights and the status of the barriers, the RSU chooses the adequate alerts to send to the control room and the adequate DENM to broadcast to the On Board Unit installed in the approaching cars. Every alert sent to the control room is accompanied by the related piece of video.

The smart detection system is at a technical evaluation stage, a proof-of-concept and the functioning of the system were tested for three tests operation. The system addresses mainly situations where there are traffic disruptions on LC, such as stopped vehicles or traffic jam, by providing better situation awareness for the traffic management. the Key Performance indicators (KPI) were defined and calculated in order to evaluate each solution. the results of the evaluation phases were discussed in deliverables 3.4 and 4.4.

All these results show that the existing communication standards used in our tests have some limitations in terms of the range and number of lost frames especially in complex propagation environment (presence of multi paths, disappearance of the propagation path ...).

The level crossing setting is considered to be a particularly relevant environmental factor affecting safety. There are particular characteristics of the LC that can impact on the conspicuousness of the crossing, most notably the sight distances. In fact, sight distances can be obstructed by trees, buildings, and the roadway-crossing geometry as well. Poor sight distance and impediments to LC visibility is of particular importance at unprotected crossings where driver's decision to cross the LC also depends on his ability to detect an oncoming train within a safe time margin (especially in the case of unprotected LCs). Another source of hazards is related to undetected objects and other vulnerable LC users (pedestrians, wanderers, animals).

From classical accident research, collisions at LCs can be linked to various errors of perception and efficient knowledge driven decision-making. The experimental scenarios of SAFER-LC are focused on the validation of perception functionality supported by advanced V2X technology. This objective is achieved with the integration of a camera-based smart detection system (SDS) in the C-ITS ecosystem. SDS can detect various incidents and hazards in the LC. The information generated by the SDS is then used for sharing with different stakeholders by means of standard ITS-G5 awareness protocols.

The way how it is done, the integration of SDS into LC communication infrastructure, the rail specific modification of the standard V2X technology are, however, open issues which require further research.

For the solution of combined incident detection and hazard information sharing, SAFER-LC suggested the experimental use of the new Collective Perception Message (CPM) service. CPM is a new facilities layer service of ITS-G5. The usage of this new messaging methodology is under standardization in ETSI and SAFER-LC was the first action to validate its implementation in the frame of a real field trial. Validation results will be feedbacked to the standardization process in which Commsignia is involved. In the following section we characterize CPM functionality very briefly.

Dissemination of perception data provided by the smart detection system

V2X communication systems generate and share environmental information among road users on a large scale. Location and kinematic data of vehicles residing in the same geographical region is normally disseminated by using the standard Cooperative Awareness Basic Service (CABS), which provides a cooperative awareness service to neighboring nodes by means of periodic sending of status data of communicating vehicles. This facility layer service generates and distributes Cooperative Awareness Messages (CAMs) in the ITS-G5 network in a deterministic timely basis (from 1 to 10 Hz frequency, depending on the context). This provides information of presence, positions as well as basic movement status of communicating ITS-S (ITS Communication Station) stations to neighboring ITS-S stations that are located within a single hop distance.

In contrast to CABS, Decentralized Environmental Notification Message (DENM) service handles messages in an event driven manner and provides the key messaging functionality for hazard warning. Both CAM and DENM services are standard features of ITS-G5 technology (see [8] [9]), and are triggered by a particular ITS communication station application (i.e., an OBU or RSU). DENM messages.

CPM is a novel V2X service which aims at disseminating sensory information about the current driving environment by letting vehicles and road infrastructure elements transmit data about detected objects and their timely behaviour (i.e., the behaviour of other road participants, obstacles and dynamic road hazards) in abstract descriptions. These descriptions then will be included in broadcast messages called CP messages (CPMs).

Though the objective of CPM and DENM services are rather similar (in fact they are both event driven data dissemination protocols), DENM focuses on traffic and road related hazards (emergency breaking, priority vehicle warning, compromised road conditions, etc.) while CPM is specifically used for sensor information dissemination. Because of the different requirements (performance and other operational requirements) of the two services it seemed reasonable to implement them separately in the protocol stack.

The key differences between DENM and CPM are the following:

a. While DENM message repetition is related to the same event type i.e., the triggering event generates a DENM message whose content remains the same until the hazard stays, CPM messages are sent out periodically with continuously refreshed data content. In this sense CPM is much akin to the time triggered CAM.

b. CPM is about to cooperative fusioning of the received sensory data and distribution of this information in the immediate geographical vicinity. This requires the use of a distribution logic different from DENM services.

CPM standardization is currently ongoing at ETSI ITS [7]. According to the latest draft definitions of CPM services, the originating ITS communication station (i.e., the station, which obtains or generates the sensory information) continuously transmits CPMs carrying abstract representations about the status of detected objects. It is the originating stations' responsibility to select around objects worth to be shared between traffic participants. These are objects (both static and dynamic ones) which represent safety risk in the traffic situations, and therefore are to be included in the sharing process in order to warn other traffic participants about the issue.

Static detected objects are fixed stationary elements of the infrastructure, or vehicles and other temporal road objects in the dangerous zone of the LC. Dynamic detected objects are moving objects, such as for e.g., pedestrians walking, or wandering, moving cars entering the dangerous zone of the LC, etc. Performance requirements of the inclusion of vulnerable road users in the perception mechanism is described in [10].

In order to reduce radio congestion and messaging complexity, originating stations have to use a censoring system and select only objects for transmission that might be "directly" relevant in a particular safety context. This means that nonrelevant objects like fix infrastructure elements along the carriageway and/or pedestrians walking in a direction which does not affect the safety zone must be filtered out and exclude from transmission. Annotation is a special data characterization according to which a relevant object is parameterized. Object annotation is an enveloping process performed by the V2X communication system by which the descriptions of selected objects are assigned with their physical parameters upon which the object can always be reconstructed on the receiver side.

The collective perception scenario applied to SAFER-LC is depicted in Figure 1. The cooperative scenario consists of a V2X enabled smart detection system (SDS), V2X enabled road and rail vehicles and other vulnerable road users in the LC.

Early detection and hazard information sharing by means of collective perception messaging and driver's warning

Consistent with the validation program detailed in SAFER-LC deliverable D4.4, the project demonstrated the usability of three V2X communication-based safety applications, aiming to improve the safety of LCs. This program was designed and performed by Commsignia.

- by warning drivers of both road and rail vehicles about dangerous traffic events identified in LCs,
- by assisting road users to escape in case of dangerous situations, and
- by assisting drivers of both road and rail vehicles to avoid and mitigate the danger of hazardous situations (e.g. by stopping the car or the train prior to the LC).

The evaluation program included the following main use case implementations, which can be classified in three categories:

1. Intersection assist safety applications in LCs including various traffic scenarios. The scenarios are about the avoidance and mitigation of the severity of collisions between road and rail vehicles at LCs. It is assumed that both road and rail vehicles are V2X enabled vehicles meaning they are equipped with on-board communication units (OBUs). The intersection assist safety applications are installed and operated on these OBUs.

Scenario title	LC intersection management from view of the ego (road) vehicle
V2X application	LC intersection management safety application (LIMA)
Objective	The safety app issues critical collision warnings to road vehicles and the train when the trains' collision with a V2X enabled road vehicle is imminent. The safety app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It helps car drivers to avoid front-to-train and side-to-train collision situations and mitigate the severity of collision hazards for trains.
Enabling technology	Intersection movement assist safety application based on CAM processing and sensor fusion
Related standards and other specifications	[11, 12, 13, 14]

Clearance assurance in the following use cases means the proper monitoring and processing of movement information of V2X capable vehicles around LCs, as well as last second warning of drivers in case of imminent hazard.

Scenario title	LC clearance management for train I. – II.
V2X application	LC intersection management safety application (LIMA)
Objective	The safety app issues critical collision warning to road vehicles and the train when approaching LCs in the forward path of travel when a collision with a V2X enabled vehicle is imminent (dangerously approaching road vehicle towards LC). The app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It helps train driver to mitigate the severity of collisions in LCs. The safety application issues critical collision warning to both rail vehicle and the subjected car when train is approaching and the car is near stationary (or stopped) at the dangerous vicinity of LC and the collision with the V2X enabled vehicle is imminent. The app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It warns the car driver about the approaching train and/or helps to escape from the car in case of last second hazard situations. It also helps to avoid front-to-LC collisions for train drivers and/or mitigates the severity of collisions in LCs.
Enabling technology	Intersection movement assist safety application based on CAM processing and sensor fusion
Related standards and other specifications	[11, 12, 13, 14]

Scenario title	LC clearance management for train III.
V2X application	CPM generation and distribution upon detected object triggering
Objective	The safety app issues critical collision warning to the approaching rail vehicle when a detected pedestrian (or any pre-specified type of object) blocks the LC and the collision with the arriving train is imminent. The app provides collision warning and hazard mitigation and clearance assurance for train drivers. It helps to avoid front-to-LC collisions for train drivers or mitigate the severity of collisions in LCs.
Enabling technology	Smart Object Detection system SDS with CPM processing
Related standards and other specifications	[7], [8]

2. Range enhancement of detection of approaching trains in LC environments. This use-case scenario demonstrated the capabilities of the CPM service of V2X technology in LC environments in extending the perception range of the cars for several km’s and invisible areas. Relying on this service, cars wanting to cross the LC will be able to elongate their warning horizon in hazard situations, significantly. Train position information is made available in the LC that can be used in the calculation of the timing of other safety actions such as barrier closing and opening.

Scenario title	Remote detection and monitoring of the approaching train
V2X application	CPM generation and V2X sensor fusion
Objective	This use-case is about to advertise the presence of the approaching train by sensing and disseminating rail specific CAM messages by means of collective perception technology and CPM messaging. Train position information is made available in the LC, which information can be used in the calculation of the timing of safety actions such as barrier closing and opening.
Enabling technology	CAM and CPM processing and distribution, V2X sensor fusion
Related standards and other specifications	[7], [8]

3. The capability of the multi-hop DENM forwarding technique in early train detection was also demonstrated. The method is based on the Geonetworking protocol and fast forwards train position (arrival) information initiated by the train itself to a distant LC making use of the available V2X infrastructure.

Scenario title	Remote detection of the approaching train by means of multi-hop DENM forwarding with drivers warning
V2X application	Multi-hop DENM messaging
Objective	This use-case is about announcing the presence of the approaching train by triggering DENM messages on train upon arrival and disseminating these messages by means of multi-hop forwarding using the available V2X infrastructure and/or intermediate V2X capable vehicles' functionality.
Enabling technology	Multi-hop DENM message forwarding is based on Geonetworking protocol and geofencing.
Related standards and other specifications	[9], [15], [16]

4.2. System deployed in the Thessaloniki Pilot site (CERTH)

Architecture and results

The LC safety measure developed and tested in Thessaloniki consists of different modules operating tasks in parallel and communicating with a central backend system hosted by CERTH-HIT. The train monitoring is executed by dedicated GNSS receivers installed in locomotives. The backend system processes those data in real time and estimates the time of train arrival to LCs located in Thessaloniki. The road vehicle tracking module is contained in a mobile application which should be installed in a smart mobile device in the vehicle. It communicates with the backend system whenever the vehicle enters predefined areas around LCs, which triggers the auditory and visual warnings (Figure 2). More details about the system's architecture are documented in deliverable D3.2.

This safety application is robust to reasonable positioning inaccuracies and errors of up to a few meters both for the train and road vehicle. The areas around LCs in which the warnings are triggered typically contain at least fifty meters of road before meeting the rail. Those road segments are located in urban environments with speed limited to 50 km/h or less.

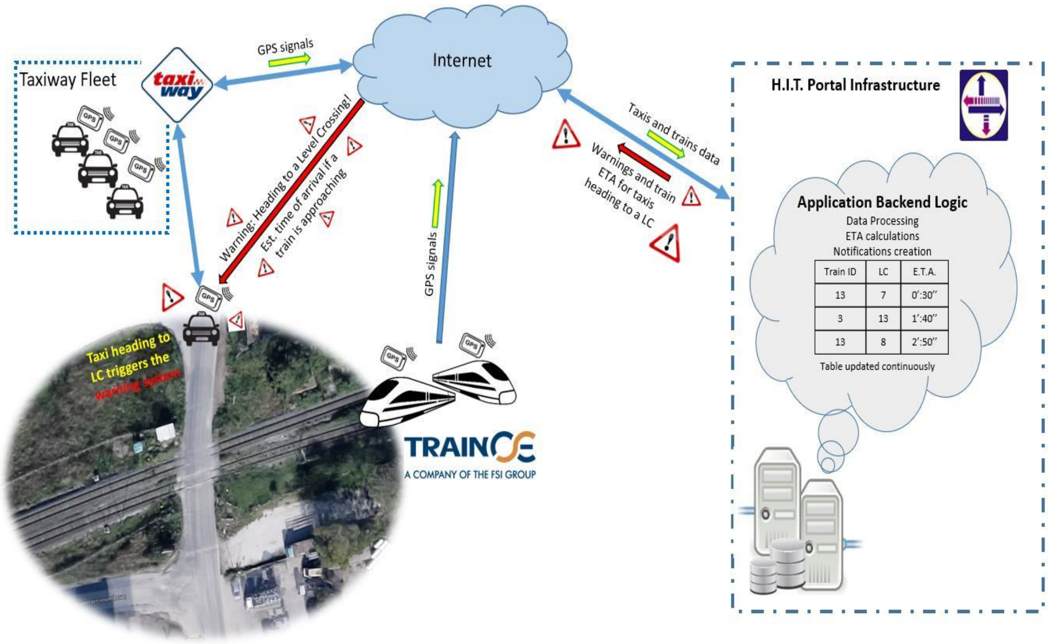


Figure 2: The architecture of the measure developed by CERTH-HIT

5. RECOMMANDATIONS.

5.1. Recommendation regarding to the new technical solutions (smart communication /detection)

One of the main advantages of ITS-G5 is its capability of low latency communications. In fact, being a direct communication between the source and destination, and bypassing the basic service set configuration, ITS-G5 can achieve around 3-5 ms message return time. However, this advantage may degrade as the network density increases. The /CA "listen before you talk" behavior leads to higher latency when the number of users grows. Furthermore, the range of ITS-G5 is limited to 1 km in the best conditions. In the European standard, GeoNetwoking protocol was introduced to perform multi-hop and increase the communication range. Nonetheless, it increases complexity. From a PHY layer point of view, this multi-hop functionality is challenging.

C-V2X has also been designed to meet vehicular communication requirements. However, it is based on which requires complex equalization algorithms. Furthermore, the initial design of LTE was not intended to support a big number of connected devices, hence when the number of vehicles increases, the C-V2X performance may also degrade [13].

Finally, both C-V2X and ITS-G5 adopted a fixed spectrum allocation strategy which is not optimal, especially for application where the number of users is very high. In fact, assigning 10MHz for a single user simplifies synchronization, but leads to sub-usage of the available resources. Furthermore, their PHY layer is based on conventional OFDM. This scheme, though simple, suffers from the lack of spectral containment, leading to high interferences in the adjacent channels. Furthermore, the orthogonality of subcarriers is crucial in OFDM. Whereas vehicular communication suffers from Doppler effect leading to carrier frequency offset in OFDM, hence increasing its Bit Error Rate (BER). For all these reasons, the promises made by 5G motivate the research on 5G vehicular communication for the transport application, especially regarding LC scenarios.

5.2. Proposed recommendation for some scenarios

5.2.1. Scenario 1: Detection of the incident and transmission to the road users

In this case, the incident is detected by the video detection system and transmitted to the on-board unit of the cars heading to the level crossings for a graphic visualization of the incident and to allow a better reactivity to the incident.

Communications scenarios of Safer-LC designed and implemented by IFSTTAR with GLS consisted of :

- Detecting the Level crossing status and transmitting it to the road users by Infrastructure - Vehicle communication using CAM and DENIM.

- Retransmission of the LC status to all vehicles heading to the LC using V2V communication by means of CAM and DENIM: Multi-hop scenario.
- Experimental methods according to existing standards were tested on the field. The experimental applications were tested and operated in real environments in order to evaluate this proposition in terms of range, speed, robustness of propagation channel in various conditions (snow, trees, speed…).

In the next step, it will be interesting to evaluate these solutions in terms of cybersecurity level. Cyber security in V2X communications for ITS has been addressed by various works in the recent years. In fact, the cybersecurity is a hot topic and a raises opportunity related to the development of secure and safe ITS applications. In fact, V2X communications in ITS are much more vulnerable to attacks than wired networks. In V2X, every vehicle node can move freely within the range of the V2X network and stay connected. In the next step, this aspect will be considered and evaluated.

5.2.2. Scenario 2: Detection of the incident and transmission to train driver

In this case, the incident is detected by the video detection system and transmitted to the on-board unit of the train coming to the level crossings for a graphic display of the incident. This will allow the driver to perform upstream the necessary maneuvers, ideally, so as to stop the train prior to the LC. In order to ensure efficient cross modal information exchange between road and rail systems and guarantee the efficient use of the available spectrum, a shared use of the 5.9 GHz band between road ITS systems and rail systems is required. The most efficient sharing between the applications could be reached by deploying a harmonized communication technology for both application domains.

Communications scenarios of SAFER-LC consisted of communication methods which can be placed in three particular groups:

- There are methods which are fully compliant with existing standards, such as CAM, DENM. No further actions are needed regarding their applications in rail environment.
- There are methods which are based on modified versions of existing standards (rail specifically modified CAM and DENM). Based on the above discussion, one has to define a new or an updated message set for introducing urban rail and conventional rail as part of the ITS-G5 system.
- Experimental methods according to draft specifications of standards under preparation were field tested (CPM). The experimental applications were tested and operated in real traffic environments and under hazard conditions.

In future works, the test setup needs to be further extended and verified. Moreover, adaptation towards any similar use cases described in this document before the content of modifications is presented for SDOs for consideration, should also be envisaged. Though modifications and added enhanced features could improve the usability of the methods in rail environments, it is mandatory to maintain backwards compatibility and interoperability with existing standards.

5.2.3. Scenario 3: Detection of the incident and transmission to the room control

Based on the experimentation results in Aachen with the SDS, here are the recommendations that can be made regarding the transmission of the incident to the control room.

First of all, the communication protocol between the RSU and the control room should be lightweight and function with push notifications. The RSU has to inform the control room immediately when an incident occurs. That is why a “poll” from the control room is not advised.
Moreover, using such a protocol guarantees free bandwidth to be used for video transmission (that is the heaviest transmission).

The second recommendation is to pause the video transmission in case of nominal situations (no incident is running). This also aims to preserve bandwidth and network availability for the RSU. The video can be buffered and send only when it is useful.

The ideal is to limit the bandwidth used by video transmission. This can be done in the protocol used for video transmission, or also in the video quality selection. Choosing a lower quality format can preserve bandwidth and also provide videos with enough quality to be interpreted in the control room. Finally, display on the control room HMI must also be done in real time. The ideal HMI should use popup alerts that play a sound, so that the agent monitoring the LC does not have to manipulate anything to be aware of the situation.

5.3. Proposed recommendations according the results of Thessaloniki tests (LTE solution)

The LC safety measure developed and tested in Thessaloniki by CERTH-HIT utilizes GNSS receivers for tracking, and cellular communication for exchanging data between the system’s modules. Based on the experience gained through the large-scale testing in real world conditions, several recommendations can be made.

The accuracy of GNSS receivers is sufficient for the proper operation of this system. The system was tested by more than 600 taxis and the analysis of the taxi location data, in the context of system evaluation, revealed acceptable inaccuracies in the order of a few meters. The receivers are plain tablets, typically low-cost and low-specification devices. Those results are rather encouraging, as it seems that mainstream smart devices meet the standards for this safety application.

Train tracking has utilized dedicated GNSS receivers installed and maintained by TRAINOSE. Those receivers communicate with a central database system where all data from monitored trains are collected and stored. The system was developed to obtain data for moving trains in real time, by establishing a connection to this database. It is recommended that for future applications and implementations of similar measures, the trains should be monitored directly by the same backend system that tracks taxis, to minimize network bandwidth and latency. Furthermore, it is foreseen that it would be more efficient if all modules are operated and monitored by one stakeholder, which can optimize the system and its modules. For instance, fail-safe mechanisms can be developed for the cases when train tracking services are offline, and the frequency at which the location of trains is captured can be adjusted to improve the estimation of train arrival time.

A requirement for providing road users with the estimated time of train arrival is internet connection, both for the vehicle and the train. However, road users will still receive the LC proximity alert even in those cases, provided that their mobile device location service is enabled.

5.4. General recommendations

Because of the lack of standardized messages between railway and road vehicles, regarding automatic driving, it could be interesting to prepare a set of standardised messages, to allow the level crossing and approaching trains to communicate with road vehicles.

At a protected level crossing (with lights, half or full barriers), the artificial vision system of an automated driven car can react and recognize the danger and stop accordingly before the level crossing (the same way they do in front of a traffic light at a road crossing).

By installing vehicle modules in the trains, it would be possible for the automatic driven cars to cross safely an unprotected level crossing.

A train approaching a level crossing would broadcast its position and speed, and together with the type of vehicle (train), approaching cars would know if there's a conflict between the train's route (fixed) and the car's route (variable). The system could decide whether to safely cross the unprotected level crossing (no train approaching), to stop at the level crossing if the train is approaching and the distance is below the safety margin, or to search for an alternative route if it is possible, without crossing the level crossing in case of system malfunction.

From UIC side, the requirements for adaptation of level crossings to automatic driven cars could be included in one of the several IRS[1] (International Railway Solution) UIC has published as recommendations regarding the protection of level crossings, with worldwide recognition.

Also, in the current leaflets[2] (UIC leaflet 761- Guidance on the automatic operation of level crossings), UIC could include the recommendations extracted from the scenarios, regarding the installation of video detection systems for obstacles at level crossings, the interfaces with the traffic management centre and the communication of dangerous situations to train drivers.

Some low-cost measures (those related to road marks, signals and road devices) could be included in the UIC Leaflet 760 –"Level crossings – Road signs and signals", as an update to level crossing passive protection and new recommendations based on the studies performed within the frame of Safer-LC.

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1 An International Railway Solution (IRS) is a document drawn up by consensus and applied in a voluntary basis, which aims to facilitate and harmonise railway operation. Members of UIC participate in the creation of IRSs, of which they benefit in full. Furthermore, marketing to railway stakeholders contribute to the sharing and harmonisation of good practices.

2 UIC leaflets, are the precedent of IRSs. With the same spirit and content, all leaflets will be migrated to IRSs

The following table, we summarize all standards, realized tests and recommendations in SAFERLC context.

Standards	In SAFER-LC context	Result of tests	Recommendations
LTE **&** **GNSS**	Offered as a mobile application. Provides auditory and visual LC proximity warnings to road users' mobile devices (e.g. smartphone or tablet). The estimated time of train arrival is included in the visual warning whenever an incoming train is expected to reach the LC within the next minute. The system was tested in Thessaloniki by more than 600 taxis in road segments located in urban environments with speed limited to 50 km/h or less. .	This solution is robust to reasonable positioning inaccuracies and errors of up to a few meters both for the train and road vehicle. The accuracy of GNSS receivers embedded in common tablets is sufficient for the proper operation of this system. The system uses widespread, general purpose devices and technology. It is not fail-safe and warnings are not guaranteed to appear (for instance the users' device might crash or not operate as expected due to other applications or unexpected circumstances). the safety measure could either be considered as an additional to the existing ones, or dedicated hardware should be used to ensure it is fail-safe.	It is necessary to investigate and validate that cellular communication is available in the area around the LC. The areas around LCs in which the warnings are triggered should be designed in a case by case approach, in order to consider safe breaking distance w.r.t. local speed limits (even in events of short delays caused e.g. by slow processing speed of the mobile device) and minimize the frequency of false positive LC detections. To increase the positioning accuracy, it is possible to combine GNSS with other positioning solutions, for instance odometry
ITS-G5 (IEEE- **802-11 p)**	Tested in Aachen pilot site. Share information of an LC status, in relation with a smart detection system (SDS) whose capabilities are to detect dangerous situations	Transmission duration is less than milliseconds The range is about 80 m Possibility to increase the range with multi-hope schema. transmission information very advance provides to increase the safety of drivers.	Cybersecurity will be considered and evaluated.
New Collective Perception Messages	Tested in Aachen pilot site. Range enhancement of detection of approaching trains in LC environments	Detection of not connected vulnerable road users: can be perceived by other road users' perception sensors. Detection of safety incidents Increased awareness: Information aggregation about the behavior of other traffic participants in real time increases awareness and the safety of drivers.	It was shown that CPS can effectively be used not only in native road environment but in intersection scenarios shared with rail systems

Table 1: *Summary of all results and recommendations in SAFER-LC context.*

6. CONCLUSIONS

In this deliverable, all communication standards used in the SAFER-LC are given.

These standards are analyzed, evaluated and tested in two site pilots (Aachen and Thessaloniki).

Some recommendations are given regarding scenarios defined in the SAFER-LC. The recommendations regarding the future ITS communication standards are also given while taking into account the requirement of Communication V2X in Level crossing environment.

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