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Deliverable D4.3

Pilot operation report

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SAFER-LC

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	Geoloc Systems	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

This document describes the test activities carried out in the Task 4.2 of WP4 (Pilots execution). Specifically, the Task 4.2 concerns the implementation and the execution of the tests built in various level crossing environments in different countries. Simulation tools (in-vitro) and prototype systems running in close-to-reality situations under controlled conditions are used for better understanding human reaction to the proposed measures and to optimize the system operation and design, by means of testing and fine-tuning the solutions developed in WP3. Additionally, various measures are tested under these environments for cases too dangerous or complex to test in the real-world pilot activities. The integrated tests are implemented in the test-track hosted by the Aachen University, where the whole chain, from detection and communication to awareness increase and barriers operation have been demonstrated. In addition, some functionalities are tested under real-world conditions. The simulation, controlled and field tests carried out are based on the use cases defined in WP1 and WP2 as well as the scenarios proposed by WP3, feeding them and WP5 with quantitative and qualitative outputs.

These series of pilot tests across Europe and Turkey are rolled out to demonstrate how these new technological and non-technological solutions can be integrated, validate their feasibility and evaluate their performance. The challenge is also to demonstrate that the proposed solutions are acceptable by both rail and road users and can be implemented cost-effectively.

Most of the developments identified within the SAFER-LC project are tested when possible and improved under a combination of environments in various test-sites in different countries (France, Turkey, Finland, Greece and Germany). The various test-sites available in SAFER-LC are a perfect fit for solutions and measures at different stages of maturity. Early stage developments can be tested in simulation environments or on controlled test tracks, while measures that are more sophisticated can be evaluated in field experimentations. The test-sites aim at:

- testing and fine-tuning the solutions developed in WP2 (WP for user-oriented measures) and WP3 (technical-oriented WP);
- evaluating the technical performance and the efficiency of the measures under simulated and real-world conditions; evaluating as well intermodal cooperative communication solutions (vehicle-to-vehicle V2V; vehicle-to-infrastructure V2I)
- evaluating and improving the human factors methodological framework defined in WP2 (that will ultimately assess human factor issues regarding the design of the safety measures proposed);
- feeding the business models in WP5 with accurate and realistic data regarding benefits.

Regarding the pilot tests, some changes to the DOW and the deliverable D4.1 can be mentioned:

- the pilot tests initially plan in Vaires (France) was done in Aachen (Germany). The project partners decided to move the pilot tests in order to have a stronger test location and potentially have synergies between the pilots that was executed there in Aachen;
- a new pilot test is executed by VTT in Finland. This test is used to evaluate safety measures that are connected to the behaviour of the self-driving cars at LCs;
- a new pilot test is also executed by SNCF in France. This test is also focused on driving simulation activities to evaluate impacts on human processes adapting infrastructure design to end-users;

- a new pilot test is also executed by NTNU for the LCs barrier condition monitoring that was done in Aachen (Germany).

The pilot tests executed in the Task 4.2 can be subdivided in three types of pilot activities:
- simulation tools;
- prototype systems running in close-to-reality situations under controlled environments, especially for cases too dangerous or complex to test;
- real-world pilot conditions.

It is possible to underline that three different pilot tests are referring to each of the three types of test activities. Various partners worked together in Aachen, in which the whole chain of detecting, communicating and informing has been tested under real world conditions in a track of the Aachen University. The other partners have tested in each location one or, more often, various measures. Specifically, simulation activities have been led by DLR in Germany, by SNCF in France and by VTT in Finland. Test-track pilot activities and capabilities have been involved various partners in Aachen (Germany), by CEREMA in France and by VTT in Finland. Real world pilot activities have been carried out by DLR in Germany, by CERTH in Greece and by INTADER in Turkey.

Some pilot tests have implemented a series of human-centered low-cost countermeasures selected from those identified in Deliverable 2.3. This process has included defining the simulator studies´ procedure, experimental design and evaluation framework with a focus on objective and subjective data to assess the effects of selected countermeasures on road user behaviour and experience. The total number of measures tested is 18 of a total number of possible countermeasures identified in D2.3 equal to 89. Four of these are tested in more than one pilot tests.

All the pilot tests have been successfully implemented and executed at the time of this report with the exception of two pilot tests that has been delayed. The success of the testing is evident for many reasons. First of all, the large number and the very diversified typologies of tests activities carried out permits to explore many promising solutions both of technical nature, such as smart detection services and advanced infrastructure-to-vehicle communication systems and of human-centred typology to adapt infrastructure designs to road user needs. About this point, it is important to underline the effort done for testing a very large number of human-centred low-cost countermeasures (18 of a total number of possible countermeasures identified in D2.3 equal to 89). with a focus on effects on road user behaviour and experience. Moreover, the extension of the timeplan from M24 to M26 in most of the sites has allowed for collecting more data so providing more accurate and robust results. Finally, all the forecasted activities have been fully achieved without incidents, leading to a better understanding of situations, circumstances and measures for safer LCs.

Table of content

1. INTRODUCTION

The SAFER-LC project (Safer level crossing by integrating and optimizing road-rail infrastructure management and design) aims to improve safety of level crossings (LCs) by minimising the risk of LC accidents. This is done by developing a fully integrated cross-modal set of innovative solutions and tools for the proactive management of LC safety and by developing alternatives for the future design of level-crossing infrastructure.

The solutions and tools that are developed in the SAFER-LC project will enable road and rail stakeholders to find more effective ways to: (1) detect potentially dangerous situations leading to collisions at level crossings, (2) prevent incidents by innovative user-centred design, and (3) mitigate the consequences of 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 which will integrate the project's practical results, tools and recommendations to help both rail and road stakeholders to improve safety at LCs.

The project focuses both on technical solutions, such as smart detection services and advanced infrastructure-to-vehicle communication systems 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 4 (WP4) is to evaluate the positive and negative impacts of lab tests and field implementations executed within SAFER-LC project e.g. in terms of usability and user acceptance, railway capacity (possible effects on maximum permitted train speed), road capacity (possible effects on car speed limits and/or closure times of level crossing), safety and environmental benefits.

1.1. Purpose of the document

This document describes the test activities carried out in the Task 4.2 of WP4 (Pilots execution). Specifically, the Task 4.2 concerns the implementation and the execution of the tests built in various level crossing environments in different countries. Simulation tools (in-vitro) and prototype systems running in close-to-reality situations under controlled conditions are used for better understanding human reaction to the proposed measures and to optimize the system operation and design, by means of testing and fine-tuning the solutions developed in WP3. Additionally, various measures are tested under these environments for cases too dangerous or complex to test in the real-world pilot activities. The integrated test are implemented in the test-track hosted by the Aachen University, where the whole chain, from detection and communication to awareness increase and barriers operation have been demonstrated. In addition, some functionalities are tested under real-world conditions. The simulation, controlled and field tests carried out are based on the use cases defined in WP1 and WP2 as well as the scenarios proposed by WP3, feeding them and WP5 with quantitative and qualitative outputs.

1.2. Structure of the document

This deliverable collects all the information related to the pilot tests executed in WP4 and consists of the following chapters:

1. Introduction 2. Overview of the implementation and execution of the pilot tests 3. Description of the pilot tests 4. Observations and lessons learned 5. Conclusions

The document starts with a general introduction of the document by setting out the purpose and the structure of the deliverable (D4.3) and the source of data used for its development. Chapter 2 presents a general overview of the pilot tests performed in WP4 for the description of the relationships among the different test performed and the position and their roles within the SAFER-LC project. Chapter 3 provides a detailed description of each pilot test, separated depending on the testing environments (simulation, controlled or field tests), about the measures tested and the implementation and the execution phases of these tests. Chapter 4 contains the observations and the lessons learned by the implementation and the execution of the tests. Finally, the report ends with some final observations resuming the main results of the activities carried out within the Task 4.2.

1.3. Source of data

The data collected for the development of the document derives from data received by the involved partners of the project related to the different pilot tests executed (mainly from pilot site and test leaders). The aim was to collect detailed data covering all the activities of testing from the definition of the measures to the execution.
The data and the information have been collected through three different sources:

- the presentations done by each partner during various Progress Meetings about the description of the test executed;
- the discussions developed during specific teleconferences with WP4 partners mainly concerning the definition of the measures and the presence of possible difficulties in the implementation and execution phases;
- the Periodical Progress Report that is a standard form to collect all information about the test and the control of the status of the implementation and execution phases in each pilot tests.

It is important to underline that this form represents the main source used for data and information. It reports the progress of the implementation and the execution of the measures piloted in WP4 of the SAFER-LC project. The information on this form has been filled in by the pilot site and test leaders during the execution of the tests. Specifically, the progress report has been updated every three months (December 2018, March 2019 and June 2019) by the pilot site and test leader. The information reported on this form provided the basis of the chapters describing the implementation and execution and the resulting data collection concerning any specific measures tested, respectively in Deliverable 4.3 (*Pilot operation report, output of task 4.2)* and in Deliverable 4.4 (*Results of the evaluation of the pilot tests, output of task 4.3*) of the SAFER-LC project*.*

The Periodical Progress Report form is composed of four sections (see Annex 1): Introduction, Progress Report, Conclusion and References. While the introduction explains the aim of the form, the Conclusion is used to include some general observations about tests executed and the references section is used to list the literature and reports used to build the pilot tests. The most important section is represented by the second one where the most relevant information is given in terms of the description of the measure, implementation of the measure, execution of the tests, evaluation data and lessons learned.

1.4. Definition and acronyms

Definition	Description
Active LC	A level crossing which is equipped with an active protection system such as automatic half-barrier or full barrier, warning lights, or sound.
Passive LC	An unmanned level crossing that has no crossing barriers, gates or road traffic signals. It has a 'Give Way' sign on each road approach.
Human Factors (HF)	The application of psychological and physiological principles to the design of products, processes, and systems.

Acronyms	Description
AIM	Application platform for Intelligent Mobility
AV	Automated vehicle
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CPM	Continuous Phase Modulation
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communication
ETA	Expected Time of Arrival
GDPR	General Data Protection Regulation
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GSM-R	Global System for Mobile communications – Railways
IM	Infrastructure Manager
ITS-G5	European profile standard for communications in the 5 GHz band
JSON	Java Script Object Notation
LAN	Local Area Network
LC/LCs	Level Crossing / Level Crossings
LED	Light Emitting Diode
LTE	Long-Term Evolution
MRU	Motorized Road User
MTD	Mobile Traffic Data acquisition
NDS	Naturalistic Driving Study
OBU	On Board Unit
RSU	Roadside Unit
SDS	Smart Detection System

SPaT	Signal Phase and Timing
VACC	Véhicule d'Analyse du Comportement des Conducteurs
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User
WLAN	Wireless Local Area Network

2. OVERVIEW OF THE PILOT TESTS ACTIVITIES

2.1. Objective of the pilot tests activities

The project focus both on technical solutions, such as smart detection services and advanced infrastructure-to-vehicle communication systems and on human processes to adapt infrastructure design to end-users and to enhance coordination and cooperation between different stakeholders from different transportation modes at various levels (infrastructure managers, individual drivers, professional drivers, pedestrians…).

Taking into account these observations, a series of pilot tests across Europe are rolled out to demonstrate how these new technological and non-technological solutions can be integrated, validate their feasibility and evaluate their performance. The challenge is also to demonstrate that the proposed solutions are acceptable by both rail and road users and can be implemented cost-effectively, which is analysed in WP5.

The main objective of Task 4.2 is to evaluate the impacts of lab tests and field implementations executed within SAFER-LC project e.g. in terms of technical capabilities, usability and user acceptance, road capacity (possible effects on car speed limits and/or closure times of level crossing), safety and environmental benefits.

Most of the developments identified within the SAFER-LC project are tested when possible and improved under a combination of environments in various test-sites in different countries (France, Turkey, Finland, Greece and Germany). The various test-sites available in SAFER-LC are a perfect fit for solutions and measures at different stages of maturity. Early stage developments can be tested in simulation environments or on controlled test tracks, while measures that are more sophisticated can be evaluated in field experimentations. The test-sites aim at:

- testing and fine-tuning the solutions developed in WP2 (WP for user-oriented measures) and WP3 (technical-oriented WP);
- evaluating the technical performance and the efficiency of the measures under simulated and real-world conditions; evaluating as well intermodal cooperative communication solutions (vehicle-to-vehicle V2V; vehicle-to-infrastructure V2I)
- evaluating and improving the human factors methodological framework defined in WP2 (that will ultimately assess human factor issues regarding the design of the safety measures proposed);
- feeding the business models in WP5 with accurate and realistic data regarding benefits.

Regarding the pilot tests, some changes to the DOW and the deliverable D4.1 can be mentioned:

- the pilot tests initially plan in Vaires (France) was done in Aachen (Germany). The project partners decided to move the pilot tests in order to have a stronger test location and potentially have synergies between the pilots that was executed there in Aachen;
- a new pilot test is executed by VTT in Finland. This test is used to evaluate safety measures that are connected to the behaviour of the self-driving cars at LCs;
- a new pilot test is also executed by SNCF in France. This test is also focused on driving simulation activities to evaluate impacts on human processes adapting infrastructure design to end-users;

- a new pilot test is also executed by NTNU for the LCs barrier condition monitoring that was done in Aachen (Germany).

2.2. Interactions with other tasks within the project

The main inputs to Task 4.2 work from other SAFER-LC activities are coming from WP1, WP2 and WP3. Specifically, D1.3 (SAFER-LC consortium, 2018a) provides several scenarios built by the partners concerning risk assessment, smart detection system, optimized closure time of the barrier, early detection of failures on the LCs and communication systems to be further developed in WP3 and tested in WP4. Overall, the needs and requirements as well as the scenarios described in this deliverable are considered as the starting point for the developments of the specific measures to test in Task 4.2.

Specific measures tested in WP4 are also derived from the results of Task 2.3 ("Definition of new human-centred low-cost countermeasures") with the final phase of definition of low cost countermeasures to enhance the safety of current LCs making them more self-explaining and forgiving. The ideas generated in the previous subtask shaped the proposal for new LC design and technological and non-technological LC safety measures. The proposals also encompassed the upgrade of existing measures to enhance their innovation potential, self-explaining and forgiving nature.

The methodological framework developed in Task 2.2 to analyse how safety measures can be better adapted from a user perspective in order to make LCs safer, has been tested within WP4 pilot tests activities through its application in the evaluation of tested safety measures, supported by an application guide and feeding WP2 with the outputs. The framework allows the analysis and the evaluation of the following types of measures (effectiveness for road and rail users):

a) Non-technological: LC safety layout and design and physical measures (angle of approach for road users, visibility, lighting, type of crossing spots, type of barriers, stopping distances, wayside horns, signage, ground markings);

b) Technological safety measures (vehicle-activated signage, on board devices).

The data generated will contribute towards the evaluation of human-centred low-cost measures to be reported in Deliverable 2.4. The feedback collected in the demonstration phase through the Human Factor (HF) assessment tool allows the evaluation of the developed measures and recommendations to be made regarding technical specifications and human and organizational processes. At the same time, based on the feedback from the test sites, the HF methodological framework and assessment tool will be adjusted and improved (D2.5).

Important interactions are related also with WP3. The goal of this work package is to develop technological solutions to improve safety at level crossings as well as at working zones through sharing information and giving warnings to trains/vehicles approaching/arriving to level crossings and to workers at or near train passing zones. All these technological solutions are tested within the WP4 on controlled test tracks or, more developed measures, evaluated in field experimentations.

The main outputs from Task 4.2 work to other SAFER-LC activities are going to Task 4.3 and WP5. Data collected during the execution of the pilot tests will be used within Task 4.3 for assessing the technological performance and the impact of the tested technologies and measures respectively. With regards to WP5,Cost-Benefit and Cost-Effectiveness analyses are developed using the "measured" benefits, implementation, operation and maintenance costs, in order to facilitate the development of Business Models for the deployment of the solutions suggested by SAFER-LC project. These analyses are conducted in a comprehensive way, to ensure that the infrastructure is

examined as a whole, based on the data collected during the demonstration phase (WP4) as well as in additional data collected within WP5.
These interactions among the different WPs of SAFER-LC project is graphically described in Figure 1.

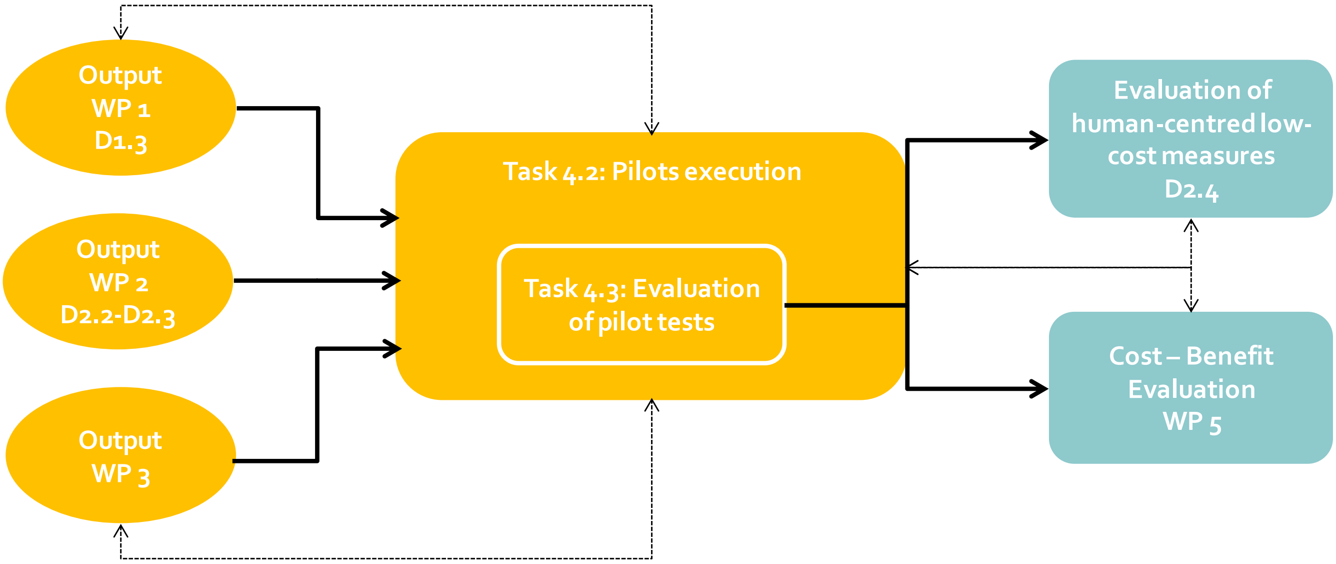

Figure 1. Links between the work packages.

2.3. Location and type of pilot activities (Simulation, Test-track and Real-world pilot activities)

The pilot tests executed in the Task 4.2 can be subdivided in three types of pilot activities:

- simulation tools;
- prototype systems running in close-to-reality situations under controlled environments, especially for cases too dangerous or complex to test under real-world conditions;
- real-world pilot conditions.

Specifically, the following table summarizes the nine different pilot tests, three under each environment, executed in relation to the type of activities, the location of site test and the partners involved. It is possible to underline that three different pilot tests are referring to each of the three types of test activities. Various partners worked together in Aachen, in which the whole chain of detecting, communicating and informing is being tested under controlled conditions in a test track of the Aachen University. The other partners have tested in each location one or more measures.
Specifically, simulation activities are led by DLR in Germany, by SNCF in France and by VTT in Finland; test-track pilot activities and capabilities are led by CEREMA et al. in Germany, by CEREMA in France and by VTT in Finland; real world pilot activities are conducted by DLR in Germany, by CERTH in Greece and by INTADER in Turkey.

Table 1. Location and type of pilot activities.

Partners involved	***Location***	***Type of pilot activities***
DLR	Braunschweig (Germany) at DLR premises	Driving simulator
SNCF	France	Driving simulator
VTT	Tampere (Finland)	Two simulation environments
RWTH CEREMA UTBM IFSTARR GLS COMMSIGNIA NTNU	Aachen (Germany) at RWTHs rail testing track	Test-track pilot activities
CEREMA NTNU	Rouen (France) at CEREMA Rouen test site	Test-track pilot activities
VTT	Sääksjärvi (Finland)	Test-track under real rail environment
DLR	Braunschweig (Germany)	Real-world pilot activities
CERTH TRAINOSE DLR	Thessaloniki (Greece)	Real-world pilot activities
INTADER	Karabük (Turkey)	Real-world pilot activities

As already highlighted in the previous chapter, the pilot tests have also implemented a series of human-centered low-cost countermeasures selected from those identified in Deliverable 2.3. The list of all the measures tested referring to D2.3 is reported in the following table. Many of these are developed for testing in two separate simulator studies (France and Germany). This process has included defining the simulator studies´ procedure, experimental design and evaluation framework with a focus on objective and subjective data to assess the effects of selected countermeasures on road user behaviour and experience.

The total number of measures tested is 18 of a total number of possible countermeasures identified in D2.3 equal to 89. Four of these are tested in more than one pilot tests.

Table 2. Description of the implemented measure referring to D2.3.

Measure name (D2.3)	Implemented Measure	Rank	Pilot test	
Improve train visibility using lights	Improve train visibility using lights	9	Car simulator at DLR premises	Simulation activities
Blinking lights drawing driver attention	Blinking lights drawing driver attention	11		
Pre-signage before the LC	Sign *look for train*	39		
Noise-producing pavement	Noise-producing pavement	57		
Colored pavement markings to mark the danger zone (MRUs)	Coloured marks	19	Driving simulator of SNCF	
Tunnel effect stick	Tunnel effect stick	42		
Rings	Rings	43		
Traffic lights	Traffic lights	46		
Sound theme bump and flashing post	Bump and flashing sticks	50		
Proximity message - information sharing via connected device (in-vehicle display, satnav, mobile device, etc.)	Message in connected vehicle	1		
Proximity message - information sharing via connected device (in-vehicle display, satnav, mobile device, etc.)	V2X messaging system between automated vehicles and passive level crossings	1	Junavaro data simulator & Road traffic simulator	
Warnings of object on LC tracks	Smart Detection System	35	LC mock-up installed at Aachen test site	Controlled tests
Satnav intelligence	Early train detection and hazard information by means of cooperative perception messaging and drivers' warning	22		
Satnav intelligence/Warnings of object on LC tracks	Smart communication system	22/35		
Warnings of object on LC tracks	Video surveillance system	35		
Improve train visibility using lights	Additional warning light system	9	Additional warning light system at front of the locomotive	
Sign to increase search behaviour	Amber blinking light with train pictogram (Electronic sign/Message written on the road)	44	Mobile traffic survellance system	Field tests
Proximity message - information sharing via connected device (in-vehicle display, satnav, mobile device, etc.) / Message on smartphone/ watch to warn on approaching train	In- vehicle train and LC proximity alert	1/13	Thessaloniki living lab	
Flashing/moving lights on barriers/ground	Flashing moving lights on barriers	41	Real LCs in the field (TCDD network)	
Pavement markings to mark the danger zone (MRUs)	Coloured pavement markings	19		
Attractive signs for children at their height	Attractive sign for children	61		

2.4. Time plan of the implementation and execution phases

The activities of the Task 4.2 started officially in April 2018 (M12) with the implementation phase. This activity ended in October 2018 (M18) whereas the execution phase began and it finished in April 2019 (M24). Taking into account the various issues related to the testing activities, during the period M18-M24, the WP4 activities focused on the finalisation of the pilot preparations and the execution of the planned tests, which continued until M26 in most of the sites. This has allowed for collecting more data so providing more accurate and robust results.
The following tables contain the type of measures implemented and the time plan of the implementation and execution phases disaggregated for type of the developed tests (simulation, controlled and field tests).

Table 3. Time plan of the activities for the simulation tests.

Simulation tests					
Partner	**Test site Location**	***Implementation type***	***Measures***	***Implementation***	***Execution***
DLR	**Germany**	Car simulator at the DLR premises	4 measures at passive LCs	June 2018 - May 2019	May – July 2019
SNCF	**France**	Driving simulator	6 measures at passive and active LCs	July 2018 – March 2019	April – May 2019
VTT	**Finland**	Two simulation environments: Junavaro data simulator & Road traffic simulator	V2X messaging between automated vehicle and passive LCs	March 2019	March – May 2019

Table 4. Time plan of the activities for the controlled tests.

Controlled tests					
Partner	**Test site Location**	***Implementation type***	***Measures***	***Implementation***	***Execution***
CEREMA et al.	**Germany**	LC mock-up installed at Aachen test site	Smart Detection System/ Communication system / Condition of LC barrier	November 2018 - January 2019 (01/2019 for implementation on site)	January 2019 March 2019 May 2019
CEREMA	**France**	Rouen test site for monitoring and remote maintenance	Condition of LC infrastructure	December 2018- February 2019	January-June 2019

VTT	**Finland**	Additional warning light system at front of the locomotive at a real rail environment	Warning light system	September and November 2018	March 2019

Table 5. Time plan of the activities for the field tests.

Field tests					
Partner	**Test site Location**	***Implementation type***	***Measures***	***Implementation***	***Execution***
DLR	**Germany**	Mobile traffic data acquisition platform	Amber blinking light with train pictogram	July 2019 (delay due to difficulties in implementing the equipment)	August-September 2019[1] (delay due to difficulties in implementing the equipment)
TRAINOSE + CERTH	**Greece**	Thessaloniki living lab-testing in real life conditions at 30 LCs	LC and train proximity in-car alert	March – November 2018	First test period Dec. 2018 – March 2019 Second test period May 2019- July 2019
INTADER	**Turkey**	Real LCs in the field	3 measures at active LCs	Expected for October 2019 (delay due to the change of the TCDD management)	Expected for October 2019[2] (delay due to the change of the TCDD management)

[1] The implementation of this measure and the execution of the pilot test have been delayed due to difficulties in implementing the equipment. Considering the type of measure to be tested (human-centred, low-cost measure), the implementation and the execution will be reported in D2.4.

[2] The implementation of the selected measures was planned to be done in February and March 2019. However the General Manager and some part of the board of directors have been changed in TCDD and the management policy of the present deputy General Manager is different from the previous one with important limitations about the acquisition and use of data from TCDD network. The permanent General Manager of TCDD is going to be in charge in the near future with the probable restoration of the policy before adopted. Considering the type of measure to be tested (human-centred, low-cost measure), the implementation and the execution will be reported in D2.4.

3. DESCRIPTION OF THE TESTS

This chapter reports a detailed description of the nine pilot tests implemented and executed by different partners in various countries.
Following the structure of the Progress Report, each pilot test's description reports a specific set of information about the measure, the implementation phase and the execution phase:

1. an in-depth description of the piloted measure including some specific information as:
   - relevant details (e.g. pictures and relevant features of measures), type of level crossing (e.g. passive, active with light signals, active with barriers and light signals), expected safety effect (i.e. how the measure is expected to improve the safety of LCs), circumstances under which the measure is expected to be effective;
   - objectives of the measure (incl. e.g. target group(s) of people, target incidents or behaviour;
   - description of the intended effect mechanism (possible effect mechanisms are listed in D2.2);
   - previous experiences from similar measures.

2. a detailed description of the implementation phase introducing the following information as:
   - report of the implementation site(s) including the equipment installed, eventual vehicles equipped and LCs involved in testing using maps, photos and eventually pictures of layouts and/or designs.
   - implementation schedule;
   - organisations involved and their roles.

3. a detailed description of the execution phase introducing the following information as:
   - report of the test execution at the site(s) (e.g. start and closure of operations, status of sensors and equipment, vehicles and participants involved, etc.);
   - test activities schedule.

3.1. Simulation activities

The simulation activities have been conducted through driving simulators developing different scenarios for each test conducted and specifically:

- simulation activities led by DLR testing four measures to enhance train detection at passive LCs;
- simulation activities led by SNCF testing six measures at active and passive LCs to analyse the effect of the introduction of the specific measures;
- simulation activities led by VTT using two simulation environments to study the interaction between automated vehicle and passive level crossing.

The following table contains specific information concerning the pilot test leader, the measure, the type of implementation, the variables and the quantification of the safety effects. It allows summarizing the general characteristics of the test carried out.

Table 6. General description of the measure and activities conducted in simulation tests by each Pilot test leader.

Pilot test leader	Measure	Implementation type	Variables	Quantification of safety effects
DLR	Measures to enhance train detection at passive LC: - Blinking lights drawing driver attention - Improve train visibility using lights - Noise-producing pavement - Sign look for train	Car simulator at DLR premises	Visual checking for train, Distance to LC at first check for trains, Train detection time, Train detection rate, Velocity profile during approach (theoretical possibility to stop before LC)	Changes in possibilities to stop before LC (based on changes in train detection time and approach speeds)
SNCF	Coloured road markings Tunnel effect stick Rings Traffic lights Speed bump and flashing sticks Proximity message via in-car device	Driving simulator	Comparison behaviour between a crossing of a conventional LC and a LC with a measure Interview topics: - Detection and identification - Ability to elicit and retrieve relevant information - Behavioural execution - Acceptance - Trust - Self-explaining nature	Changes in possibilities to stop before LC or awareness (based on movement of foot, of eyes and approach speeds)
VTT	V2X messaging between automated vehicle and passive level crossings	Two simulation environments: Junavaro data simulator & Road traffic simulator	Different scenarios the automated vehicle use to stop before the LC Different scenarios how fast the automated vehicle will move again after the stop	Expert assessment on optimal solution from safety viewpoint

3.1.1. Car simulator at DLR premises

Test site location: Braunschweig (Germany)
Pilot test leader: DLR
Involved organizations and their roles:
The responsible organization for the measures is DLR. Its responsibilities include:

- Implementation of the measures
- Execution of the tests

Description of the measure(s)

Four measures are tested in the driving simulator of DLR. All of those measures have the goal to support the safe behaviour of traffic participants at passive level crossings. They are supposed to have a safety effect especially on the probability that an oncoming train is detected by eliciting early visual checking behaviour to the left and right region of the level crossing. Since many road traffic participants, especially drivers, tend not to check the environment of a level crossing for an approaching train, the following measures have been evaluated:

- Improved train visibility using lights
- Blinking lights drawing driver attention
- Noise-producing pavement
- Sign *look for train*

The measures are mainly targeting fast-moving road users, especially motorized road users, since these are responsible for a majority of accidents at level crossings. The target behaviour that is supposed to be elicited is a shift of the visual attention (executed voluntarily or by automatic capture) to the tracks on approach to a LC, such as to enhance the probability of detecting a train if one is coming.
The exact effect mechanism that underlies the enhanced probability of detection differs between the described measures.

The *improvement of the train visibility by using lights* relies on a facilitation of the detection by enhancing the salience of a locomotive (Figure 2 - left). The additional warning light system is positioned at the front of the locomotive model in the simulation. The positioning of the additional lights is in line with the specifications given in EU regulation No 1302/2014. No restrictions that oppose the positioning of additional warning lights in the proposed way are known. Warning lights integrated in the locomotive are supposed to exogenously capture the visual attention of road users by a stimulation of the cones, special photoreceptor-cells in the retina of the human eye that are sensitive for a stimulation by e.g. moving objects with high contrasts (e.g. blinking lights drawing driver attention). The analysis of additional light systems installed on locomotives is a joint initiative by DLR and VTT within the project. There is an ongoing exchange between the partners about this approach to enhance safety for road users at passive level crossings. While VTT pursues the demonstration of the technical system in a real world level crossing context, DLR verifies the capability of the system to positively influence road users' visual detection of trains in the context of an empiric simulation study.
The *blinking lights* are positioned stationary in the peripheral vicinity of a level crossing (Figure 2 – right) and are activated whenever a road user is approaching. The system relies on the same psychophysiological effect mechanism as the improvement of the train visibility with additional lights. Both measures are assumed to elicit an orientation reaction that can be qualified as involuntary or automatic. With a comparable approach, Grippenkoven, Thomas and Lemmer (2016) showed positive short-term effects of stationary peripheral light sources at passive level crossings on the visual orientation of drivers. In a study on additional light sources to improve the conspicuity of locomotives, Cairney (2003) showed positive effects of the installation of additional light sources on railway cars.
The lights were installed to the train according to the prevailing regulations (e.g. below the head lights).

Figure 2. Additional lights that complement the regular triangular lights of a locomotive

As a contrast to the light solutions, the sign *look for train* directly addresses the road traffic participant with a written message and a pictogram. It requires a conscious processing of the content and subsequently a voluntary visual search for a train. Since the study was conducted with German participants, the messages in the sign, as shown under Figure 3, are in German language. Of the two versions proposed initially, the one that asks the road user “Kommt ein Zug?” (Is a train coming?) has been chosen for brevity over the alternative (“Links und rechts nach Zug schauen!”, i. e.Look left and right for a train!”). In a comparable setup, the effect of a *look for train* sign has been studied earlier (Noyce & Fambro, 1998). The sign has been detected by more than half of the participants in their driving study. However, since other measures have been studied in parallel, it is not clear whether the positive effect found for the train detection can be ascribed to the sign. A positive effect can be assumed, but has not been proven yet in a methodologically sound way.

Figure 3. Sign used to indicate safe behavior for road users at passive level crossings asking the road user to check whether a train in approaching.

The *noise and vibration producing pavement* elicited a rumble effect when a driver passes it (Figure 4). It is assumed that this measure first of all had an impact on drivers’ choice of speed. If drivers indeed decrease their speed, the time to detect a potentially approaching train would be increased. However, it is unclear to what extent a vibration-producing pavement really has a beneficial effect on visual processes like the early detection of a train. Earlier studies have been conducted on rumble strips in the context of level crossings (e.g. Radalj & Kidd, 2005), still, the effect on the visual search during the approach towards a level crossing has not been focussed on in a sufficient manner to date.

Figure 4. Rumble strips and other purposeful alterations of the road surface are supposed to influence the driving behavior of motorized road users during the approach towards level crossings.

Implementation of the measure

The experiments of the measures described took place in a driving simulator of DLR (Figure 5). At earlier stages it was planned to conduct the study in a simulator that presents the driving environment to the participant via a projection. The plan changed from the use of a projection technique to the use of high resolution monitors, since two of the measures that were tested entail light sources that are meant to foster the detection of a train and the monitors allow for achieving higher contrast than a projection.

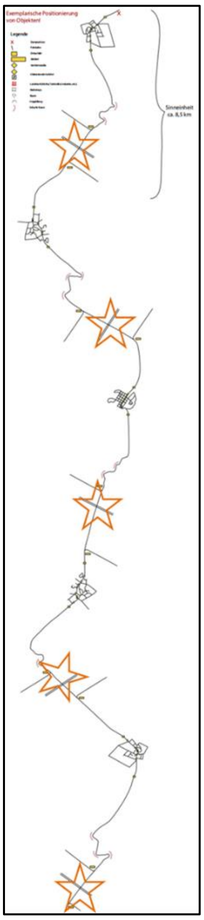

Figure 5. Driving simulator and Schematic layout of the main part of the programmed driving route for the DLR simulation pilot.

A lot of effort has been put into the definition of a driving environment that allows studying multiple measures in a *within-subjects* experimental design, meaning that one participant can be confronted with multiple measures without making him or her suspicious that the study is about level crossing safety. A long driving course has been therefore planned, consisting both of village parts and rural roads between them. To distract the participant from the level crossing focus of the study, one secondary task has been implemented in each of the villages in between the LCs. For this purpose, the participant got a message on a mobile phone, requiring her or him to execute a little task and sent a short reply to the enquirer (e.g. “Please find the photo of the electric kettle I wanted to put on ebay and send it to me”, “Please tell me again at what time I arrive in Hanover when I take the train from Braunschweig at 10”, “I forgot my password, but I saved it in the notes app, please send it to me”, etc.). The secondary task was part of the cover story used to justify the purpose of the study in the initial instruction. Participants have been debriefed on the real purpose after the study.
The schematic design of the course to be driven by the participants is shown in Figure 5. Each star represents an area with a level crossing. The intermediate sections between each level crossing are long enough to guarantee at least a driving duration of seven minutes, before the participant encountered the next level crossing. Different kinds of curvy sections are programmed in the areas that lead to each level crossing to force drivers to reduce their driving speed to the target speed of 50 km/h before arriving at a straight road that leads towards each level crossing. Each level crossing

has to be crossed in an angle of 90 degrees. These precautions regarding speed and crossing angles have been taken to ensure a comparable and standardized driving situation for each level crossing passage.

The Progress of the implementation is described as follows:

- Multistage collection of potential countermeasures to be tested (11/2017 – 05/2018)
- Multi-step priorization of countermeasures for testing (06/2018 – 08/2018)
- Specification of experimental paradigm and design, preparation of simulation (environment, measures, traffic) (09/2018 – 04/2019)
- Remote Eyetracking System installation, setup, and refinement for simulation environment (01/2019 - 04/2019)
- Pretests and debugging (04/2019 - 05/2019)

The implementation phase was particularly long due to the complex programming of the countermeasures that include blinking light sources and the construction of the scenario with the complex and long route needed for the study.

Execution of the tests

The execution of the tests follows the experimental procedure shown in Figure 6. After a phase of introduction, explanation and calibration (A-D) participants start with a training course to get used to the simulator. Afterwards they cross a level crossing six times. The first LC-passage serves as a baseline: a passive LC is crossed without a train arriving.

The second to fourth level crossing passage entail a passage without a train coming, but with different safety-measures in place (sign, peripheral light or rumble strips). These three experimental passages are encountered by all of the participants. The order of the measures is varied and balanced across participants to correct for effects of measure position in time.

At the fifth level crossing each participant encounters an arriving train. Half of the participants are confronted with a usual train (baseline). For the other half of the participants, a train with additional blinking lights occurs. The comparison between the usual train and the train with additional light thus takes place in a between-subjects design.

				Factor 1 (within subj.)	Factor 2 (within subj.)	Factor 3 (between subj.)		
Trial / Phase	**Duration**		**Contents**	**LC measure**	**Train presence**	**Train design** (nested in „train coming")		
A	5 min		*Welcome and instruction*					
B	5 min		*Informed consent*					
C	2 min		*explanations in simulator*					
D	8 min		*calibration of eyetracking system*					
0	5 min		*training drive*	**no LC**	**no train**			
1	7 min		***Baseline** test (always first)*	**no measure** (=control / baseline)	**no train** (=control / baseline)			
2	7 min	↻	***Effects of Factor 1** - Position of measure balanced across subjects*	**Blinking PeriLight Rumble strips Sign** *Look for train*	**no train** (=control / baseline)			
3	7 min							
4	7 min							
5	7 min		***Effects of Factor 2** - only one train design per subject*	none	**train coming**	**Normal** (=baseline for train-specific comparisons)	or	**Blinking Lights on train** to enhance train detection
6	7 min		*(optional): **Effect of train exposition** - additional LC traverse for testing the hypothesis*	**no measure** (= experimental condition after train exposition)	**no train**			
E	18 min		*Survey of subjective data on the scenarios experienced (5 or 6)*					
F	3 min		*Debriefing*					
G	2 min		*Disbursement and farewell*					
driving time	47 min				**n subjects**	18		18
total duration	**90 min**				**total**	**36**		

Figure 6. Procedure and time plan simulation study measures at passive LCs.

The last trials before the start of the experiment have been executed from 06-05-2019 to 20-05-2019. The data acquisition period started on 21-05-2019. Data have been collected from 40 participants (17 women, 23 men) by the time of this report. The mean age in this subsample is 34.7 years (SD = 13.8) with a minimum of 18 and a maximum of 65 years equally distributed in gender and three age groups. Testing will continue until the end of July to achieve the greatest possible balance in the representation of different participant groups concerning age and gender and to strengthen the overall data base.

However, according to the tests executed, there are some cases with restricted data quality due to simulation sickness (only part of the simulation driven, n = 1), problems with gaze detection (n=2), calibration quality (n = 1) in eye-tracking or lack of compliance with instructions (n = 1). The duration of test sessions varied between 2.5 and 3.5 hours.

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3.1.2. Driving simulator of SNCF

Test site location: France
Pilot test leader: SNCF
Involved organizations and their roles: SNCF
The responsible organization for the measure is SNCF.

Description of the measure

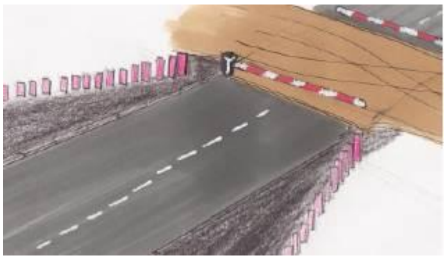
Six measures have been tested in the driving simulator of SNCF. All of those measures have the goal to support the safe behaviour of traffic participants at active and passive level crossings. They are supposed to have a safety effect especially on the probability that an oncoming train is detected by eliciting an early visual checking behaviour. Specifically, the following six measures have been evaluated:

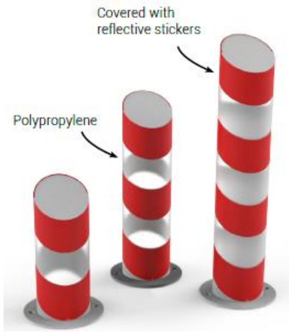
- Coloured marks located in an urban area on automatic level crossing

1st yellow band of 5 cm at 150 meters
2nd orange band of 10 cm at 100 meters
Train band 50 cm at 75 meters
3rd 20 cm red strip at 2 meters at the fire line of effect

The objective of this measure is to improve visibility and readability of LC to rise the vigilance of drivers as they approach the LC and the intended effect mechanism is to reduce speed and increase vigilance of road users.

• Tunnel effect stick located in urban or rural area on automatic or passive level crossing implanting between 10 and 15 posts with a diameter of 200mm to 5 meters upstream of the LC with an "entonoir" effect.



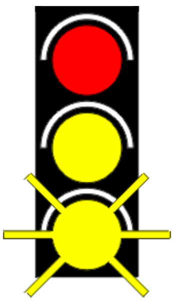


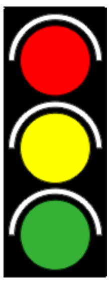
The objective of the measure is to improve visibility and readability of LC to rise the vigilance of drivers as they approach the LC and the intended effect mechanism is to reduce speed and increase vigilance of road users.

• Two rings located in rural area on automatic level crossing: one ring at 150 m and the second one at 10 m upstream of the LC. The ring consists of a set of LEDs and an orange light (diameter of 300 mm) must be moved on the right side at mid-height of the arc.

The objective of the measure is to improve visibility and readability of LC to rise the vigilance of drivers as they approach the LC and the intended effect mechanism is to reduce speed and increase vigilance of road users.

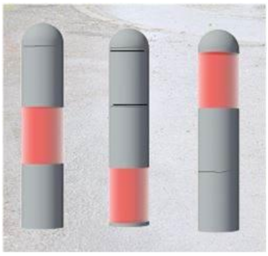
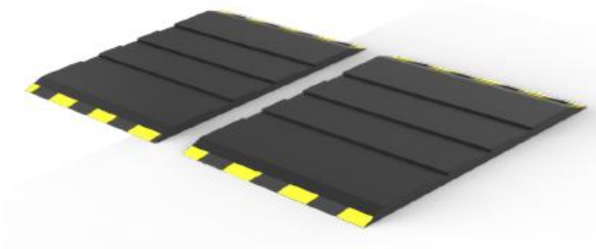
• Traffic lights located in urban or rural area on automatic level crossing and the traffic light on the right lateral side replaced the R24 lights of the LC.





The objective of the measure is to improve the stop at the activation of LC and the intended effect mechanism is to respect the stop.

- Bump and flashing sticks located in rural area on automatic level crossing: the sticks were equipped with a red LED lamp, the 3 poles work in alternating flicker located at 150, 100 and 50m from the LC on the right edge of the roadway. These bumps are located 150, 100 and 50m from the LC. The number of inner lines was different according to its location of the LC (1, 2 or 3 lines).

The objective of the measure is to improve visibility and rise the vigilance of drivers as they approach the LC and the intended effect mechanism is to reduce speed and increase vigilance of road users.

- Message in connected vehicle using different type of message display on dashboard in the vehicle.

The objective of the measure is to improve the safety and the intended effect mechanism is to adapt the driving behavior and the speed of the vehicle.

Implementation of the measure

The experiments of the measures described took place in a driving simulator that allows studying multiple measures in a *within subjects* experimental design, meaning that one subject can be confronted with multiple measures in order to avoid making him suspicious that the study is about level crossing safety.

The developed route in the simulator is characterized by a duration of 20 to 30 minutes composed of 2 to 3 minutes journey in the city with stop points as STOP, traffic lights, give way, a roundabout and a road outside agglomeration with different speed in a straight line and curved one. The schematic design of the course used in the simulator by the participants is shown in Figure 7.
For the coloured marks measure, the driver travels in urban area in straight line at 40 km/h. After 800 meters, the driver arrives at the advanced signalling of the LC. At the crossing of the system, the driver must feel vibrations. For the tunnel effect stick measure, the driver crosses 1 or 2 agglomerations for 2 km, there is the presence of a panel A7 and then the LC (not activated) on a departmental road in a straight line. The driver crosses the LC. For the rings measure, the driver comes out of agglomeration and he circulates since 1.5km in a straight line with clear view (field harvested). At 500 m from the LC, the lights go off and the lights on the ring had the same frequency as the R24 light. At the arrival of the driver at the LC, the gates are lowered and the train arrives on the LC. For the traffic lights measure, the driver travels on the road department out of agglomeration. After 1 km, the driver encounters the presence of the A7 sign and then the LC. By default, the bottom yellow lights flashes (no triggering the LC) with light on gallows. The driver crosses the LC after 1 km, he returns to the built-up area, he crosses a roundabout with traffic and then, after 400 meters, he encounters the presence of the A7 sign on the road in a straight line. The traffic light is green (no train). For the bump and flashing sticks measure, the driver travels out of town in a straight line for 2 km. 200 meters before the LC the one goes off. The light poles are triggered at the same time as the R24 light but their ignition frequencies are not correlated. At the crossing of the device, the driver must feel vibrations.

Figure 7. Routes developed in the simulator.

The simulation required the use of the following sensors: foot movement on the brake pedals and accelerator; steering wheel movement; video of driver in the vehicle and video of simulation (compare time lapse); speed sensor of the vehicle compared to speed limit in the scenarios.

The Progress of the implementation is described as follows in the months from July 2018 to March 2019:

- redaction of scenarios (07/2018 – 08/2018)
- development and integration in simulator (09/2018 – 01/2019)

- Debug and validation of course with pre-test panel (02/2019 – 03/2019)

Execution of the tests

The test period started from April to May 2019.
The execution of the tests is planned for following a detailed plan. In both scenarios, after a phase of introduction, explanation, participants start with a training course to get used to the simulator.
Afterwards they cross 9 different level crossings for safety course and 6 different level crossings for connected course. In both scenarios, the first three LC-passage serves as a baseline with and without train.
The fourth to twelfth level crossing passage entail a passage with and without train coming, but with different safety-measures in place (traffic light, bump, or ground light …). The thirteenth to eighteenth level crossings entail a passage with and without train coming with different level crossing status (closed, in works …). In both scenarios, all of the participants encounter these three experimental passages.

In addition to the simulation, a cognitive expert according to Vermersch method has interviewed each person.
The interview is composed by the following two sets of analysis:

a) Question according to the pre-selected character of the action: 1. Avoid inducing the conscious (what, rather than why) 2. Descriptive questions 3. Relaunching the denials (the pre-flicted is not known), 4. Question the gestures (witness of the pre-flicted), 5. Ericksonian reminders and empty formulations of content, 6. Solicit concrete memory.
b) Question according to the properties of the action: 1. Questioning the prosecution (Identification, realization, the test-action-test cycles, Causal, temporal, logical coherences ;) 2. Master the granularity of the description of an action. 3. Guiding the vocation 4. Question the linguistic implicit (method).

The duration of interview is between 30 and 45 minutes by subject.

A panel of 70 subjects has been planned with the following distribution of 40 subjects for the safety course and 30 subjects for the connected course.
As LC accidents occur with a very heterogeneous population, the choice has been made to select a panel of volunteers with a variety of profiles. The panel selected had the following characteristics:

- people holding driving licenses;
- in terms of sex, 50% women and 50% men;
- in terms of age,12 people from 14 to 24 years old, 19 from 25 to 35 years old (of which at least half of them with children), 25 from 35 to 50 years old (of which at least half of them with children);
- in terms of education, 30 individuals with a mix of education and 10 professionals (commercial, taxis, technicians, etc.);
- in terms of number of km travelled per year, 10 less than 5000 km /year; 20 between 5000 and 20000 km / year and 10 more than 20000 km / year;
- in terms of number of years of license, 7 less than 2 years of license, 8 between 2 and 5 years of license and 43 between 5 and 30 years of license.

3.1.3. Driving simulator at VTT premises

Test site location: Tampere (Finland)
Pilot test leader: VTT
Involved organizations and their roles:
The responsible organization for the measure is VTT. Its responsibilities include:

- Implementation of the measure
- Execution of the tests

Description of the measure

The piloted measure was a V2X messaging system between automated vehicles and passive LCs. The detection ranges of sensors used in automated vehicles today are too short to detect trains at the required distances for crossing LCs safely. To overcome this, V2X messaging is required to increase the awareness of automated vehicles (AV) of approaching trains. However, there are currently no standardised V2X messages for this purpose.

The aim is to improve safety especially at passive LCs, as they are typically located far from the infrastructure required for traditional level crossing installations (safety measures, road side units etc.), making them cost-intensive. This distance from infrastructure is also the reason why ITS-G5 roadside units are unavailable in most cases. With ITS-G5, based on IEEE 802.11p technology, the communication range is too short for direct communication between the train and the AV. The use of a centralised server, which keeps track of the train traffic, provides estimated arrival times and creates virtual barriers for all level crossings, is the only cost-effective solution to this problem (Figure 8). In addition, the information produced is not exclusive to a single technology or platform; it can be communicated on information displays, as well as sent using ITS-G5 messages either with DSRC (dedicated short range communication) devices or LTE/5G mobile networks.

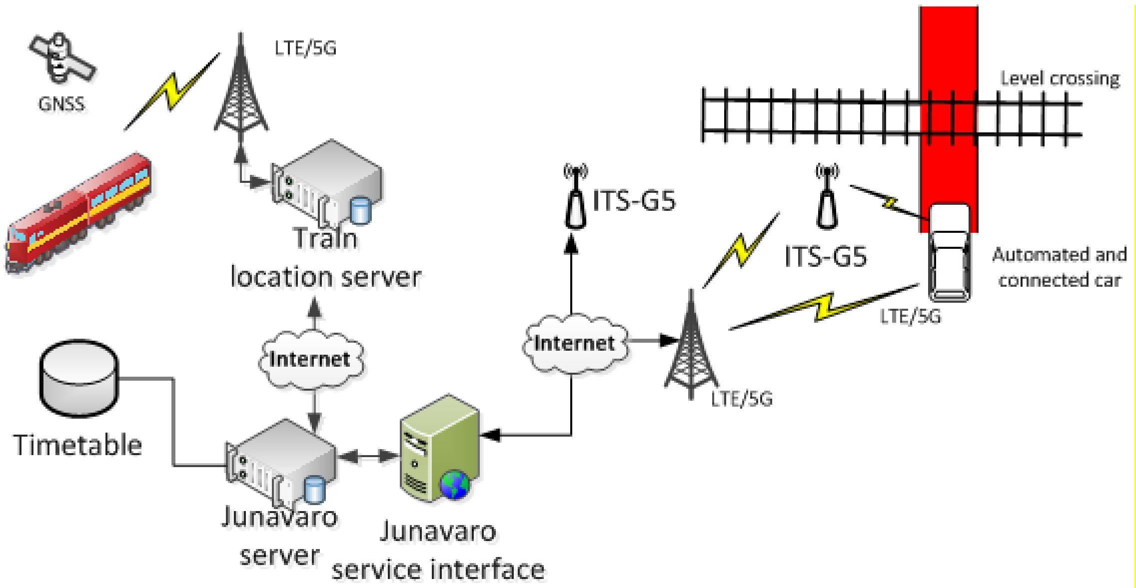


Figure 8. System architecture to provide approaching train information to automated and connected vehicles.

Implementation of the measure

The implementation of the measure requires the preparation of two different simulation environments (Figure 9).

The **Junavaro data simulator** contains train and level crossing data from Finnish rail section 142 between Hanko and Karjaa (see Figure 10) and uses of train traffic data recorded during May 2010. The simulator plays back the recorded train movement using GNSS data and the produced message timestamp converts to the current time. The simulator also produces an estimated arrival time to each level crossing along the route. This estimation is not restricted to level crossings only, as any geolocation can be added to the list to which an estimation can be calculated as well. A user sends a query containing the level crossing ID to the simulator and it sends back a JSON (Java Script Object Notation) string containing the arrival time data. The simulator also has a capability to initiate adaptive closing, where level crossing is closed 30 seconds before train arrive to level crossing.

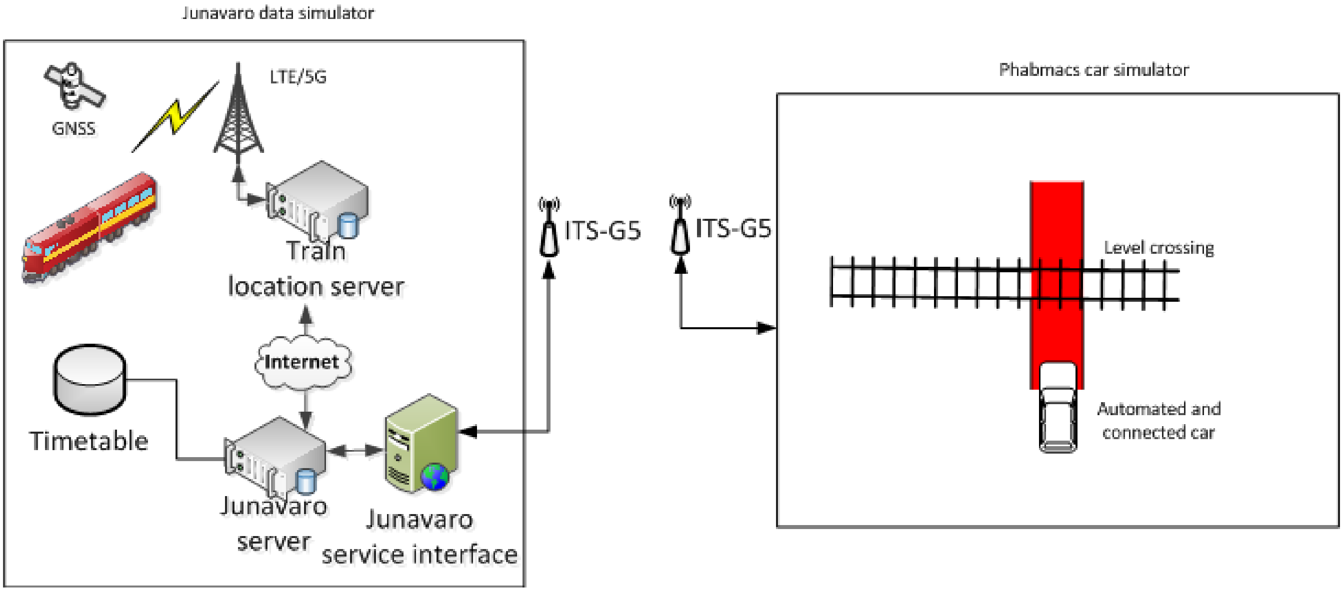


Figure 9. Testing and piloting environment including two different simulation environments.

Figure 10. Rail section 142 and its level crossings. Red circle means protected LC, green is unprotected, blue circle is a station.

The specific level crossing to be used in the simulation is called as 'Kirkkotie' (see Figure 11 and Figure 12). There was no particular reason to select this level crossing aside from its location near the beginning of the rail section.

Figure 11. Level crossing Kirkkotie from above © Google Maps.

Figure 12. Level crossing Kirkkotie used in simulation © Google Street View.

The user interface of the Junavaro simulator is presented in Figure 13. A client sends a query containing the level crossing ID to the simulator and it replies with a JSON string containing the arrival time data. The simulator is available online at the address: http://130.188.59.178:8004/?id=XXXX, where XXXX is the placeholder for the level crossing ID number. ID numbers can be found with the query: http://130.188.59.178:8004/list, which prints a list of level crossing names and ID numbers. Note that the query cannot include spaces. For example, data for the Kirkkotie level crossing can be queried with http://130.188.59.178:8004/?id=39258. The service response should be:
{"timestamp":"1544711086","id":"39258","name":"Kirkkotie","train":"H385","arrival":"15:52:43","status":"PASSED","distance":"-41966.6"}. The message content may change during the development work.

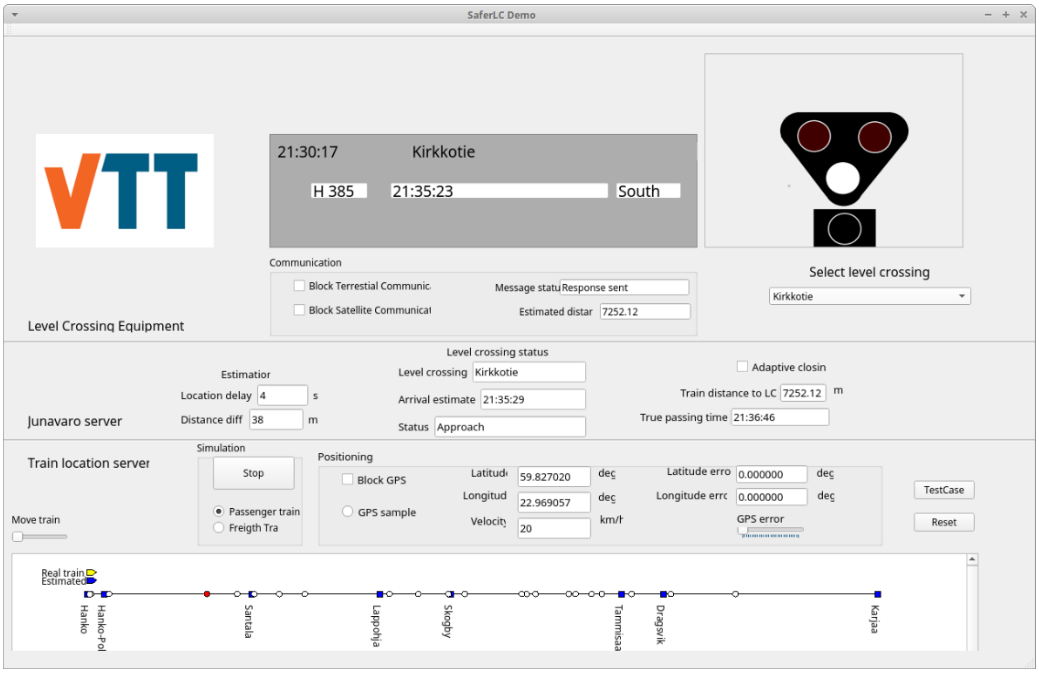


Figure 13. User interface of the Junavaro simulator.

The **road traffic simulator** is based on the Phabmacs simulator (Figure 14). Due to the system's ability to utilise GIS information from OpenStreetMap, the simulator environment can be designed to include desired level crossing surroundings. The simulated vehicle is driven with VTT's automated car software stack, which has an interface for ITS-G5 messaging.

Figure 14. Picture of road traffic simulator view.

The level crossing is equipped with an ITS-G5 DSRC, which is simulated by a computer and ITS-G5 modem (Figure 15). The road side unit sends queries to a Junavaro server and translates the received responses to ITS-G5 messages. The car simulator has a similar unit to receive messages and forward them to the car's software stack for further processing.

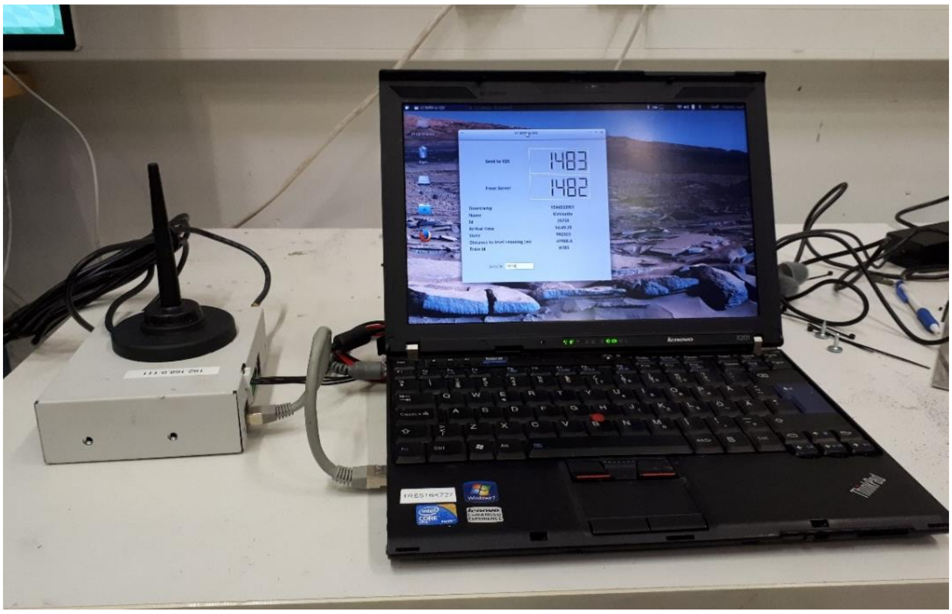


Figure 15. ITS-G5 RSU simulating level crossing which is equipped ITS-G5 capability.

ITS-G5 communication is implementable as hardware in a loop fashion. One ITS-G5 unit communicates with the rail traffic simulator. The message exchange occurs wirelessly to another ITS-G5 unit, which then delivers messages to the road traffic simulator.
The LC can be compared to a road intersection with traffic lights. However, there are two main differences:

- the LC equipped with warning lights does not have a yellow light, which indicates that the status of traffic lights in the road intersection is going to change; in addition, the green light in the traffic lights at road intersection is replaced with blinking white light at LC.
- In LC, car always drives straight over, there are no right or left turns. Thus, if the LC is closed, it is closed for all. Passive LC is also either open or closed, because the train has privilege for passing. Traffic regulation say that "*It is not allowed to pass the level crossing if any train is approaching, traffic lights oblige to stop, warning sound is heard or barrier is down or moving. One must stop at* ***safe distance*** *from tracks, before barrier or semaphore*".

Autonomous car has no idea about the safe distance to stop before the LC. Therefore, a simple map of the LC including the defined stop lines is required. Figure 16 presents an example of such a map. At minimum, the map should include a rectangle, which defines the area where car cannot enter if the LC is closed. The car is not allowed to stop inside the rectangle or "no stop zone" because it is on the tracks. The length of the rectangle varies and it depends on number of tracks.

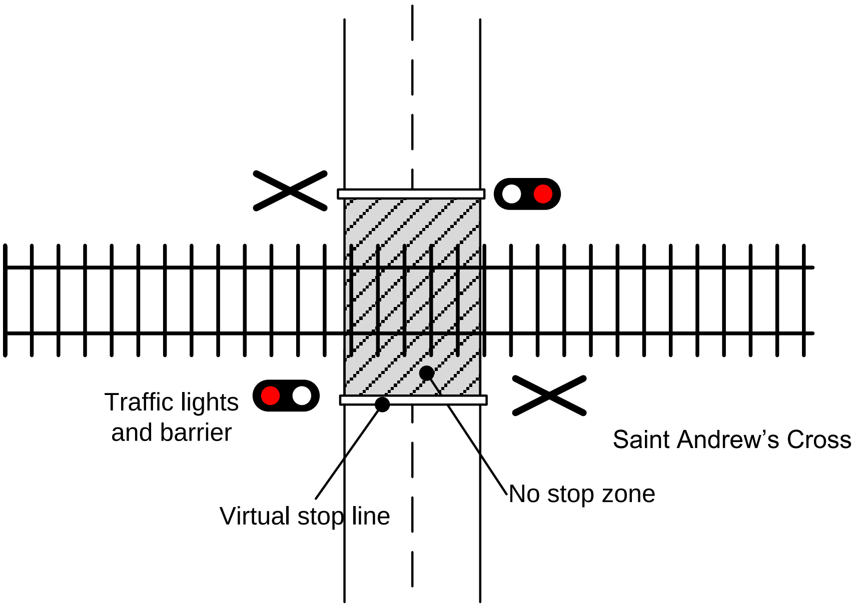


Figure 16. LC from the autonomous vehicle point of view.

The protective devices of LCs require power and hence it is possible to install ITS-G5 DSRC radio roadside unit (RSU) to the LC. The messages that can be used are:

- the Decentralized Environmental Notification Message (DENM) (EN 302 637-3) Its main purpose is to notify road users for potentially dangerous road events;
- the Cooperative Awareness Message (CAM) (EN 302 637-2) is for the exchange of information between road users and roadside infrastructure, providing each other's position, dynamics and attributes. Road users may be cars, trucks, motorcycles, bicycles or even pedestrians while roadside infrastructure equipment includes road signs, traffic lights or barriers and gates;
- MAP (SAE J2735) - topological definition of lanes within an intersection, links between segments, lane types and restrictions.
- the Signal Phase and Timing (SPaT) (SAE J2735) - Traffic light signal phase and timing information and the status of traffic controller. Prediction of duration and phases.

DENM message can be used to inform the connected car about the presence of the LC and the location of the dangerous location (starting and ending point). However, since it does not contain information about the LC status, its usefulness for the autonomous car is limited. Autonomous cars use pre-planned route and a routing algorithm can include LC data to the route.

CAM messaging from the approaching train could provide train location information to the automated car but the main problem is the communication range of the ITS-G5, which is only few hundred meters (Gozalves et al. 2012). Therefore, a relay station is needed to achieve required communication range. The second challenge is the reliability of the communication. The communication is not failing since one does not know if missing message means that no train is approaching or no message is transmitted.

SPaT message could send information on the LC status and thus ensure sensor-based recognition. However, since the states are only “open” or “closed”, one cannot benefit from “time to green” or “remaining green” values.

MAP is very useful and contains required features to describe LC geometry precisely.

As a conclusion, using RSU which sends DENM, SPaT and MAP messages together with sensor-based recognition provides enough data for safe passing of LC for the level 4 or level 5 cars. In case of level 2 cars, the control can be passed to the driver when approaching LC and the driver performs the action manually.
For the passive LC, the Junavaro system can be modified to produce SPaT information. In this case “Remaining green” -time is the time the train takes to arrive to the trigger point where the LC is set to “closed” -state. “Time to green”-value is the time from the trigger point to moment where the last railway car passes the LC. The train composition is usually known in the backend systems, therefore the length of the train is known. If not, one can use some conservative value such as 450 m. Nevertheless, car sensors can detect the train and know if the LC is free or not.

The Progress of the implementation is described as follows:

- Selection of the LC and simulator map data (20.9.2018)
- Simulation system is ready for piloting (20.12.2018)

Execution of the tests

Figure 17 presents an example of SPaT data produced by the modified Junavaro system from Kirkkotie level crossing. The data is produced by using a distance-based trigger point 1.2 km before the LC. If the adaptive closing scheme is used, remaining open time is “arrival time to LC” minus 30 seconds. The remaining open time is set to the infinity value after the train has passed the LC. The red line represents LC status, which is either “open” or “closed”. The results of the simulation show that equivalent SPaT messages can be produced to both railroad level crossings and road intersections.

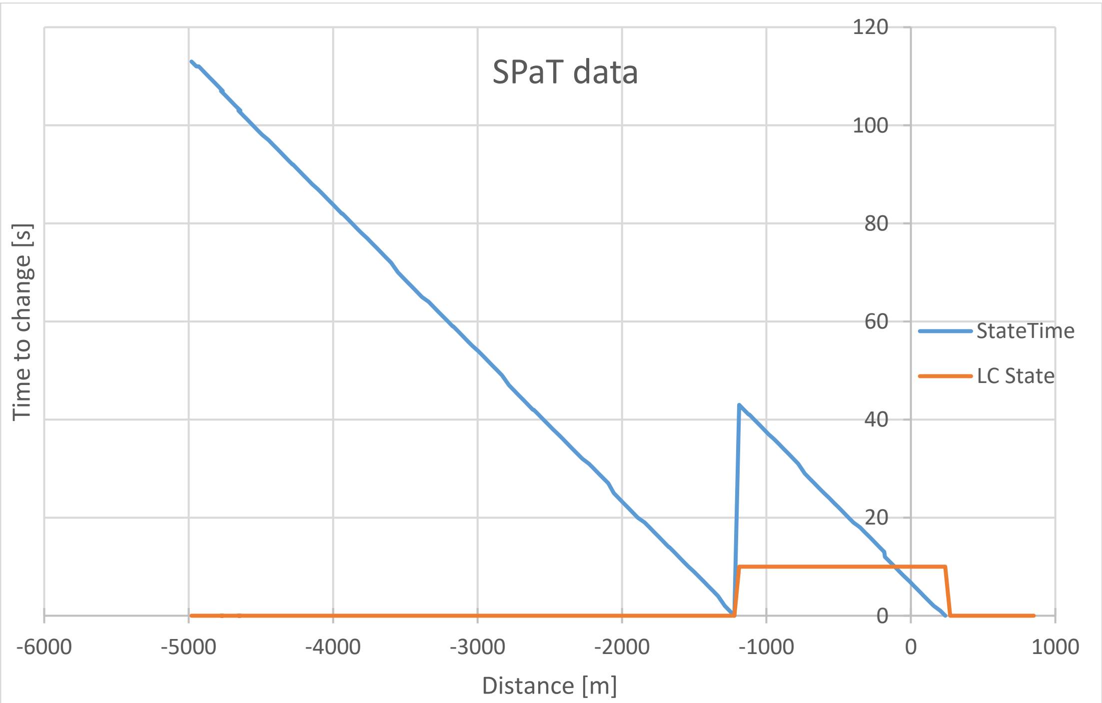


Figure 17. Example of the SPaT data produced by the Junavaro system.

The behaviour of an autonomous car is illustrated in **Erreur ! Source du renvoi introuvable.**Figure 18.

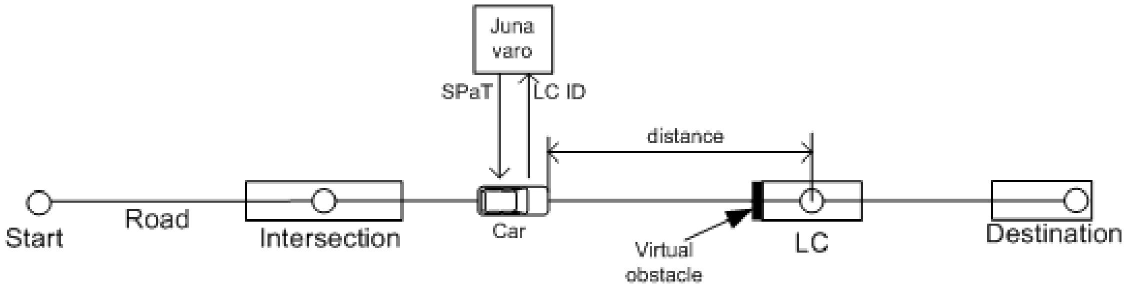


Figure 18. Autonomous car behavior when approaching the LC.

First, the user defines the destination of his/her route, based on which the route planning module produces a coarse route plan. During route planning, the route module searches for static events along the route such as zebra crossings, intersections, bus stops and level crossings, and divides the route to shorter sections. Then, a set of pre-defined behavioural rules are adapted to each identified section. During the execution of the route plan, a trajectory planner continuously creates a new trajectory for the autonomous car. In the case of the LC, it sends requests using LC identification (LC ID) to the server and receives SPaT messages as a response. After receiving the SPaT messages, the trajectory planner checks their relevance and ignores the irrelevant messages. Next, it estimates the arrival time of the autonomous car to the LC. If the analysis shows that LC is “closed” when the car arrives to the LC, a virtual obstacle is set. Once the LC is “open”, the virtual obstacle is removed and the autonomous car continues its journey by following the behavioural rules set for the LC until the car leaves the section.

The piloting of this measure started during March–May 2019.

- Car software stack is modified to react SPaT messages (20.3.2019)
- Modification of Junavaro simulator output (April 2019)
- Field test on reaction of autonomous vehicle to SPaT messages (May 2019)

References

- ETSI - EN 302 637-3 Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specification of Decentralized Environmental Notification Basic Service.
- ETSI - EN 302 637-2 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service.
- Gozalvez, J., Sepulcre, M. and Bauza, R. (2012). IEEE 802.11p vehicle to infrastructure communications in urban environments, in IEEE Communications Magazine, vol. 50, no. 5, pp. 176−183, May 2012.
- SAE J2735. Dedicated Short Range Communications (DSRC) Message Set Dictionary J2735_200911.

3.2 Test-track pilot activities and capabilities

The test-track pilot activities and capabilities have been conducted through various tools and equipment and specifically:

- test-track activities involving CEREMA, COMMSIGNIA, GLS and IFSTTAR for the combination of different technologies at Aachen test site;
- test-site and lab activities led by CEREMA for the monitoring of LC infrastructure;
- test-track activities led by VTT using additional warning light system at front of the locomotive.

The following table contains specific information concerning the pilot test leader, the measure, the type of implementation, the variables and the quantification of the safety effects. It allows summarizing the general characteristics of the test carried out.

Table 7. General description of the measure and activities conducted in controlled tests by each Pilot test leader.

Pilot test leader	Measure	Implementation type	Variables	Quantification of safety effects
CEREMA	Smart Detection System	LC mock-up installed at Aachen test site	Detection accuracy, Detection rate, Processing time, Sample size, Ability to transmit information	The smart detection system is a technical evaluation, a proof-of-concept and will not provide safety effects. However, the safety effects (potential accidents to be avoided and the effectiveness of the system in avoiding these potential accidents) could be estimated with rail operators (e.g. SNCF).
COMMSIGNIA	Early train detection and hazard information by means of cooperative perception messaging and drivers' warning	Various V2X use-cases deployed in the Aachen test site	Detection range, Usability conditions, Stability and maturity of the solutions, Environment conditions for processing, Ability to work in hard conditions,	Objective of measure is to avoid collisions at LCs between trains and vehicles. Both train and vehicle drivers are warned in advance of potential hazards.
GLS	Operating the barrier depending on the train's position Aggregating alerts detected by the camera detection system and ITS-G5 messages	RSU deployed in the Aachen test site and mock control room installed on a distant server	Detection range High availability Video upload interval Stability	The first objective of the measure is to close the LC barrier depending on the train position to warn the drivers and reduce collision risk.

	Alert dissemination via ITS-G5 DENM to equipped vehicles Alerts presentation on the control room HMI			The second objective is to warn the arriving drivers of potential dangerous situations. The last objective is to warn the LC operator and providing him a detailed view of the current situation (video).
IFSTTAR	Smart communication system: Transmit the ITS CAM to all equipped vehicles arrived to LC: indicated the position of the LC Alert dissemination via ITS-G5 DENM to equipped vehicle	I2V communication in the Aachen test site	Detection range, conformity of exchanged messages en environment conditions effects, time latence of exchanged messages	the goal of measure is to avoid collisions at LCs . the vehicle drivers are warned in advance of potential hazards. this message is repeated by the vehicle, nearest at LC, to all vehicles arrived to Level crossing,
CEREMA Rouen (&NTNU)	Monitoring and remote maintenance	An automated real time system to monitor the condition of LCs using sensors on the track and road (seismic sensors, photogrammetric system, VACC and thermo-infrared method). It has been applied on a level crossing mock-up at Rouen test site.	Detection of conflict point at LC: Measurement of the LC's topography profile calculated with geometry of the exceptional transport vehicle. Level of LC condition estimated from the vibration impact for different road configuration and photogrammetric system. (Good condition, bad condition, LC worst condition which may lead to safety risk)	To avoid collisions at LCs between trains and heavy vehicles which are prone to stuck at LCs through informing the geometrical limits and requirements for a safe running over the specific LC. Expert assessment on the level of LC infrastructure condition to inform owners when to maintain it.
VTT	Additional warning light system at front of the locomotive	Installation of the system at real rail environment to test the system also from locomotive driver perspective. Train was not part of the piloting facilities, but it was rented separately.	Road user: - Visibility of approaching train with and without lights - Visibility of approaching train with lights on during day time vs. during darkness - Possible annoyance of train lights Train driver: - Possible annoyance of train lights	Estimation on the share of LC accidents which could be prevented with improved train visibility

3.2.1 LC mock-up installed at Aachen test site

Test site location: Aachen (Germany)
Pilot test leader: RWTH Aachen University as owner of the test-track

Involved organizations and their roles:
The responsible organization for the implementation of the LC mock-up is the Chair and Institute for Rail Vehicles and Transport Systems. Its responsibilities include:

- Implementation of the mock-up of a real level crossing;
- Providing an Interface for closing/opening the level crossing;
- Provision of any other feature and structure for the implementation of the measures (power supply, place for control room, internet connection, cars with On Board Unit (OBU), etc...)

The other participating organizations are:

- CEREMA (Toulose branch) as developer of the software for the smart detection system and the exchange module with the RSU of GLS;
- UTBM as support for the development of the software for the smart detection system;
- IFSTTAR as developer of the communication system in close collaboration with GLS to exchange data between the RSU and the cars with OBU;
- GLS as responsible for the RSU and the connections among the various systems in operation;
- COMMSIGNIA as responsible for the V2X system for detecting and alerting trains and cars at LC;
- NTNU for the monitoring of the LC barrier.

Description of the measure

Various partners worked together in Aachen for testing, under real-world conditions in a test-track of the Aachen University, the whole chain of detecting dangerous situations, communicating among LC operators, trains and cars and informing about obstacles detection and/or trains approaching. Additional testing is also defined for monitoring traffic light signals and barrier LC condition.
Specifically, the single measures developed and tested in Aachen are the following:

- smart detection system based on video images with the classification/categorization of dangerous situations (scene understanding by LCs operator) from CEREMA and UTBM;
- multi-hop V2X for the early detection of trains and cars at the LC from COMMSIGNIA;
- multi-hop communication of alerts through V2X from IFSTTAR;
- alert provision to road vehicles through V2X and barriers operation, communication to the LC control center about train approaching and/or obstacle detected from GLS and COMMSIGNIA.

The measures cooperate among them in the following manner (see Figure xxx):

- detection: potentially dangerous situations are detected by cameras and V2X
- communication: wired communication between the cameras and the LC unit; ITS-G5 communication between the RSUs and LC unit; ITS-G5 communication between the LC unit and the road vehicles
- information: barriers down when the train is approaching based on ETA; in-vehicle messages about a dangerous situation using DENM and continuous phase modulation (CPM).

In particular, for the communication, IFSTTAR with GLS used the unmodified version of the existing standard (ITS-G5) and Commsignia showcased with an experimental version of collective perception messaging, which represents a future extension of the standard feature set of ITS-G5. The aim is not to compare them but to test an additional solution.

These measures are applied to a level crossing mock-up, installed on Aachen test site. This mock-up represents an active LC in which scenarios of dangerous situations can be reproduced. It contains light signals and operates in two possible different statuses: barrier closed and barrier open. The objective of these measures is to verify the in-situ performance of the different technology systems installed and the capacity of the overall system to integrate and cooperate for providing added value to the whole chain.

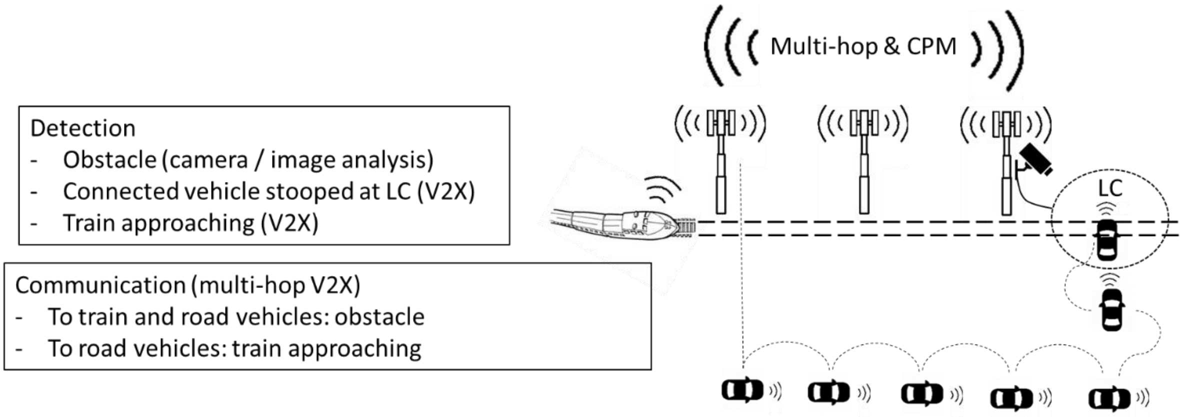


Figure 19. Detection and communication scenarios tested in Aachen.

The detection scenarios tested are the following:

- Obstacle at the LC detected by image analysis (Figure 20 left)
- Obstacle at the LC detected by V2X (Figure 20 middle)
- Train approaching detected by V2X (Figure 20 right)

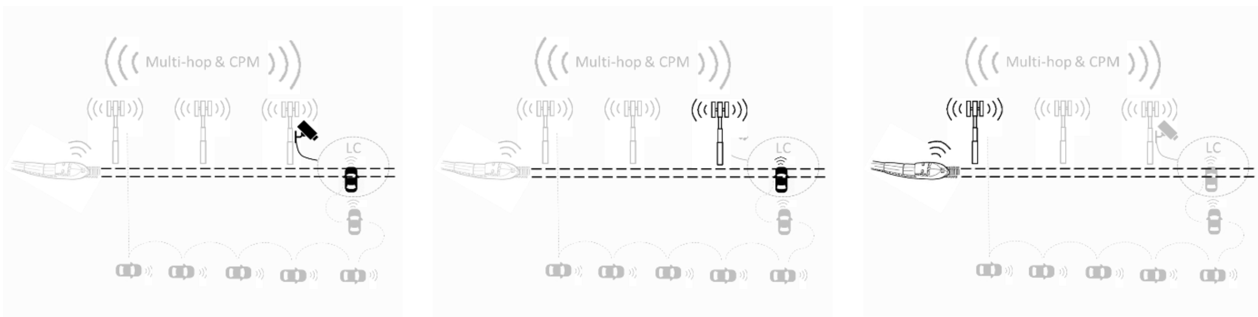


Figure 20. Detection scenarios tested in Aachen.

The communication scenarios to be tested are the following:

- To train and road vehicles: obstacle - (Figure 21 left)
- To road vehicles: train approaching - (Figure 21 right)

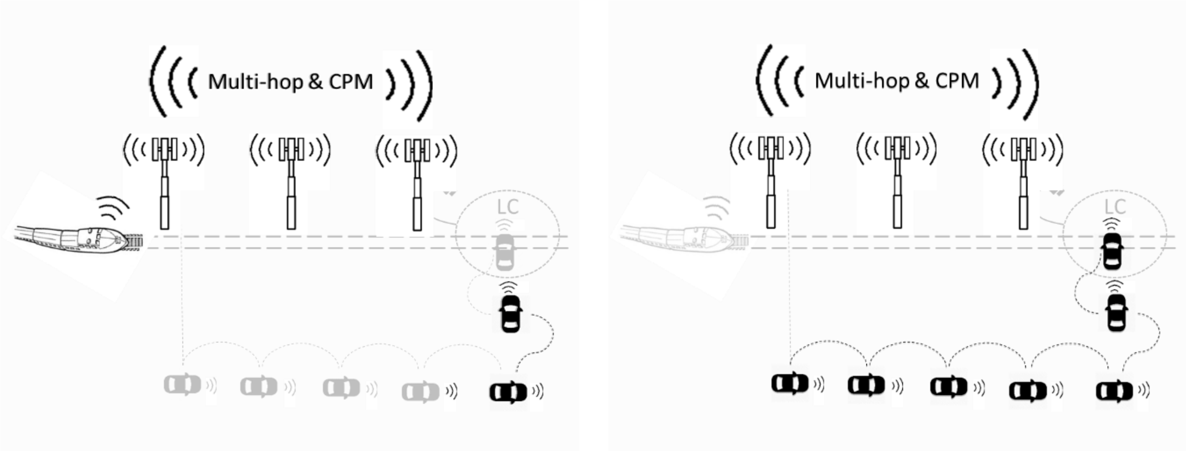


Figure 21. Communication scenarios tested in Aachen.

The measures to be jointly tested are the following:

- Measure 1: Train approaching in-vehicle warning?
- Measure 2: Operate barriers based on train approaching detection and Expected Time of Arrival?
- Measure 3: Obstacle warning to train driver?
- Measure 4: In-vehicle obstacle warning for road vehicles?

Aligning with the three main objectives of SAFER-LC regarding the use of advanced vehicular communications technology in the enhancement of LC safety, SAFER-LC partners showcased with both standard and experimental V2X applications in acc. with the use-case scenarios specified below. The scenarios demonstrated the capabilities of V2X-based monitoring and clearance assurance of LCs and the role of V2X technology in early train detection and hazard information sharing by means of cooperative perception and drivers' warning technologies were shown, such as

- warning drivers of both road and rail vehicles about dangerous traffic situations encountered in LCs;
- assist road users to escape from dangerous situations;
- assist drivers of both road and rail vehicles in the avoidance and mitigation of dangerous hazard situations.

These V2X use-cases operate by collecting relevant environmental information, such as the detection of hazardous objects and events occurring in LC vicinity and sharing this information among road and rail users/drivers by communication in an attempt to support the preparation of corrective actions. The solutions are tested and operated in real traffic environments and hazard conditions.
The performance of the system in terms of scenario recognition are carried out using video data. Video data and interactive log files are used as input but also as ground truth that will be attached to this validation report.

Implementation of the measure

The mock-up of LC, used to demonstrate SAFER-LC equipment, is located at the Chair and Institute for Rail Vehicles and Transport Systems, RWTH Aachen University. The level crossing is implemented with half barriers and light signals for the road user. For controlling the barrier machines and light signals, a standard microcontroller with Controller Area Network (CAN) interface is used. The barrier machines are powered with three 12 V batteries in series which are connected to a charging rectifier, which is state of the art. The level crossing manufacturer Scheidt&Bachmann kindly provided the barrier machines. The microcontroller offers a bidirectional interface to control and get the status of the level crossing (open/closed). The interface is used by the RSU from GLS.

Figure 22 shows a map of the facilities. The test site is located near the “Aachen West” railway station. It features 200 m of private railway track with a maximum permitted speed of 25 km/h. The track features a large road/rail intersection area where different level-crossing scenarios can be implemented. Parts of the tracks are located in a workshop hall that offers possibilities for mounting mechanical and electronic components to the testing rail vehicles. A round-trip circuit for testing from an automotive perspective, crossing the railways at an angle of approximately 45 degrees, has been implemented by using the rear exit of the testing facility and the public road next to it (see blue line in Figure 22). Depending on the driving direction, the level crossing would be either in plain sight of the approaching car (when driving counter-clockwise on the blue path depicted in Figure 22) or hidden behind a corner of the workshop building (when driving clockwise).

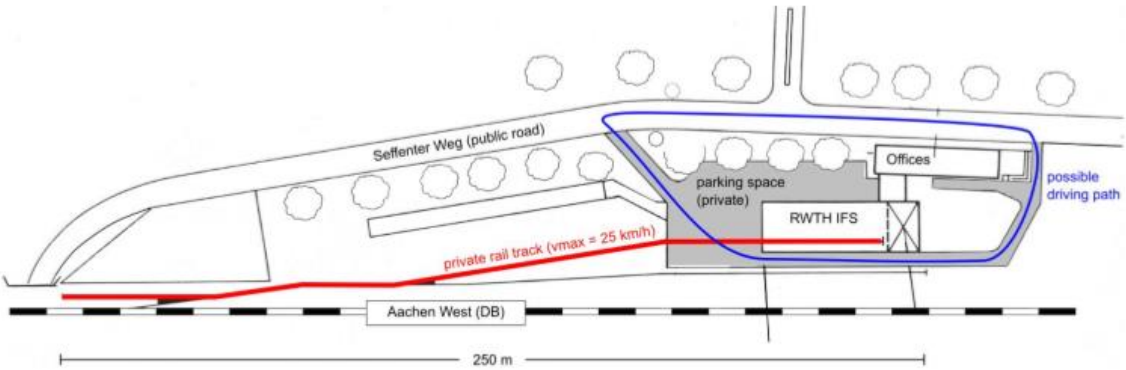


Figure 22. Map of the facilities.

Figure 23. Aerial image of the test site.

Figure 24. Road/rail intersection at Aachen test site.

Figure 25. Testing rail vehicle with barrier and light signal.

The smart detection system (SDS) consists of one or two video sensors connected to a processing computer. The SDS is then extended with the devices of the V2X communication system that aims to provide means for sharing detection information with drivers and travelers in and around LC's immediate vicinity. The most important V2X devices are RSUs which are located in the LC and connected to the detection system directly. Real barriers and traffic light signals complete the LC installation. The overall detection and warning system summarised in Figure 26 is capable to demonstrate the capabilities of a cooperative perception and hazard warning scenario in road-rail LC environments.

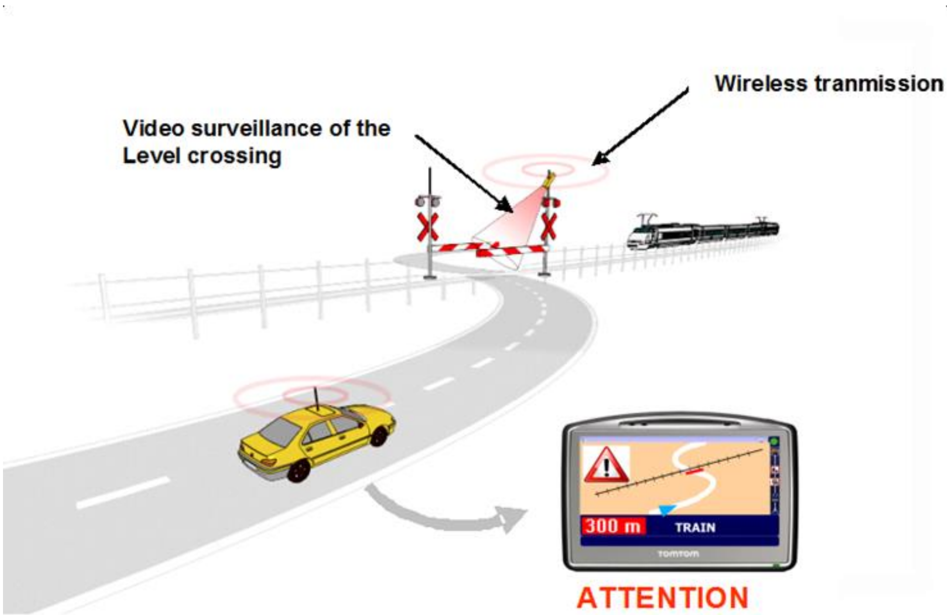


Figure 26. Implementation of the measures.

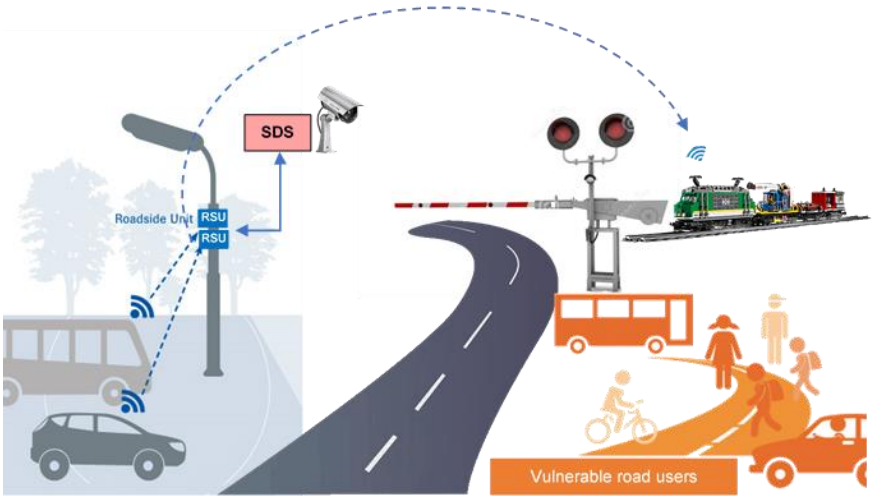


Figure 27. The cooperative perception scenario of SAFER-LC.

The SAFER-LC plans for testing in Aachen can also evaluate performance of a number of different, sometimes not standardised and experimental technology elements, which are not compatible between them. Therefore, the LC equipment contains two RSU devices. One device is provided by GLS and another by COMMSIGNIA. This multivendor RSU deployment at Aachen test site is shown briefly in Figure 28. Note, however, that a single RSU configuration assigned to a particular LC can satisfy the requirements normally. A third, remote RSU which is located in a faraway distance from the LC is also part of the deployment. This RSU has been provided by COMMSIGNIA and is used in the early train detection perception scenarios.

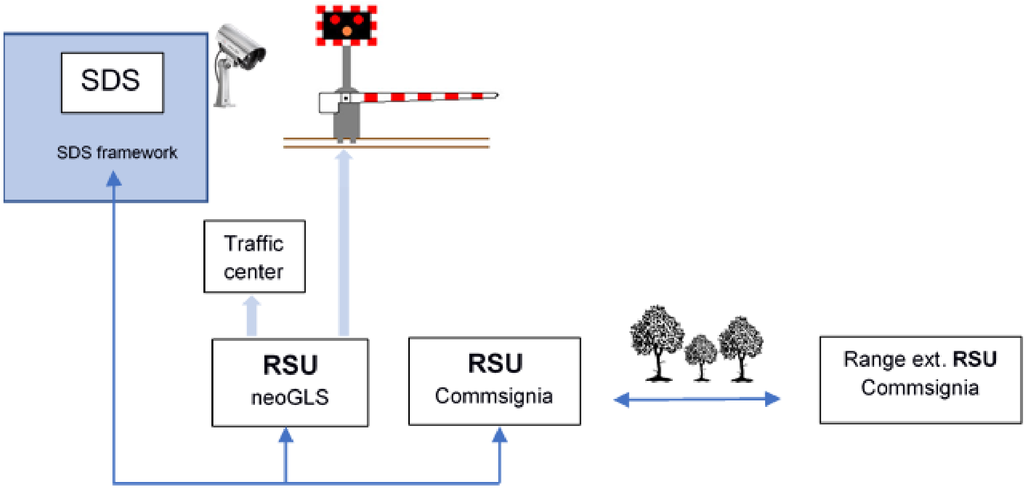


Figure 28. Multivendor RSU deployment at SAFER-LC validation site Aachen.

Various scenarios with four cars crossing the LC (one car belonging to IFSTTAR, one rented by GLS, two cars rented by RWTH) at different speeds are planned. The scenarios included vulnerable road users (pedestrians) and other objects, etc. to demonstrate the accuracy of the system to detect a wide range of road hazards. The cars have been equipped with V2X on-board units to receive the detection messages. A specific web platform has been installed in RWTH University.
The implementation phase started in November 2018 for the construction of the mock-up of LC and for the development of all other equipment. The implementation has been completed at the end of January 2019 for the on-site installation and for preliminary testing of all the modules of the system.

Execution of the tests

The tests have executed during three different test periods in Aachen reported as follows:

- first period of trials from 25 January 2019 and 27 January 2019 with the participations of the following teams: CEREMA, UTBM, IFSTTAR and GLS;
- second period of trials from 26 March 2019 and 28 March 2019 with the participations of the following teams: CEREMA, UTBM, COMMSIGNIA, IFSTTAR, GLS and NTNU;
- third period of trials from 27 May 2019 and 29 May 2019 with the participations of the following teams: CEREMA, UTBM, COMMSIGNIA, IFSTTAR and GLS.

First trials period (25-27 January 2019)

The first phase has been dedicated to test the main functionalities of the smart detection system as a standalone demonstrator. The video system has been installed on the test site and the different functionalities have been tested separately:

- the recognition of the sensor by the software;
- the acquisition module;
- the processing module.

To test these functionalities one by one, different scenarios including LC crossing of vehicles, pedestrians have been simulated. During this first session of testing, the smart detection system has been also connected to the GLS interface to verify the messages exchange and verify that everything is working well. These tests have been carried out based on several dozens of simulated scenarios including different events at the LC.

In the same phase, some preliminary connections between GLS system and IFSTTAR were also carried out. The global architecture of the system used for testing in this first trial is represented in Figure 29. It includes the smart detection system and the smart Road side Unit with the GLS interface connected to IFSTTAR communication system able to send information to surroundings cars or to the train. Figure 30 reports the global processing chain implemented based only on the smart detection system. The different processing modules are mentioned on the figure with the predefined scenarios to detect and recognize events as the presence of an obstacle or a traffic jam at LC, atypical behaviour and pedestrian(s) at LC.

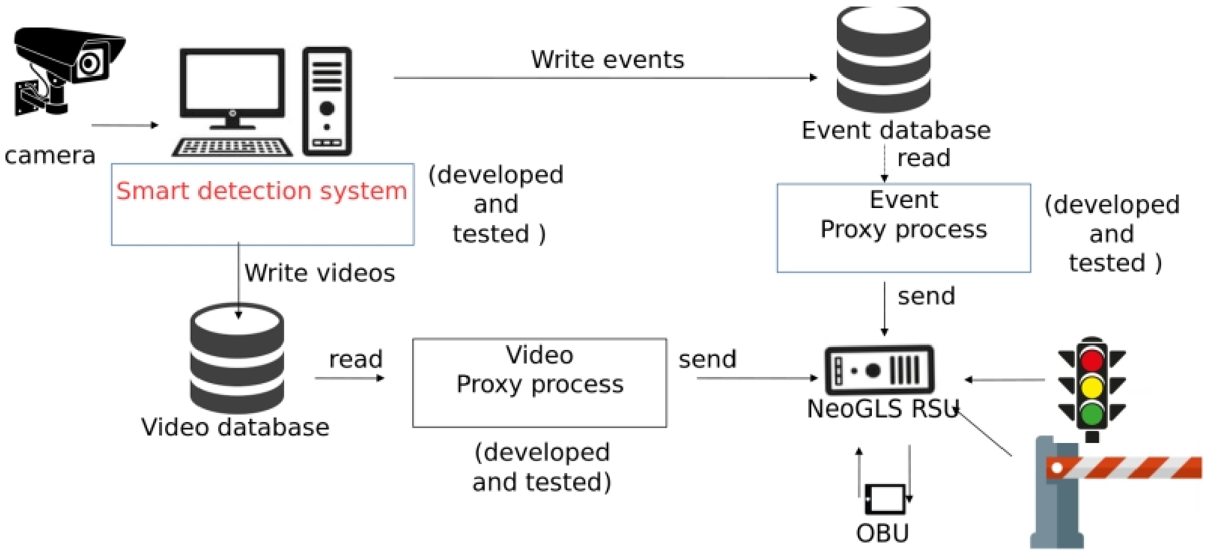


Figure 29. Synoptic of the global system composed of detection + Road side unit.

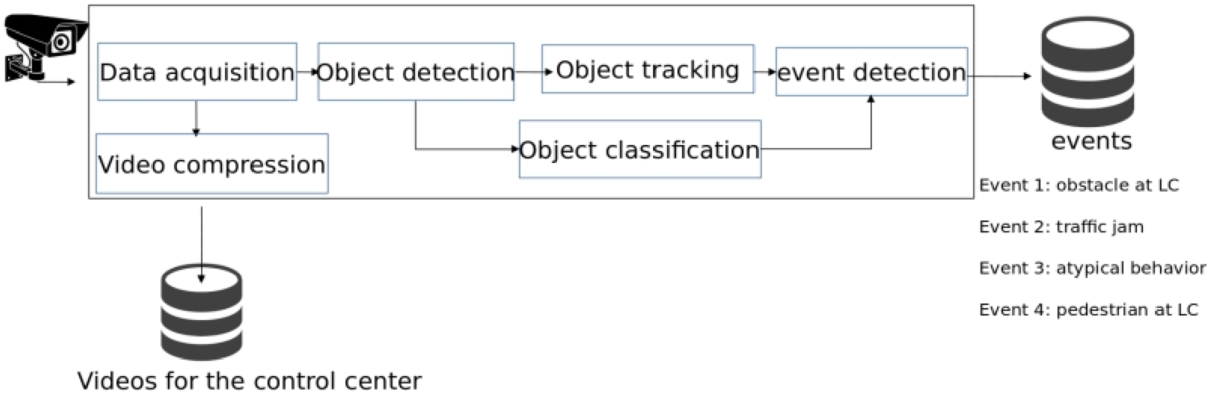


Figure 30. Synoptic of the smart detection processing chain.

The Figure 31 reports the detection system interface and the process of detection of a bicycle.

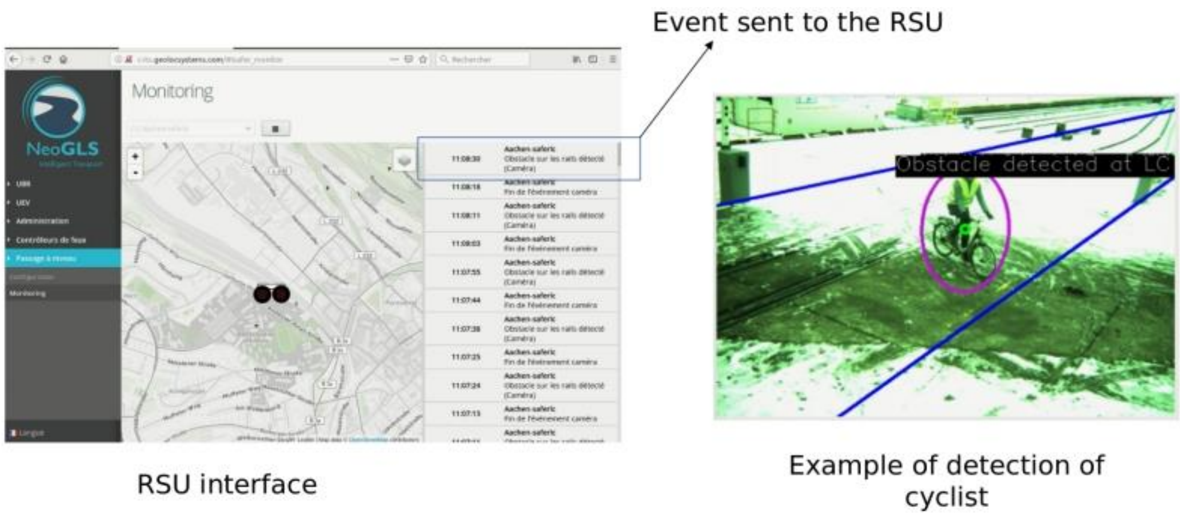


Figure 31. Example of a detection of a bicycle crossing the LC: left - events' interface, right - illustration of the detection.

About the communication system, the objective of the first phase of testing was to test the communication functionalities between RSU and OBU. Two scenarios are tested and evaluated:

- Scenario 1: Detection of the incident and transmission to the road users;
- Scenario 2: Detection of the incident and re-transmission to all road users.

During this first session, the smart communication has been installed and connected to the smart detection system. The connection between GLS interface and OBU (IFSTTAR) is tested and evaluated.

Second trials period (26-28 March 2019)

During the second phase, the tests executed about the smart detection system, the cooperative intersection assist safety applications, moreover, the experimentation with the perception range extension new technologies have as main objective:

- the capacity of classification of the objects;
- the validity of the connections between GLS and IFSTTAR;
- the validity of the connection with the control room and the possibility to provide video data at the same time than the alert messages.

Another important task of activities during this second phase has been the execution of the simulation scenarios. Four scenarios have been identified and executed: obstacle on the tracks, pedestrians crossing, atypical behaviour and presence of traffic jam. Each scenario is simulated with repetitions to be statistically representative using different configurations of the barriers (closed barriers periods and during open barriers periods). For each scenario, video data has been stored, the detection process has been performed and the information exchange between smart system and GLS interface is carried out.

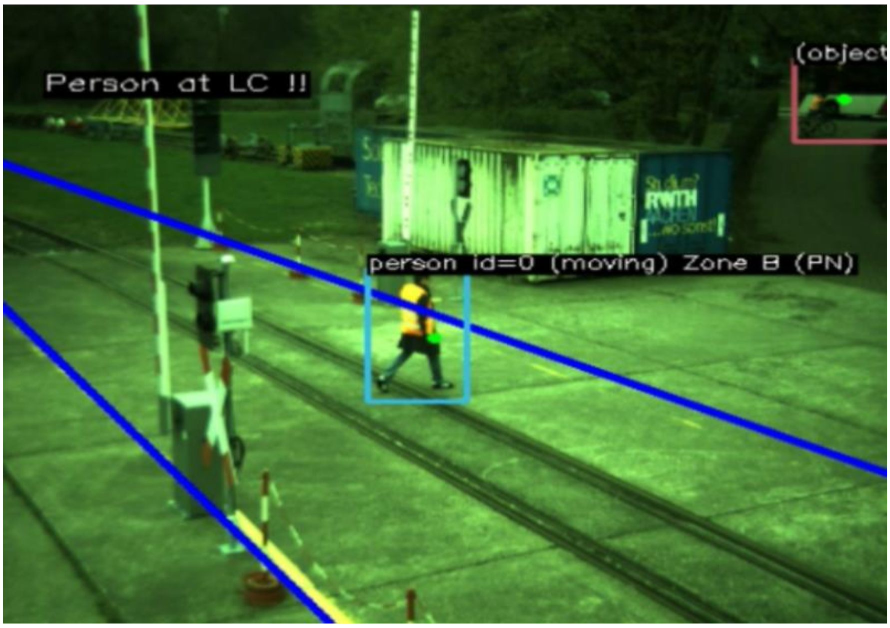


Figure 32. Example of a pedestrian crossing the LC.

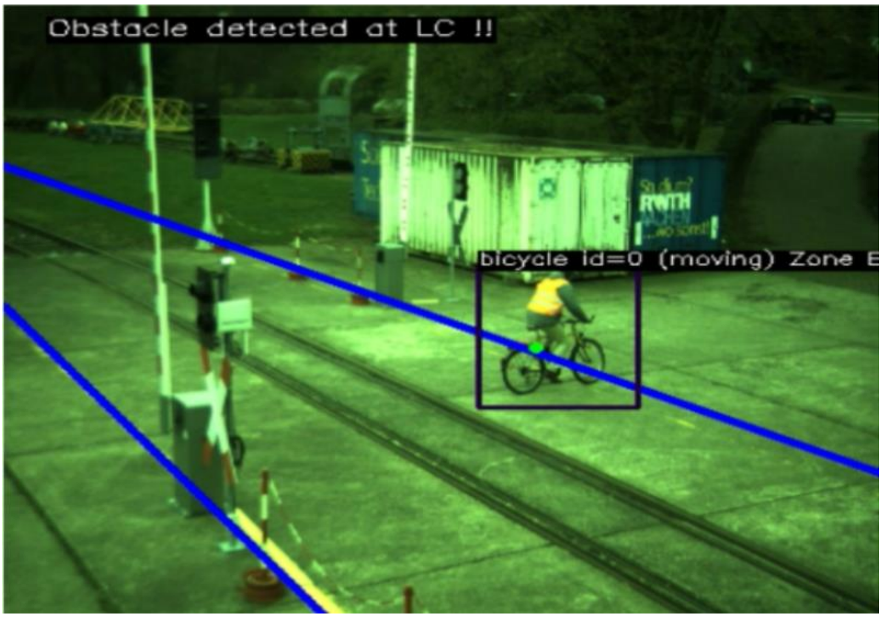


Figure 33. Example of a detection of a bicycle crossing the LC.

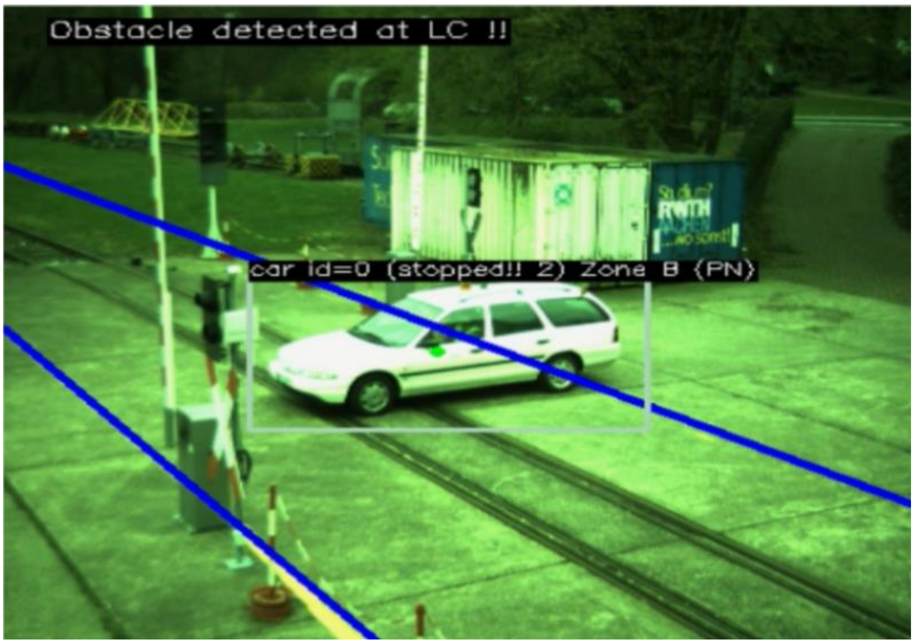


Figure 34. Example of a car stuck on the LC.

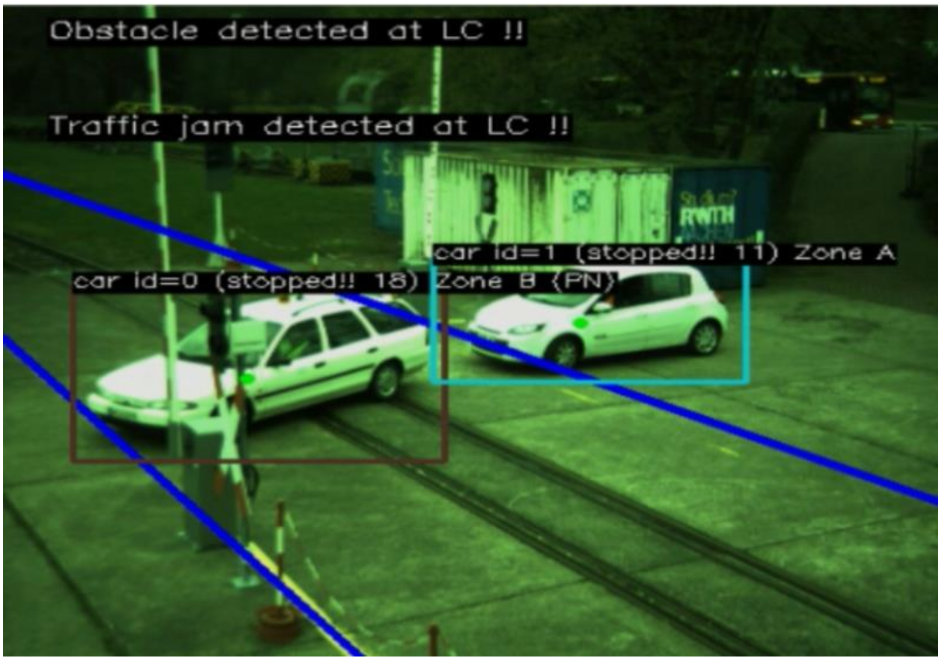


Figure 35. Example of a detection of a traffic jam on the LC.

The main objective for the communication system during the second phase of tests is the evaluation of the connection between GLS and the smart detection systems in case of others scenarios. An example of these scenarios is reported as follows:

- when traffic jams occur to the level crossing;
- when a car is blocked between the barriers;
- when a vehicle forces a closed barrier;
- when a pedestrian is detected in the LC.

The main objective for the most recent V2X safety applications from COMMSIGNIA is to demonstrate the performance and capabilities of these V2X applications in the clearance assurance and safety enhancement of LCs. The safety applications were developed in response to the need of cross-modal information exchange between road and rail vehicles drivers. Clearance assurance means the proper monitoring and processing of movement information of V2X capable vehicles in and the close vicinity of LCs, as well as last second warning of drivers in case the hazard is instantaneous.
The applications realizing the scenarios were verified by event logging and time stamp analysis of the safety messages, by measuring and evaluating safety parameters (e.g., target radius, dangerous closest distance, time to collision) which values have direct influence on the performance and sensitivity of the communication.
This system validation program was implemented as a variation of test scenarios. The scenarios were about the avoidance and mitigation of the severity of road/rail vehicle collisions in LCs. It is assumed that both road and rail vehicles are V2X enabled vehicles meaning they are equipped with OBUs. The intersection assist safety applications are installed and operated on these OBUs.

Third trials period (25-27 May 2019)

The main aim of this third session for the smart detection system was to test two different things:

- in case of a detected event, send an alarm to the control room with the life video data accordingly. For this functionality and with a specific application in an internet platform, the smart detection system sends all the time 5 seconds video data buffers to the control room that could be far from the LC. When an event is detected, a visual alarm is sent to the control room with the corresponding video data. For testing these functionalities, also in this case a large set of different scenarios including cars, pedestrians, has been carried out;
- the second thing about the functionality was to test the global chain: smart detection (CEREMA and UTBM) + smart interface (GLS) + communication system (IFSTTAR).

The main objective for the communication system for the last phase is to test the multi hope scenarios. The objective is to evaluate the maximum communication range. The nearest vehicles send the same received DENM to other vehicles coming to the Level crossing.

All scenarios have been tested for the multi-hope schemas. All DENMs has been received correctly if the distance of OBU and RSU is lower than the maximum range of communication in the case of line-of-sight the maximum range is about 250 m. In case of NLOS "Non line of sight" the maximum range in Aachen site for the presence of trees is about 60 to 80 m. With the multi-hops solution, using two vehicles, the maximum range is between 160 to 180 metres.

About the interface between smart detection system and GLS RSU, the tests have been carried out to fetch and aggregate video files from the camera to provide vision to the agent monitoring the LC. The process consisted in the smart detection system that pushed video files periodically to the smart RSU. Then the smart RSU choosed if the video file was relevant regarding the running events on the LC, the video files have been sent to the control room.
These tests have been carried out during the third trials period because during the second session some encoding issues stopped the tests. On the first day, the activities have permitted to set up the SSH context to send video files in a secured way between SDS and the RSU, using a key

authentication. After that, the video upload has been tested using dummy scenarios predefined. During the second day, the tests have been extended to the complete chain with real scenarios using the smart detection system. When an event has been detected by the camera, the RSU was uploading it to the platform, and by clicking on the alert, the video files have been aggregated, starting from the event detection until the end of the event.

Another important series of tests have been carried out by COMMSIGNIA during the second and the third session of testing in Aachen. The tests involved the use of advanced vehicular communications technology in the enhancement of LC safety with standard and also experimental V2X applications. Increasing the range of the detection horizon of trains in LC environments may have critical effect on hazard mitigation, detection and warning performances especially in cases when high speed trains are involved. The following use-case scenario demonstrates the capabilities of the collective (or cooperative) perception service of V2X technology in LC environments in extending the perception range of the cars for several km's. Cars wanting to cross the LC will be able to elongate their warning horizon in hazard situations. These perception range extension methods are based on the new experimental collective perception technology and on multi/hop DENM messaging.

These V2X use-cases have been operated by collecting relevant environmental information and sharing this information among road and rail users/drivers by communication in an attempt to support the preparation of corrective actions. The solutions are tested and operated in real traffic environments and hazard conditions.

The performance of the system in terms of scenario recognition has been carried out using video data.

The first series of four scenarios was related with the intersection management safety application in which both rail and road vehicles are V2X enabled vehicles equipped with OBUs. Specifically, the four scenarios have been defined as follows:

Scenario 1.1:

Step 1: Car travels in a neutral direction regarding the LC geometry. This means either the car is yet outside critical LC proximity or it travels in a neutral direction (presumably not wanting to cross the rail track).

Step 2: Car suddenly changes travel direction and heads for the crossing of the rail (or it gets close to the LC enough) and its movement trajectory might have a probable collision with the arriving train.

Step 3: Train is approaching the LC

Step 4: The app triggers notification to both car and train depending on the sensitivity parameters of the setup. Triggering conditions may differ depending on the real geolocation information of the LC, road and train track geometry.

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Scenario 1.2:

Step 1: An unwary car approaches the LC (e.g., in dangerous speed or cautious behavior) presumably not wanting to stop before of the rail track and its movement trajectory might have a probable collision point with the arriving train.

Step 2: Train is approaching the LC

Step 3: The app triggers notification to both car and train depending on the sensitivity parameters of the setup. Triggering conditions may differ depending on the real geolocation information of the LC, road and train track geometry.

Scenario 1.3:

Step 1: Car crosses the LC in a very slow speed or stops suddenly due to traffic jam or technical criticality.

Step 2: Train is approaching the LC.

Step 3: The app triggers notification to both car and train depending on the sensitivity parameters of the setup. Triggering conditions may differ depending on the real geolocation information of the LC, road and train track geometry.

Step 4: Car moves away

Step 5: Train HMI stops showing warning.

Scenario 1.4:

Step 1: A pedestrian crosses the LC in a very slow speed (wandering) stops suddenly from any reason.

Step 2: Train is approaching the LC.

Step 3: The video object detection system detects the wandering pedestrian (or any other pre-specified type of objects) and conditionally triggers notification to the RSU. Triggering conditions may be varied (pedestrian in between closed barriers etc.) and may depend on the sensitivity parameters of the setup

4: RSU generates and distributes CPM messages to the approaching train.

5: Train OBU receives and decodes CPM messages and displays notification about pedestrian on track on train HMI and warns train driver.

The second scenario executed was related with the perception range extension by means of the collective perception. Specifically, the scenario has been defined as follows:

Scenario 2.1:

Step 1: Train approaches the LC in a distant location.

Step 2: Remote RSU senses the CAM distributed by the coming train, it processes the train CAM messages and transforms them to collective perception information (CPM protocol).

Step 3: The remote RSU broadcasts CPMs to the LC, where both the local RSU and the vehicles in the LC vicinity receive and decode it. CPM protocol contains the position information of the remote train.

Step 4: RSU at the LC provides train position information dynamically for control and monitoring purposes to the LC barrier controller, which can be displayed on screen of the control center.

Step 5: Car OBUs receive the CPM and displays the closing train location information on its HMI and generate warning for cars driver

The third scenario executed was related with the perception range extension by multi-hop DENM forwarding. Specifically, the scenario has been defined as follows:

Scenario 3.1:

Step 1: Train approaches the LC in a distant location and triggers a DENM message geo-conditionally. It is assumed that the train always knows about the geolocation of the actually coming LC in its forward path of travel and triggers a DENM in the due time and distance.

Step 2: Remote RSUs (and or any V2X capable vehicle OBUs) receives the message and forwards it to any intermediate vehicle or infrastructure. This process is ad-hoc, if a V2X capable device is present, then it will be part of the forwarding process.

Step 3: Finally, the message arrives to the RSU located at the LC and broadcasts the warning of the approaching train to the vehicles in LC vicinity.
Step 4: Car OBUs receive the DENM and displays the closing train information on its HMI.
Step 5: The train cancels DENM message after passing through the LC by a safe distance.

Finally, NTNU tested, during March 2019 in the second session, independently from the other organizations, the monitoring ensured by a measurement of the electric current changes, of the traffic signal light at LC and of the LC barrier condition.
About the first measurements of the traffic signal light current, such current has been measured using a standard ammeter connected in serial. The ammeter gives the reading of the current. The traffic signal light at the mock LC is made of LEDs. There are 40 LEDs connected in serious and in parallel for the yellow blinking signals. The signal light changes from blinking yellow to red in 3 seconds. Four test scenarios have been tested:

- Scenario 1. All 40 LEDs working (100% working);
- Scenario 2. 10 LEDs are disconnected (75% of LEDs working);
- Scenario 3. 20 LEDs are disconnected (50% of LEDs working);
- Scenario 4. 30 LEDs are disconnected and only 10 are working (25% of LEDs working).

Current signals for the four scenarios are measured with three repetitions for each scenario.
About the second measurements at level of the barrier motor unit, the current has been measured using a clamp-on ammeter that measures the current flow which readout the current flowing.
The barrier booms installed at the mock LC are manipulated to test fault or failure in the barrier. The current is measured while opening and closing the barrier boom with different scenarios. Measurements are conducted for six scenarios:

- Scenario 1. Barrier boom operating normal condition (normal status);
- Scenario 2. Boom closing slowly by holding the boom straight. This is to imitate that the barrier is closing slowly;
- Scenario 3. Boom unable to come to a close status. This is to mimic if the barrier is falling on a truck/bus while passing the LC;
- Scenario 4. Boom unable to open from a closed situation. This is to imitate passengers are using the barrier as support while train passes by lying/pressing down the barrier boom;
- Scenario 5. Boom opening slowly or stopping at some angle while opening;
- Scenario 6. Boom without the barrier. This is to represent barrier being broken by strong wind or barrier crushed by driven through cars.

3.2.2 Rouen test site for monitoring and remote maintenance

Test site location: Rouen (France)
Pilot test leader: CEREMA
Involved organizations and their roles:
The main responsible organization for the measures is CEREMA. Its responsibilities include:

- Implementation of the mock-up of a real LC
- Implementation of the measures

- Execution of the tests

The other participant is NTNU.

Description of the measure

The measure consists in monitoring and remote maintenance. The objective is to develop an automated real time system to monitors the condition of LCs using sensors on the track and road (seismic sensors, photogrammetric system and thermo-infrared method). It has been applied on a level crossing mock-up at Rouen test site. Two different configurations of infrastructure are used reproducing the most common types of natural relief road configuration (bump and hollow). The different configurations are used to detect degradations of the level crossing testing four different methods: photogrammetric, thermo-infrared, vibration and VACC (instrumented vehicle - Véhicule d'Analyse du Comportement des Conducteurs).

The monitoring system ensures the safety performance of the LC through the continuous and real time monitoring with two approaches:

- the use of smart and embedded wireless sensor networks. Vibration and temperature sensors have been installed on the relevant track/road components and data were transmitted with an alert threshold to the LC operator. The system is enabled to send alerts to LC users. To measure the vibration, there is the need to use a truck crossing the infrastructure;
- a photogrammetric has been used to monitor infrastructure surface condition and to detect any deterioration of the structure. This system could also measure displacement and deterioration of the road surface. In addition, thermal infrared data enhances the interpretations of the potential disorders as cracking. High permeability zones generate a thermal anomaly of several degrees.

The objective is to detect infrastructure conditions and any deterioration of the structure to avoid collisions at LCs between trains and heavy vehicles stuck at LCs. The issue of vehicles stuck at LCs relates to the longitudinal section on either side of the LC. Railway managers have a topographic section with a lower level of precision. The photogrammetic method could improve the detection of dangerous profiles while the VACC is an instrumented Renault Mégane that can record all the data passing through the CAN bus of the car, saving the data on the dynamics of the vehicle (used by the different safety devices) and the actions of the driver. This data is also associated with shooting video (front, back, steering wheel, pedals, driver) and GPS positioning.

Implementation of the measure

The measures are implemented at the CEREMA branch in Rouen (see Figure 36) where has been built a mock-up of a real level crossing.

Figure 36. Aerial view of the CEREMA test site.

The implementation of the experimental LC structure (configuration a – see Figure 38) was composed of seven steps as follows and in Figure 37:

1. Digging for the location of the experimental LC a water lost well and a drain for evacuate meteoric water;
2. Implementation of the water lost well and the drain;
3. Implementation of a layer of gravel and levelling the bottom of excavation;
4. Implementation of the railway track;
5. Implementation of the level crossing system;
6. Implementation of the level crossing system;
7. Compaction of the cold asphalt layer.

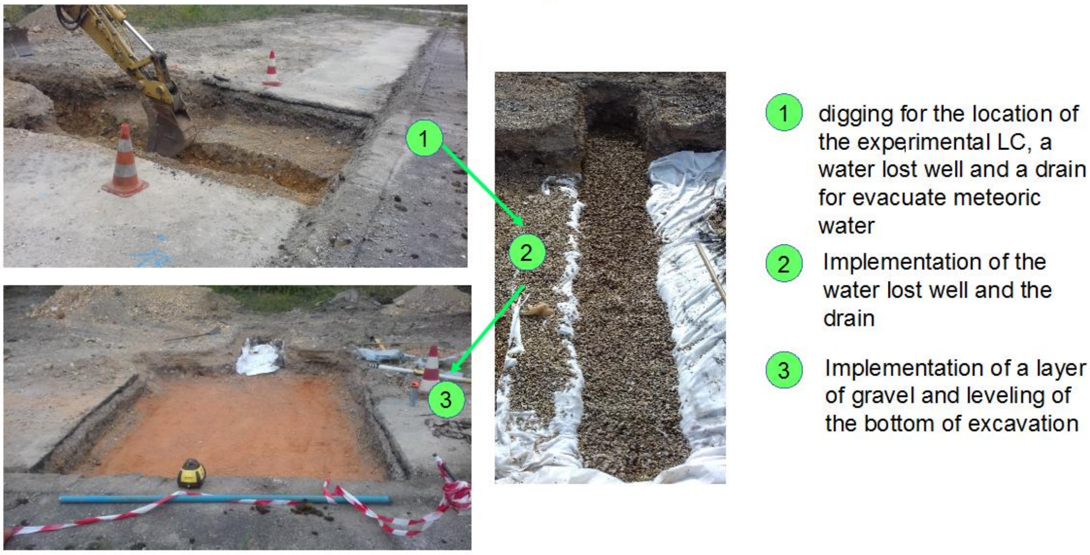

Figure 37. Different steps of construction of the LC mock-up.

Two different configurations of infrastructure are used reproducing the most common types of natural relief road configuration (see Figure 38).

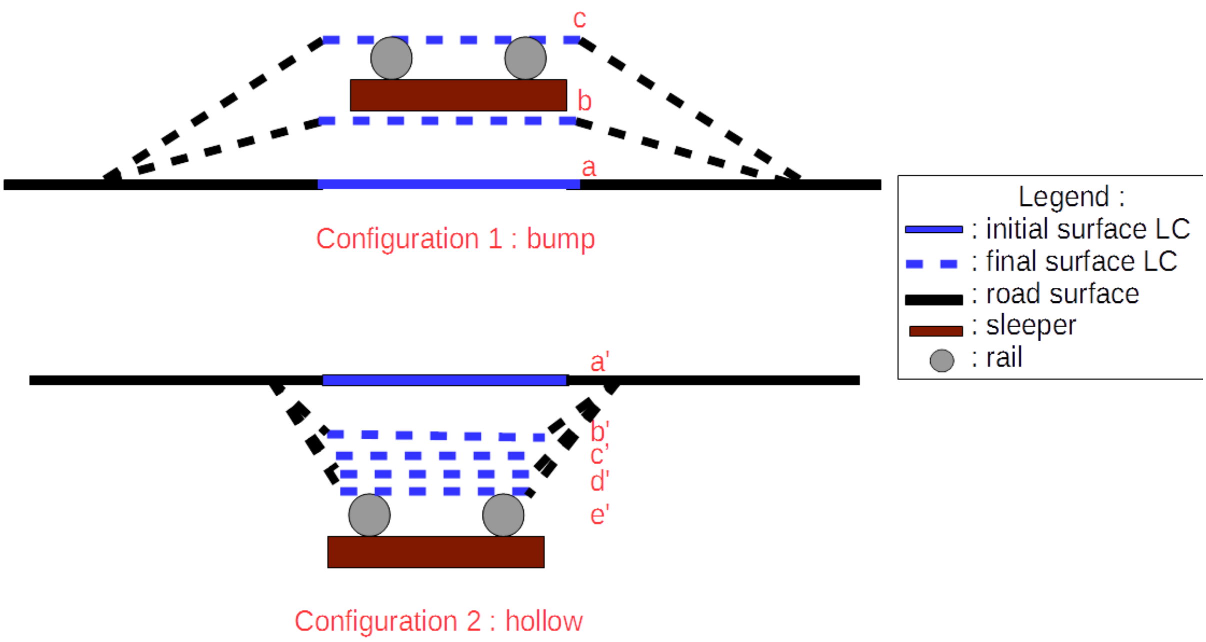

Figure 38. Different configurations of the experimental test site.

To generate different arrangements of the bump, it has been used wood beams with two thickness (see Figure 39) for the development of configurations 1b and 1c according to the following sizes:

- configuration 1a: 0 cm;
- configuration 1b: 3,5 cm;

* configuration 1c : 7 cm.

Figure 39. Configuration1 – Bump with wood beams

To simulate different hollow arrangements, it has been used water saturated sand inside waterproof film in combination with the passage of trucks to produce deterioration of the infrastructure as described as follows and in Figure 40:

* Configuration 2a': 0 cm;
* Configuration 2b': 1,9 cm, after 1 truck passage – 3km/h;
* Configuration 2c': 2,1 cm, after 1 truck passage – 12 km/h;
* Configuration 2d' :2,4 cm, after 1 truck passage – 12 km/h;
* Configuration 2e': 2,8 cm. after 3 truck passages – 3 km/h, 3 truck passages – 12 km/h, 3 truck passages – 25 km/h, after 3 van passages – 15 km/h, 3 van passages – 25 km/h, 3 van passages – 30 km/h.

Figure 40. Configuration2 – Hollow with saturated sand and truck traffic.

For the bump configuration, photogrammetric, seismic and VACC measurements have been carried out while, for the hollow configurations, the thermo-infrared measurements have been added to better see cracks in the roadway.

The progress of the implementation is described as follows:

- Construction of the experimental LC structure;
- Technical validation of the four measurements methods (seismic, thermal-infrared, VACC and photogrammetric) December 2018 and January 2019.

Execution of the tests

As follows, there is the description of the different tested scenarios executed on the real mock-up of a LC:

Bump configurations (1a, 1b, 1c) and hollow configurations (2a', 2b', 2c’ and 2d’):

- Scenario 1: instrumented vehicle crossing the LC (moving at 8,5 km/h) for photogrammetric measure - moving forward and backward
- Scenario 2: loaded truck crossing the LC (speed 1) - moving backward
- Scenario 3: loaded truck crossing the LC (speed 2) - moving backward
- Scenario 4: loaded truck crossing the LC (speed 3) - moving backward
- Scenario 5: instrumented vehicle crossing the LC (VACC)

Complementary scenario only for hollow configurations (2a', 2b', 2c’ and 2d’):

- scenario 6: field HD thermal-infrared camera by pedestrian

Figure 41. Photogrammetric measurements at Cerema Rouen test site.

The progress of the execution is described as follows:

- Seismic, VACC and photogrammetric measures for the bump configuration (February 2019)
- Photogrammetric, seismic, VACC and thermo-infrared measures for the hollow configuration (March 2019)

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3.2.3 Additional warning light system led by VTT

Test site location: Sääksjärvi (Finland)
Pilot test leader: VTT
Involved organizations and their roles:
The responsible organization for the measures is VTT. Its responsibilities include:

- Implementation of the measures
- Execution of the tests

Description of the measure

The piloted measure is an additional warning light system to be situated at front of the locomotive. Train lighting is specified by EU regulation No 1302/2014, which states:

All external lights

- The colour green shall not be used for external light or illumination; this requirement is made to prevent any confusion with fixed signals.

Head lights

- Two white headlamps shall be provided at the front end of the train in order to give visibility for the train driver.
- These head lamps shall be located: − at the same height above the rail level, with their centres between 1 500 and 2 000 mm above the rail level, − symmetrically compared to the centre-line of rails, and with a distance between their centres not less than 1 000 mm.
- Headlamps shall provide 2 luminous intensity levels: 'dimmed headlamp' and 'full-beam headlamp'.

- The installation of headlamps on the unit shall provide a means of alignment adjustment of their optical axis.
- Additional headlamps may be provided (e.g. upper head lamps).

Marker Lights

- Three white marker lamps shall be provided at the front end of the train in order to make the train visible.
- Two lower marker lamps shall be located:
- At the same height above the rail level, with their centres between 1500 and 2000 mm above the rail level.
- Symmetrically compared to the centre-line of rails, and with a distance between their centres not less than 1000 mm.
- The third marker lamp shall be located centrally above the two lower lamps, with a vertical separation between their centres equal to or greater than 600 mm.

Tail Lights

- Two red tail lamps shall be provided at the rear end of the units intended to be operated at the rear end of the train in order to make the train visible.
- The tail lamps shall be located:
    a) At the same height above the rail level, with their centres between 1 500 and 2 000 mm above the rail level
    b) Symmetrically compared to the centre-line of rails, and with a distance between their centres not less than 1 000 mm

According to regulations, there should not been any restrictions to apply extra warning light system.

The principle of the warning system is shown in Figure 42. The warning system activates automatically at a set distance from the level crossing and shuts down when the level crossing has been passed. A level crossing database contains the location of the crossings as well as warning trigger point distances, light intensity limits and used patterns. Thus, every LC can be individually tuned for best performance and minimal disturbance. Additionally, the intensity of the warning light can be automatically adjusted to take account of ambient light conditions.

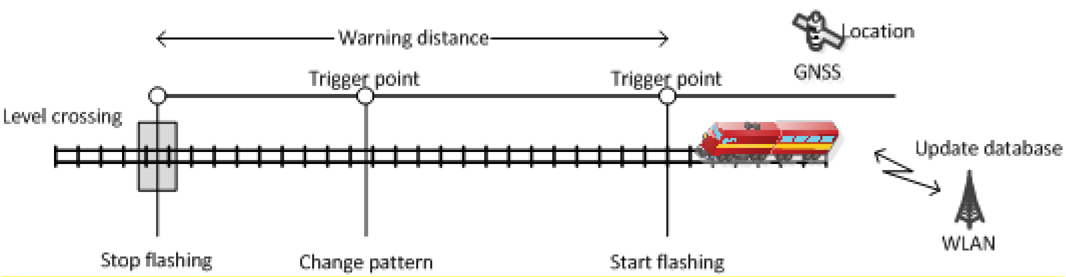

Figure 42. Warning system principle.

Figure 43 shows the block diagram of the hardware required for the warning light. The computer unit is a small-embedded controller, the GNSS unit provides time and location and Wireless Local Area

Network WLAN is used for database updates. Updates can be automated and can be done at either stations or depots, using local wireless LAN access points. Connections to the locomotive are restricted by the availability of a power supply.

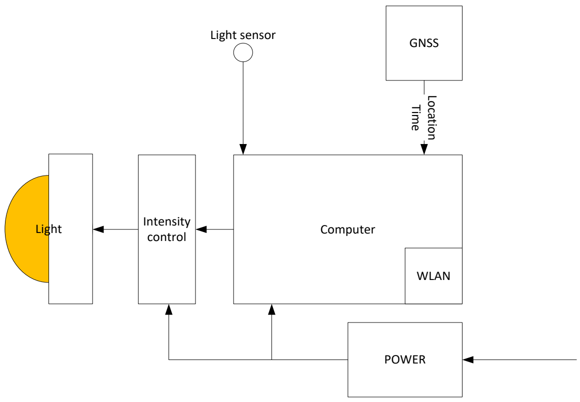

Figure 43. Block diagram of the warning light hardware.

The operation principle is straightforward. One first finds the closest LC from the database. If the direction of travel is towards the LC and distance is shortened, select the LC. Read the trigger point distance. If the distance to the LC is shorter than the trigger distance, activate the light with the associated pattern and intensity.

Implementation of the measure

The lights were installed to the train according to the prevailing regulations (e.g. below the head lights). The aim was to use similar installation as in the simulator study of DLR.
Test equipment is shown in Figure 44. It contains three high intensity LED lights and control unit. LED lights are high beam accessories and accepted to be used in road traffic. Each unit has 10,000 lumen light intensity and beam range is up to 800 meters. Lights can be controlled separately. Intensity is not controllable. In Figure 44 lights are attached to the frame, but they can be easily removed and installed to the front of the locomotive at required distances.

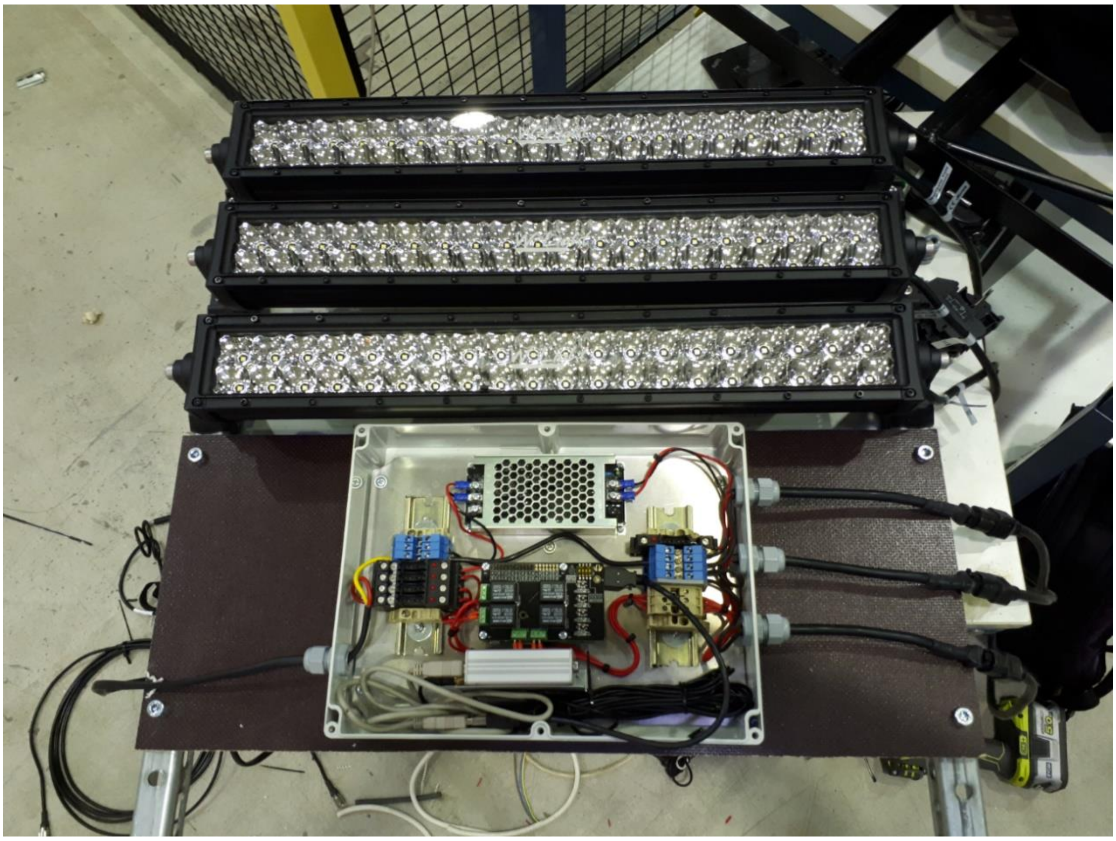

Figure 44. Prototype hardware.

The control box contains EN50150 approved electrical power unit, fuses and embedded computer equipped with GPS receiver. Unit's basic functionality is tested and it can control the lights and produce at least 100 ms light pulses. Enclosure is watertight and withstand the expected environmental conditions. Supply voltage range is large enough to supply voltages between 12−24 volts. The control software is currently under development.
The progress of the implementation is described as follows:

- Powerful LED lights purchased (15.9.2018)
- Relay cards purchased (18.9.2018)
- Microcontroller and enclosure for the test equipment purchased (21.9.2018)
- Prototype hardware installed and operation tested (15.11.2018)

Execution of the tests

The additional warning light system has been tested at real railway environment both from the viewpoint of road user and engine driver. The railway vehicle illustrating the train was not part of the piloting facilities, but it has been rented separately from the company called as Winco Ltd. Winco Ltd took care of the required permits and provided staff to run the tests. The Staff of Winco Ltd has been necessary to supervise the VTT personnel since rail maintenance work requires a special safety certification.
The tests were conducted on 14th March in Sääksjärvi in Finland (61.4552, 23.7435 WGS84). The testing has been done in the main railway network and one of the three tracks has been reserved for the tests. No official level crossing existed at the test site. However, it was a location where the

road user camera could be easily installed (two meters from the track around 1.25 meter height). The location is visualized in Figure 45. The train approached the imaginary level crossing from the bottom of the figure where the direction of the train travel is marked with red arrow. The straight track section before the imaginary level crossing and the camera is around 600 meter long. Figure 46 is taken from the camera location towards the approaching train.

Figure 45. Test location. The train approach from start point towards camera. The train was not visible at the start point for the road user © Google Maps.

Figure 46. A view from the camera location towards approaching train.

The additional lights were installed to the railway vehicle below its rail approved lights as shown in Figure 47. Power for the lights has been taken from a separate car battery. During the tests, the additional lights have been activated manually and GPS activation was not in use.

Figure 47. Warning light installation to the railway vehicle. Control unit has been placed inside the cabin.

Figure 48. Camera and the radar have been installed on tripods.

Road user view was recorded with 4K action camera and, at daytime tests, also radar has been used (Figure 48). Locations of the tripods have been marked with paint. Therefore the camera, in night time tests, has been located exactly in the same spot as in day time tests. Driver view has been recorded with action camera installed to the wind screen of the railway vehicle (see Figure 49).
The rented railway vehicle has been driven through the imaginary level crossings several times both in day time conditions and during darkness. The approach of the railway vehicle to the imaginary level crossing was video recorded both from the angle of the road user (from the road side) and from the angle of the train driver.

Figure 49. A view from the cockpit. An action camera has been installed directly to the wind screen.

The speed of the railway vehicles during the tests were 20 km/h. The visibility of the approaching railway vehicle in each test scenario has been estimated in meters based on radar data. In addition, the possible annoyance of additional warning lights has been estimated both from the road user and engine driver perspective.
Specifically, different scenarios were tested in daytime and nighttime condition:

Daylight (12:00–13:30)
Two runs for each scenario.

- First scenario (reference) with standard lights
- Second scenario (alternative 1) with 1 x 100 ms flash in every 2 second
- Third scenario (alternative 2) with 2 x 100 ms flash in every 2 second
- Fourth scenario (alternative 3) with 3 x 100 ms flash in every 2 second
- Fifth scenario (alternative 4) with 1 + 2 + 3 100 ms flash in every 2 seconds

Night (at 11 pm–1:30 am)
One run for each scenario.
First scenario (reference) with standard lights

- Second scenario (alternative 1) with 1 x 100 ms flash in every 2 second

- Third scenario (alternative 2) with 2 x 100 ms flash in every 2 second
- Fourth scenario (alternative 3) with 3 x 100 ms flash in every 2 second
- Fifth scenario (alternative 4) with 1 + 2 + 3 100 ms flash in every 2 seconds
- Sixth scenario (alternative 5) with dimmed lights 2 x 100 ms flash in every 2 seconds
- Seventh scenario (alternative 6) with 5° tilt upwards 2 x 100 ms flash in every 2 seconds
- Eighth\ scenario (alternative 7) with 10° tilt upwards 2 x 100 ms flash in every 2 seconds

The progress of the execution is described as follows:

- Agreement of pilot details with the train rental company including e.g. selection of LC for the piloting (January 2019)
- Development of light guidance software (January 2019)
- Piloting of the warning light system (April 2019)
- Development of the website for the expert survey to assess the safety effects of different light configurations (May–June 2019)
- Execution of the expert survey (June 2019)

The evaluation of safety effects focussed on the four scenarios (reference case and three different configuration with additional lights during both the day and night time). The other scenarios have been used to assess on the suitability of these different light configurations to railway environment.

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3.3 Real-world pilot activities

The real-world pilot activities have been conducted through various locations and measures and specifically:

- real-world pilot activities led by CERTH-HIT developing an in-vehicle alert system for car drivers;
- real-world pilot activities led by DLR testing two measures at a passive level crossing for pedestrians and cyclists;
- real-world pilot activities led by INTADER testing three measures at different level crossings.

The following table contains specific information concerning the pilot test leader, the measure, the type of implementation, the variables and the quantification of the safety effects. It allows summarizing the general characteristics of the test carried out.

Table 8. General description of the measure and activities conducted in field tests by each Pilot test leader.

Pilot test leader	Measure	Implementation type	Variables	Quantification of safety effects
DLR	Amber blinking light with train pictogram (Electronic sign) (Message written on the road)	The passive LC situated in the north of Braunschweig The chosen option will be applied on the road at a distance of about 20 to 40 m from the crossing tracks.	Stopping in front of LC (y/n, duration), Deceleration in front of LC, Speed in front of LC (for cyclists), Possibility to stop before the tracks (for cyclists), Time spent in danger zone, Time-to-collision (when train coming)	Identification of risky situations Changes in possibilities to stop before LC (based on changes in train detection time and approach speeds)
CERTH-HIT (&DLR)	In- vehicle train and LC proximity alert	Thessaloniki living lab - Testing in real life conditions at 30 LCs	Driving behaviour (speed, ac-/deceleration, visual checking of warning display, visual checking of train at passive LCs, visual focus on the road ahead vs. other, distance to LC at first check for trains, stops, rerouting etc.) Risk indicators (time gap between taxi and train, number of violations) System performance (false and wrong alarms etc.) Number of LC passages per week or per day	Changes in driving speeds when approaching LC (by LC type) Changes in compliance of STOP sign (if it exists before LC) Changes in the number of risky LC passages (by LC type)

INTADER	Flashing moving lights on barriers Coloured pavement markings Attractive sign for children	Real LCs in the field (TCDD network)	Number and type of identified risks and accidents Number and type of violations Number of crossings by different type of road users (including gender, age, time, etc.) and vehicles	Changes in identified near misses and accidents Calculation of possibilities to stop before LC (if information on driving speeds)

3.3.1 Mobile traffic surveillance system by DLR

Test site location: Braunschweig (Germany)
Pilot test leader: DLR
Involved organizations and their roles:
The responsible organization for the measure is DLR. Their responsibilities include:

- Implementation of the measure
- Execution of the test

Description of the measure

The aim was to test a safety measure for VRUs at a public LC in Braunschweig. Three options were initially proposed to the city of Braunschweig and the Option 1, an Amber blinking light with train pictogram next to road, was finally chosen for implementation and testing (see Figure 50). The system detects road user and gets activated.
The measure introduced aims to support the safe behaviour of vulnerable road users at passive level crossings. This is supposed to have a safety effect especially by enhancing the probability that an oncoming train is detected by eliciting an early visual checking behaviour to the left and right region of the level crossing. All measures require a conscious processing of the signal / message content and subsequently a voluntary visual search for a train.

Figure 50. Example of the amber light (option 1). Bike pictogram will be replaced with train.

Implementation of the measure

The passive LC, situated in the north of Braunschweig (see Figure 51, Figure 52), is mainly frequented by cyclists and pedestrians. The road is closed to four-wheelers, but could be used by single-track motorized vehicles such as motorbikes.

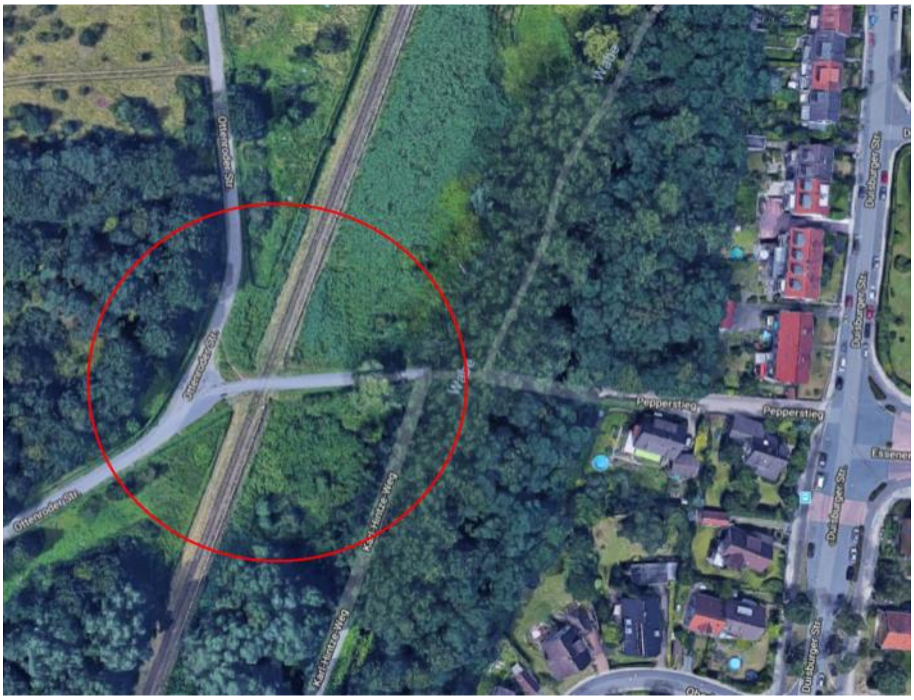

Figure 51. Passive LC at Ottenroder Straße, Braunschweig (aerial view).

Figure 52. Passive LC at Ottenroder Straße, Braunschweig (western approach view).

The chosen option is to be applied on the road at a distance of about 20 to 40 m from the crossing tracks. To examine the effects on road user behavior, the DLR mobile traffic data acquisition (MTD) system will be installed at the LC. The MTD system also provides the technology needed for the automatic detection of VRUs and elicitation of the displays that is needed in options 1 and 2.

The MTD system is part of the DLR test field AIM (Application Platform for Intelligent Mobility). It consists of semi-mobile sensor poles as instruments for detection and assessment of traffic participants' behavior. The installation consists of the pole itself holding a sensor head and different antennas and a weather-proof cabinet, containing the processing computers as well as several electric and electronic devices. Every pole installation is based on a transportable concrete foundation. The field of vision of the associated sensors can be fused to get a better performance and a wider field of detection. The poles have a remote access due to an LTE-connection. Furthermore, the system has a V2X-ability.

Figure 53. MTD sensor poles at a railway station and a level crossing (not identical to test site).

The Progress of the implementation is described as follows:

- Planning and coordination of implementation within DLR groups, negotiations with representatives of the city of Braunschweig, final choice of measure to be tested (12/2018 – 05/2019)
- Preparation of implementation at LC (06/2019)
- Technical implementation at LC (07/2019)

Execution of the tests

The pole is equipped with stereo-camera systems and an active infrared lighting system for artificial scene illumination, in order to be able to sense traffic during day and night time. The sensor data are fused and automatically processed into trajectories of the moving traffic objects detected. The data contain information about the dimensions and classification (e.g. train, pedestrian, cyclist) of the object as well as its location, velocity and other dynamic state variables. The trajectories are tracked with a rate of 25Hz and automatically stored in a database. Optionally, and in accordance with applicable law, the low-resolution scene videos that are the input to the computation of the trajectories can be stored, too. The resulting numerical trajectory data and video data can be used to study the dynamic interactions of different road users with trams and identify behavioral patterns in shared traffic areas that lead to risky situations.

The Progress of the execution is described as follows:

- 4 weeks of baseline data acquisition (08/2019)
- 4 weeks of measure operation and data acquisition (09/2019)

The implementation of the measure and the execution of the pilot test have been delayed due to difficulties in implementing the equipment. Taking this into account and considering the type of measure to be tested (human-centered, low-cost measure), the implementation and execution will be reported in D2.4.

References

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3.3.2 Thessaloniki living lab

Test site location: Thessaloniki (Greece)
Pilot test leader: CERTH-HIT
Involved organizations and their roles:
The main responsible organization for the measure is CERTH-HIT. Its responsibilities include:

- the design and development of the whole system and infrastructure
- the pilot implementation and technical validation
- the pilot and measure assessment

The other three participating organizations are the Greek train operator TRAINOSE, the taxi association TaxiWay[3] and the DLR Institute of Transport Systems. The first two organizations contribute to the pilot by providing real-time access to GNSS pulses from their operating fleet, trains and taxis accordingly. DLR has collected data on the taxi drivers' responses to the warnings to evaluate the measure from a human-factors perspective by installing cameras in three vehicles.

Description of the measure

The piloted measure called as 'In-vehicle train and LC proximity alert' belongs in the general categories of 'Warning devices' and 'Improvement of the detection of approaching train' and can be characterized as a 'Technical, high-tech' solution, following the definitions in D2.2. It introduces a mobile application developed to enhance road user safety around level crossings. The app can be installed on any common mobile device like a smartphone or tablet, and it warns users about the presence of a LC through a pop-up window and a short audio alert, whenever they approach a LC. The warning also includes an estimated time of arrival whenever an incoming train is expected to reach the LC within one minute [Figure 54].

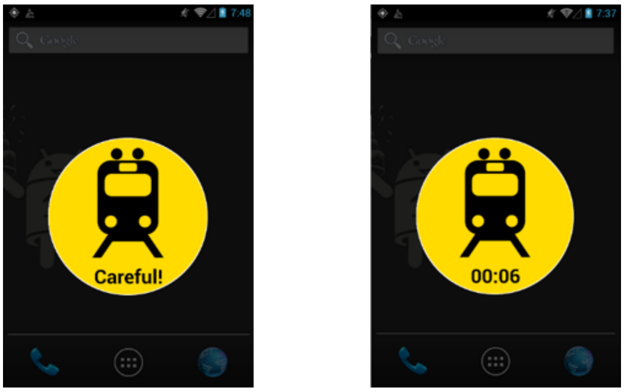

Figure 54. In car warning when no train is approaching (left) and when the train is estimated to reach the LC in 6 seconds (right).

The measure has been tested by a fleet of taxis that uses tablets for navigation and dispatching. The app was available for the whole fleet of the taxi association, in total more than 1000 vehicles.
The alert system is developed for all types of level crossing (e.g. passive, active with light signals, active with barriers and light signals). In fact, its application is feasible independent of LC and train type or state of other variables and circumstances (e.g. weather conditions), as the only requirement of the system is a predefined polygon (area) of interest around the monitored LC, in which road users should receive the warnings. The polygon areas were manually defined in a case by case approach, due to the different nature and topology of each LC and nearby road network [Figure 55]. The road segments inside each polygon are short and close to the LC, as a result it is considered appropriate that all vehicles entering a polygon should receive the warning.

[3] TaxiWay is not a project partner but is supporting the project partners in testing the service by deploying it to the associated drivers.

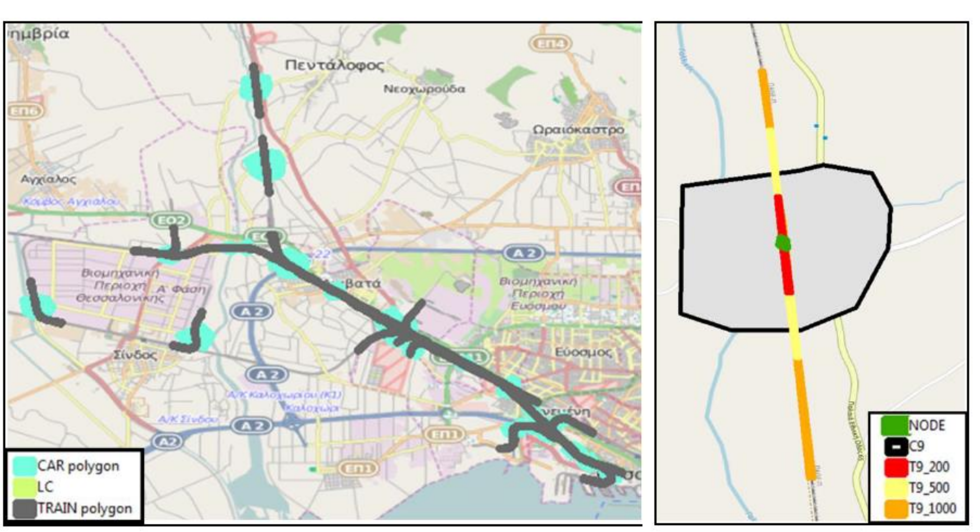

Figure 55. Polygons of the alert system implemented in Thessaloniki.

The system is expected to mainly contribute to increasing safety at passive crossings, which are unprotected, often difficult to spot and thus more dangerous. This in-vehicle warning to the driver is expected to significantly affect safety of car drivers and passengers. A dangerous scenario could occur when a driver does not anticipate a level crossing, for example while driving on a road or region he/she is not particularly familiar with, or when he/she is not properly concentrated on the road and might not notice the warning road signals. The measure is expected to assist in such cases by providing real time information about the existence and status of the level crossing.

In order to develop the arrival time prediction model, CERTH-HIT processed GNSS signals from trains transmitted up to 2000m away from monitored level crossings on available historical data of six months [Figure 56].

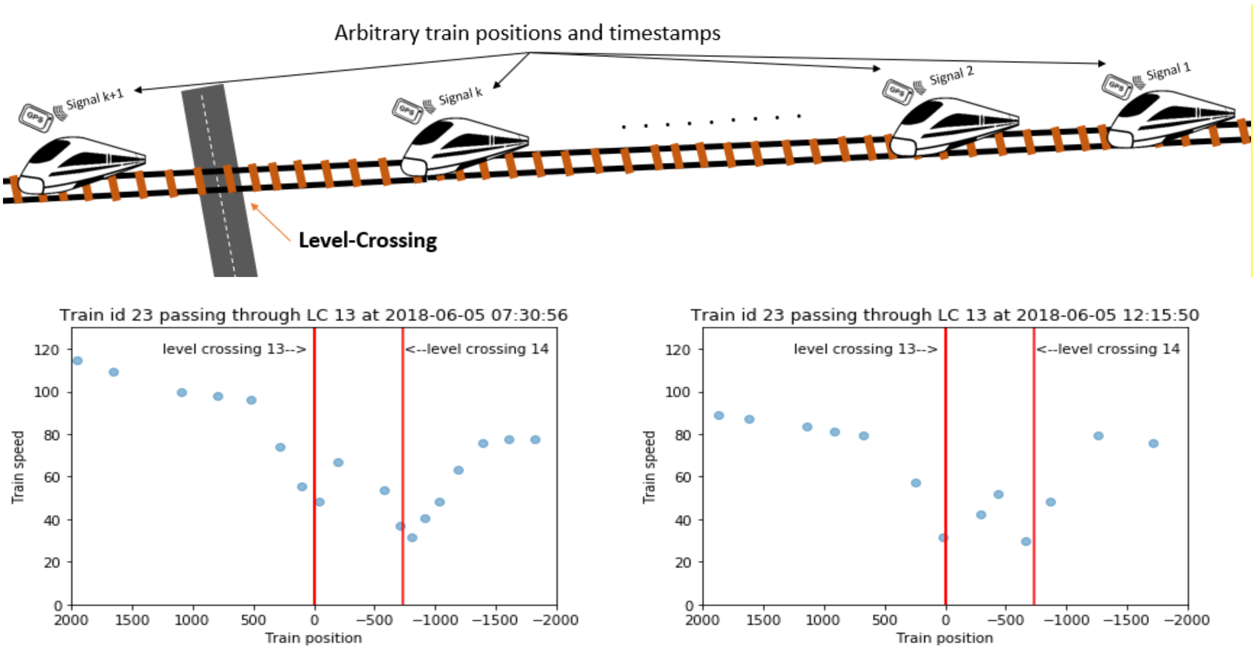

Figure 56. Theoretical and Actual Train GNSS Transmissions around a LC.

SAFER-LC

The model is based on a state-of-the-art Artificial Neural Network, which outperformed the rest of the tested models and achieved a prediction accuracy that is considered highly sufficient for our objective. Another advantage of utilizing such a predictive model is future improvement capabilities. A module that performs periodical online training for the network incorporating recently acquired data has also been developed, as it is expected that data covering longer operating periods enhanced the model and boost accuracy. Furthermore, this algorithm could easily be expanded to include additional, currently unavailable variables and data, namely driver id, train manufacturer and trip type (freight/passenger, intercity/regional etc).
The warning system based on mobile communication detects an approaching train to the LC and sends an alert to nearby taxis about the potential risky situation. The trains were equipped with GNSS enabled devices in order to be monitored in real time, while taxis are already equipped and monitored for dispatching purposes. The warning is provided through a dedicated pop-up window generated by the dispatching and navigation application already used by the taxis. The drivers that participate in the program have undergone training sessions to ensure that they should never fully entrust the system about the dangers and proximity of trains and that they are responsible for taking all necessary safety precautions when driving close to level crossings. On a technical level, GNSS transmitters and the pop-up alert work automatically, and thus no further training is required for the application users.

The major hardware elements of the warning system for level crossings are the following:

- Location tracking devices: The taxis are equipped with smart devices (tablets) connected to the dispatching center of TaxiWay. Those devices serve as vehicle geolocation sensors during the pilot tests. Some trains are equipped with GNSS devices and are monitored by TRAINOSE, which will equip more trains with location tracking devices in the framework of the SAFER-LC project.
- Alert system / human-machine interface (HMI) device: CERTH developed the custom, pop-up-based application and integrated it to the taxi navigation and dispatching software, which runs on the tablet device.
- DLR naturalistic driving study (NDS) platform: it was installed in three taxis in order to collect data for analyzing the drivers' reaction to the safety service in the context of the approach to level crossings. The NDS platform consists of a set of four miniature cameras. It monitors the environment as well as the driver's behavior and facial expressions. In addition to the cameras, a GPS sensor is implemented in the NDS system to derive driving parameters such as speed, acceleration and position of the taxis. Cameras and GPS are connected via cables to a data storage box that stores all data on SD cards. The GPS position in the combined data file can be used to extract exactly the data sequences that are recorded during the passage of the level crossing. The number of different drivers who participated is expected to be 6, however the actual number needs to be determined in the video analysis; as it is uncertain how many drivers work with each vehicle, and who of them would activate the recording system.

The LC detection system runs on each vehicle's smart device (tablet), provided that the driver has expressed his consent to participate in the tests. It compares the device's location to the set of pre-defined polygons around LCs. Whenever a match occurs, the visual and audio warnings are triggered, and a request is posted to CERTH servers regarding train proximity. If a train is within a two-kilometre distance to the LC, the server responds with the estimated time of arrival (ETA). If the ETA is 60 seconds or less, the static visual warning turns dynamic and includes a countdown to the ETA [Figure 57].

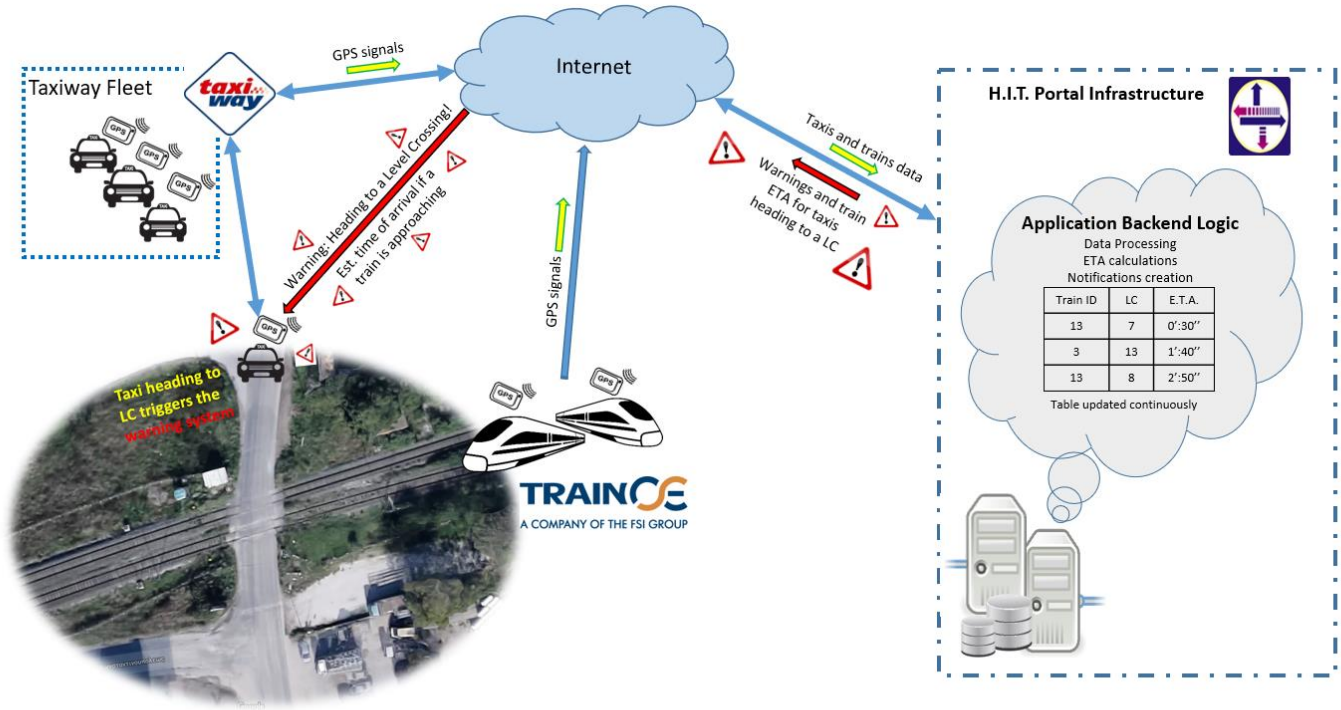

Figure 57. System Architecture.

It is important to highlight that the dynamic alert mechanism relies on availability/quality of internet connectivity for both the trains and the taxis. The alert system incorporates failsafe mechanisms to encounter technical issues when connection to the server is lost, caused by the server being offline or no internet availability. In such cases the application still detects the entrance of the vehicle inside a LC polygon, as the map-matching and location checking algorithms run on the mobile device and thus require no communication with the server. As a result, the static pop-up window has been displayed through the application's notification system every time a taxi enters a polygon. In this scenario, no countdown clock has been displayed, as the train monitoring and estimated time of train arrival calculations run on the server and results are transmitted via internet connection.

Implementation of the measure

Thessaloniki, the second largest city of Greece, is an ideal implementation site for the proposed measure due to the railway infrastructure and frequency of train routes. It is one of the most important railway hubs in the Hellenic region with a complicated railway network that connects the main railway passenger station, freight centers, depot sites and train factories. In addition, according to the General Secretariat, the total number of vehicles in the city exceeds 777,544, including private cars, heavy vehicles and motorcycles. The system is currently tested at 29 level crossings in Thessaloniki [Figure 58] and the surrounding region.

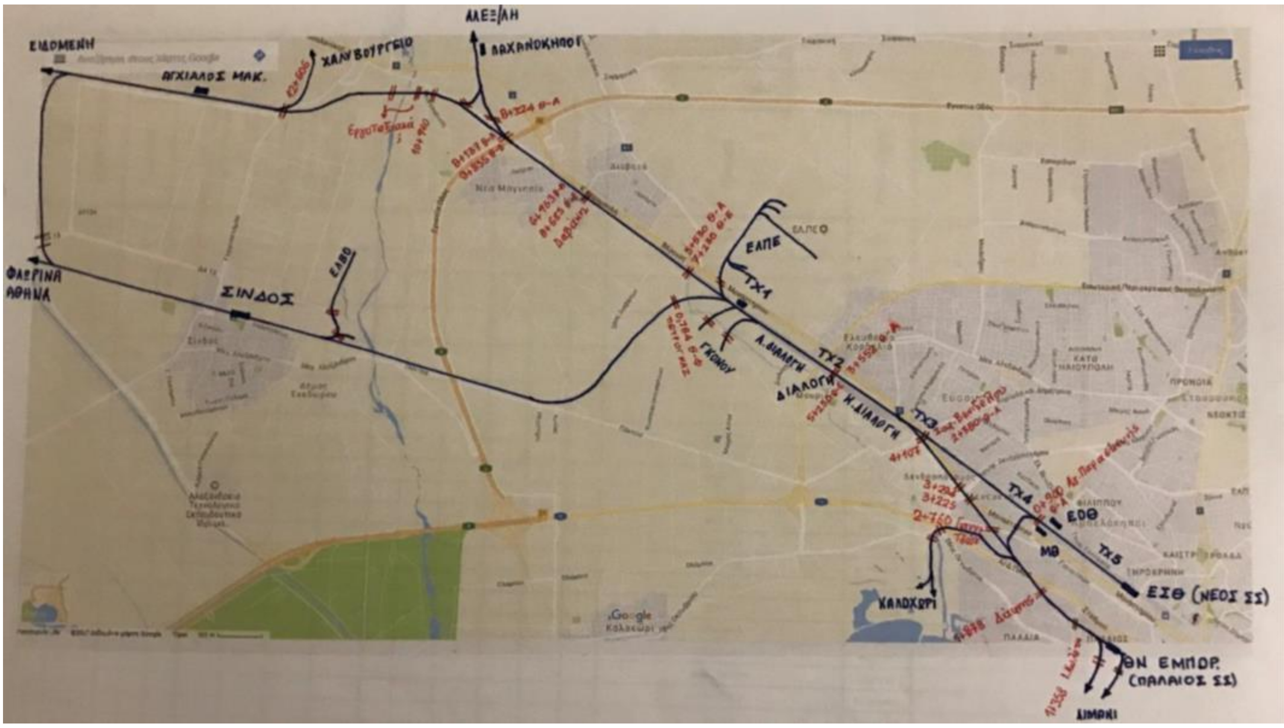

Figure 58. Railway Network and Level crossings in Thessaloniki and surrounding area.

Several TRAINOSE operating trains are being tracked by CERTH-HIT [Figure 59]. Specifically, tracking devices had been installed in SIEMENS DESIRO locomotives, operating the suburban railway of Thessaloniki. These devices have been connected to the main battery of the train and worked with 12V voltage. Moreover, a specification of EN50155 was used to be compatible with the main rolling stock. CERTH-HIT received and stored more than six months of train kinematics data from these locomotives, until June 2018, when TRAINOSE changed to a new IT service provider and the data transmission was temporarily offline. The service went online in January 2019, monitoring some of the regional and freight trains operating in the Thessaloniki region. These are ADTRANZ, SIEMENS 120 and MLW500 locomotives. TRAINOSE is gradually installing more tracking devices to track a larger part of its fleet.

Figure 59. TRAINOSE's Adtranz, Siemens 120 and Siemens Desiro Locomotives Equipped with GNSS Tracking Devices.

The trains equipped with GNSS sensors operate on the main and busiest railway which connects Thessaloniki to the capital city of Athens. In the suburbs of the city, three active and protected level-crossings lie on this railway [Figure 60] and the test vehicles circulating around them will receive both the static and dynamic warning pop-ups, depending on train proximity. The geolocation of trains travelling through the rest 26 LCs is not monitored, consequently the test vehicles only receive the static pop-up message around them.

Figure 60. Two of the three level crossings studied, fitted with appropriate road signals, protective barriers, warning alarms and flashing lights. Photos from Google Street View.

The progress of the implementation of the in-car alert system is described as follows:

- Development of back office (March– June 2018)
- Development of driver app (July 2018)
- Technical validation (Sep.–Oct. 2018)
- Finalization of back-office and driver app (November 2018)

Execution of the tests

After the mobile application has been finalized by CERTH-HIT in November 2018, it was gradually downloaded and tested in an increasing number of taxis. The application was not offered to the whole fleet at once, in order to first evaluate its performance on 32 vehicles, including the three vehicles equipped with the naturalistic driving study platform from DLR. The initial software version was also tested by 6 vehicles owned by CERTH-HIT, fitted with tablets or smartphones.
The first two weeks were regarded a trial period, during which the system's performance and drivers' opinion was monitored and evaluated. The evaluation of the app on the 32 vehicles was successful, and drivers did not report any negative feedback or complaints, except for some rare application crashes which occurred to specific devices which had not been updated to the latest application version. Minor refinements were implemented to refine the application operation and the app was offered to the whole taxi fleet after December.
The actual number of participating test vehicles and drivers was not fixed because drivers' participation to the tests was voluntarily. Drivers were also granted the right to withdraw their participation at any time, simply by uninstalling the mobile application. Moreover, according to the

taxi association, some taxis use rather basic tablets with low-end hardware (e.g. 1GB RAM) which struggle to cope with the already existing dispatching and navigation application. Those vehicles were expected to not install the application and therefore not participate in the tests. At the end of the first pilot testing phase (April 2019) the LC safety system was installed and operating in 534 unique mobile devices. Each device is planted on a vehicle which in most cases is driven by more than one driver. As a result, several hundreds of professional drivers were exposed to the 'In-vehicle train and LC proximity alert' system.

The progress of the execution of the in-car alert system is described as follows:

- First pilot period (Dec. 2018–March 2019)
- First pilot period draft assessment (Apr 2019)
- Second pilot period (May 2019–July 2019)
- Second pilot period end-final assessment (August-September 2019)

Video and GNSS data have been recorded with the NDS measurement system in three taxis, during November, December 2018 and January 2019. Four miniature cameras recorded the drivers' behavior and facial expressions and the surrounding traffic. Video data from taxis have been acquired and analyzed with the explicit consent of the taxi drivers. No passengers have been recorded. The resolution of video images is high enough to recognize different types of road users and their dynamics, but sufficiently low to warrant data protection for surrounding road users as details (i.e. faces, number plates) cannot be recognized.

The progress of the execution of the DLR Naturalistic Driving Study is described as follows:

- Installation and calibration of DLR equipment on 3 vehicles (October 2018)
- Baseline data collection period (alert application inactive) (November 2018)
- Data collection period/alert application active (December 2018)
- Finalization of data collection and DLR equipment removal (January 2019)

References

The test site has been and is being used in various projects and studies:

- EOX (http://www.mobithess.gr/): provision of info-mobility services
- COMPASS4D (http://www.compass4d.eu/): testing of cooperative services for passenger transport
- COGISTICS (http://cogistics.eu/): testing of cooperative services for freight transport
- C-mobile (http://c-mobile-project.eu/): provision of advanced cooperative services for passenger transport
- Big Data Europe (https://www.big-data-europe.eu/): use of big data tools for the provision of traffic status prediction

A list with publications on scientific journals from the above projects is provided below:

- E. Mitsakis, I. Stamos, J.M. Salanova Grau, E. Chrysohoou, G. Aifadopoulou (2013) Urban Mobility Indicators for Thessaloniki, Journal of Traffic and Logistics Engineering (JTLE) (ISSN: 2301-3680), Vol. 1 No. 2, June 2013. pp. 148 – 152. [DOI:10.12720/jtle.1.2.148-152]

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3.3.3 Real LCs in the field in Turkey

Test site location: Karabük (Turkey)
Pilot test leader: INTADER
Involved organizations and their roles:
The main responsible organization for the measures is INTADER. Its responsibilities include:

- Definition and implementation of the measures
- Analysis of the video camera records

The other participant is TCDD for the collaboration in the implementation process of the measures and for providing the video camera system at level crossings.

Description of the measure

Three measures have been tested in 5 real-world LCs in Turkey. All of those measures have the goal to support the safe behaviour of traffic participants at level crossings. They are supposed to have a safety effect especially on the conspicuity and detectability of the LCs. Since many road traffic users tend not to check the environment of a level crossing for an approaching train, the following measures have been evaluated:

- Attractive Sign for Children
- Coloured Pavement Markings
- Flashing Lights on the Barriers

The first measure planned is Attractive Sign for Children. An explanatory sign at an appropriate height will be implemented at an LC which is in city and used mostly by pedestrians and especially school children. The chosen LC is an active LC with full barriers. There exist light and sound warning. This measure is thought to be effective on pedestrians and especially on children. The sign (installed at appropriate height) is aiming to increase the awareness of children about the LC as conspicuity and detectability is thought to increase. This should increase LC awareness for children and encourage the correct behaviour so children cross the LC more safely. At the end of the study, the effect of this measure on children behaviour will be seen. On the other hand, awareness of children is thought to increase their parents attention and awareness about the LC. So, the increase of detectability is analysed for both children and other types of pedestrians.

The second measure planned is Flashing Lights on the Barriers. An example can be seen in the Figure 61 below. The lights will be on and flashing when the LC is closed and the flashing lights are thought to increase the awareness and carefulness of vehicle drivers. Figure 61 is not from Turkey, it is used only to illustrate the measure.

This measure is planned to be applied in two different types of active level crossings. One is a manual LC (the LC is opened and closed by a guard). There is no light or sound warning around the LC. The other one is an active LC with full barriers. There is light and sound warning. Both LCs have high vehicle traffic. The selected measure is thought to be effective on vehicle drivers and thus LCs having high vehicle traffic have been chosen for the pilot tests.

The objective of this measure is to increase the detectability of the LC and to avoid the accidents caused by the vehicle driver who don't see the LC or see it too late. The improved detectability of LC enables vehicle drivers to observe the LC and to decrease his/her speed while approaching the LC, if needed.

Figure 61. Flashing Lights and Barriers example.

The third measure planned is Coloured Pavement Markings, an example can be seen in the picture below (Figure 62). The photo below is not from Turkey it is used only to be able to illustrate the measure to be piloted.

This measure is planned to be applied in two level crossings. These level crossings will be active LCs with full barriers. Both of them have light and sound warning. Both LCs have high vehicle traffic. The roads are paved so that can be easier to colour. The selected measure is thought to be effective on especially vehicle drivers (Motorised Road Users) so such LCs having high vehicle traffic have been chosen for pilot measurements. The measure is thought to increase the detectability of the LC and the carefulness of the drivers so that they can become aware of the LC, slow down and stop at safe distance when the LC is closed.

The effect of this measure can be seen by analysing captured videos. The surveillance cameras are already established by TCDD and they are in operation. The video system enables gathering huge amount of the data from the level crossings and increase the efficiency to identify the risks and accidents happened in that location. The data is planned to be analysed monthly.

Figure 62. Coloured Pavement Markings example.

Implementation of the measures and Execution of the tests

The following photos represent the implementation sites for each piloted measure verifying the compliance with the existing regulations and international standards.

Figure 63. Implementation site for Attractive Sign for Children.

Figure 64. Implementation site for Attractive Sign for Children (aerial view).

Figure 65. Implementation site 1 Coloured Pavement Markings.

Figure 66. Implementation site 2 Coloured Pavement Markings.

Figure 67. Implementation site 1 Flashing Lights on the Barriers.

Figure 68. Implementation site 2 Flashing Lights on the Barriers.

This pilot test sites (LCs) are currently used in TCDD network. Video camera systems have been established on the site. The video system enables gathering huge amount of the data from the LCs and will increase the efficiency to identify the risks and accidents happened in that location. There seems no opportunity to use video analytics so most probably the video camera recordings will be watched by the staff of INTADER and related forms will be filled in. Then analysis will be done according to the forms. The video camera data is gathered by TCDD.

For the Attractive Sign for Children measure the data below will be collected by analysing the video camera records for both before and after cases.

- The total number of pedestrians using the LC
- Number of children
- Number of violations
- Ratio of violations
- Estimated age groups of children

For the Colored Pavement Marking measure the data below will be collected by analysing the video camera records for both before and after cases.

- The total number of vehicles using the LC
- Number of different types of vehicles (bus, car, agricultural etc.)
- Number of violations
- Type of violations
- Ratio of violations
- Type of vehicle making the violation

For the Flashing Lights on Barriers measure the data below will be collected by analysing the video camera records for both before and after cases.

- The total vehicle number use the LC
- Number of different types of vehicles (bus, car,agricultural etc.)
- Number of violations
- Ratio of violations
- Type of vehicle making the violation

For all the measures, the data is planned to be analysed monthly. It is planned to analyse data collected in 2 months (1 month for before case and 1 month for after case).

The implementation of the measures and the execution of the pilot tests will be delayed until M30 depending on difficulties in implementing the equipment. Taking into account this delay and considering the type of measures to be tested (human-centred low-cost measure) the implementation and execution will be reported in D2.4.

4. OBSERVATIONS/LESSONS LEARNED

This chapter describes the observations reported in the Progress Report from various partners of the project about the experiences and the lessons that have been learnt regarding the implementation and the execution of pilot tests involving safety at level crossings. Specifically, the observations highlight elements that have facilitated the successful implementation of testing safety measures and those issues that act as barriers to execute these tests. Some partners provided a response to this question with some clear themes emerging, in some cases related to the typology of tests and, in other cases, related to the activity carried out (implementation or execution).

As follows a more detailed analysis of these observations is carried out by grouping comments for typology of tests: a) simulation tools; b) prototype systems running in close-to-reality situations under controlled environments, especially for cases too dangerous or complex to test; c) real-world pilot conditions.

Taking into consideration the simulation activities, the main factor that have been identified as barrier to develop these tests is related to the long time and the very hard effort necessary for the development of effective and realistic driving scenarios. As effectively described from DLR about their experience, the programming of the driving environment took longer time than planned one. The objective to have a prefinal version ready for pretesting could not be reached by the end of January and needed to be postponed to the end of March. The delay was caused by the additional need of time to finalize the countermeasures programming, especially the train with blinking lights, and the complex and long route needed for the study. Similar consideration can be extended also to the SNCF driving simulator that have required a long time for the implementation phase (from July 2018 to March 2019).
The execution, differently from the previous phase of implementation, can be considered without very critical issues according to the information at disposal. As happened in many others simulation studies, the critical factor is dependent on the presence of some cases with restricted data quality due to simulation sickness (only part of the simulation driven, n = 1), problems with gaze detection (n=2) or calibration quality (n = 1) in eye-tracking, or lack of compliance with instructions (n = 1). The limited number of data to discard permits to solve these problems by collecting data from other additional participants. An interesting observation can be done about the attempt made to avoid behavioural bias by using a so-called cover story without telling the real objective of tests. The proportions of 40 participants who realized “something” remained quite stable during all tests carried out. The conclusion is that the cover story worked fine and is a suitable means of increasing the validity of the data collected. Concerning the oral feedback from the participants: After being debriefed of the real purpose, no participant expressed feeling bad about not having been informed on the actual focus of the later analyses, but instead, participants expressed a consensus that it is sensible to design a test session like this to avoid behavioural bias.
Before the debriefing, participants were asked in an open question to shortly sum up what they thought the study was about. After the debriefing, they were asked to indicate at what LC encounter, if applicable, they had assumed that the study could be about LCs. 30 of the 40 participants indicated they had not assumed this before the debriefing. 10 participants reported having had a hunch of this sort by the 2nd, 3rd, 4th, and 5th LC, encountered in the simulation, respectively. However, only 4

of these 10 participants expressed the idea of a LC focus already in the open item that was asked before the debriefing. Thus, it is possible to observe that the cover story proved reasonably plausible for the majority of participants to distract them from the LC focus and thus to prevent a bias of behaviour at LCs.

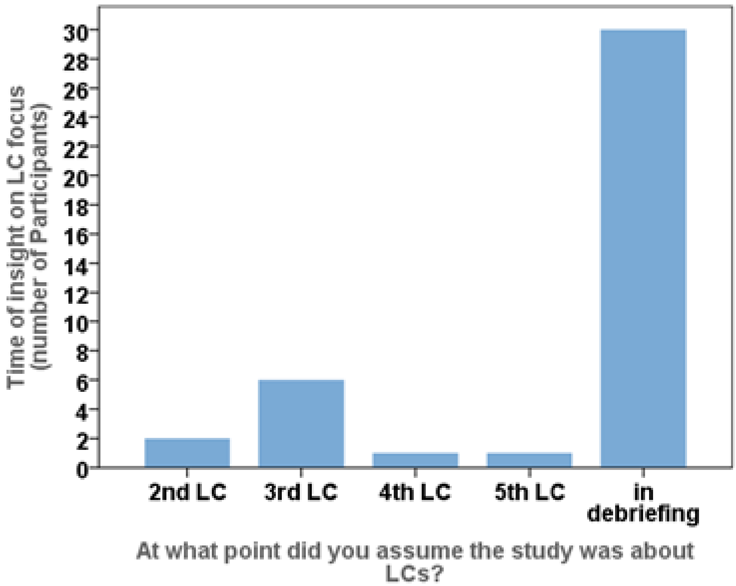

Figure 69. Number of participants who expressed having had an idea about the LC focus of the study at a given point in time.

Less difficulties are observed for the close-to-reality testing under controlled environments according to the information at disposal. Taking into account the availability in all cases of a test track, the main issues are related with technical and/or operational aspects but they have been solved easier than in the real-world field test. In fact, the control of the test sites permits to identify and carry out actions for solving the problems without specific constraints.

About the real-world pilot tests, it is important to underline that the observations at disposal are mainly related to the living-lab in Thessaloniki. The other two pilot tests in Braunschweig and in Turkey record some delays due in both cases to the need of obtaining the permits of testing from the infrastructure managers (local administration in Braunschweig and TCDD in Turkey) and complying with the operational constraints, typical of many real-world test activities.

Overall, in Thessaloniki, no significant problems have been encountered during the design and the implementation of the measure and during the data collection. However, the prolonged period of train data unavailability posed certain difficulties in testing of systems and limits the potential of this study. With the number of GNSS monitored trains being a lot less than expected, there are only a few vehicle trajectories through LCs for which a train has been detected close and thus the dynamic alert has been posted.

A minor, unexpected issue regarding the measure evaluation data is the taxis that stop inside two polygons close to a taxi stand, waiting in the queue. An algorithm that differentiates such cases to

the ones when a train is actually causing vehicles to stop is being developed and will filter out those FCD from further analysis and measure assessment KPIs.
According to discussions with the taxi association, there are no negative comments from the drivers about the operation of the app except for certain cases where alerts where alerts were received by vehicles moving in an overpass in close proximity to a LC polygon.. Raw data confirmed such events, which occurred when the vehicle geo-position sensing was slightly inaccurate and indicated that the vehicle entered the neighbouring polygon. CERTH has revised the boundaries of all polygons to avoid those false alarms.
In an attempt to further refine the alert system, feedback by the taxi drivers testing it was also collected via questionnaires. In the questionnaire handed to drivers in April, after the first pilot period, certain questions aimed at revealing potential flows of the app and alert system. The drivers were encouraged to propose their ideas on how the existing system could be improved and to comment on their experience with it. The response of drivers is overall considered positive, as the majority of them assessed the system and the issued warnings as appropriate. Remarkably, three out of four drivers denote interested in using the system after the completion of tests.

The pilot testing is implemented in real life conditions and in large scale, with more than 500 vehicles using and testing the system concurrently and continuously. There have been no issues relevant to the scale of implementation. Specifically, the development of the back-office and the driver app has been completed successfully without deviations from the plan and timetable. However, the technical validation that would provide feedback to verify and finalize the back-office operations has not been completed according to schedule, due to technical limitations. The train GNSS service went offline since June 2018 to January 2019, as the train operator changed its I.T. services provider. This unexpected technical issue rendered testing in real-world conditions impossible during August 2018, according to schedule, because the system requires real time GNSS pulses from operating trains for technical validation. However, CERTH conducted pseudo-real conditions tests using past train GNSS data to ensure the highest possible level of readiness of the systems at the laboratory.
The GNSS transmission system has been partly online since mid-January 2019. The new I.T. services provider implemented a brand-new train monitoring system, and CERTH developed the software and mechanisms to connect to the newly developed infrastructure. Data from the suburban line trains (which generated the historical dataset) are no longer available, but according to TRAINOSE GNSS sensors are gradually being installed on Intercity locomotives. However, as of March 2019, few trains are connected to the monitoring system and only 1 or 2 monitored train itineraries are completed daily, resulting in a very few cases of dynamic alerts to app users.
With regards to the data collection, part of the trajectories are not recorded when entering and leaving the polygons due to various reasons which are being investigated (abrupt stop of the application, low internet connectivity, inadequate coverage of GNSS signal…).

In general, it is possible to observe that the compliance with the existing regulations and international standards is solved without any specific criticalities. There are no relevant regulations/international standards to be applied (to the best of our knowledge) with the exception of the GDPR for the living–lab in Thessaloniki. In order to ensure full compliance to the GDPR, all users are provided with an informed consent before starting the mobile application for the first time. Briefly, this consent clearly explains all users' rights, including the right to not take part in the pilot tests. Drivers are also given the choice to revoke their consent at any time during the tests and request all their personal data to be permanently deleted and excluded from analysis.

Taking into account the other testing activities, the main issue encountered is related to the additional lights for locomotive that are meant to improve the early detection of a train. There is the need to be in line with the specifications given in EU regulation No 1302/2014. The triangular head light constellation of locomotives is specified in this regulation and shall not be harmed by innovative light designs. Both DLR and VTT comply with EU and national regulations in their pilot tests without damage for the testing.

5. CONCLUSIONS

This deliverable describes the test activities carried out in the Task 4.2 of WP4. Such task concerns the implementation and the execution of the tests built in various level crossing environments in different countries. Simulation tools, prototype systems running in close-to-reality situations under controlled environments and real-world field tests are based on the use cases defined in WP1 and WP2 as well as the technical solutions proposed by WP3. These series of pilot tests across Europe are rolled out to demonstrate how these new technological and non-technological solutions can be integrated, validate their feasibility and evaluate their performance. The challenge is also to demonstrate that the proposed solutions are acceptable by both rail and road users and can be implemented cost-effectively.

The pilot tests executed in the Task 4.2 can be subdivided in three types of pilot activities:

- simulation tools;
- prototype systems running in close-to-reality situations under controlled environments, especially for cases too dangerous or complex to test;
- real-world pilot conditions.

It is possible to underline that three different pilot tests are referring to each of the three types of test activities. Various partners worked together in Aachen, in which the whole chain of detecting, communicating and informing has been tested under real world conditions in a track of the Aachen University. The other partners have tested in each location one or, more often, various measures. Specifically, simulation activities have been led by DLR in Germany, by SNCF in France and by VTT in Finland. Test-track pilot activities and capabilities have been involved various partners in Aachen (Germany), by CEREMA in France and by VTT in Finland. Real world pilot activities have been carried out by DLR in Germany, by CERTH in Greece and by INTADER in Turkey.

All the pilot tests have been successfully implemented and executed at the time of this report with the exception of two pilot tests that has been delayed. The success of the testing is evident for many reasons. First of all, the large number and the very diversified typologies of tests activities carried out permits to explore many promising solutions both of technical nature, such as smart detection services and advanced infrastructure-to-vehicle communication systems and of human-centred typology to adapt infrastructure designs to road user needs. About this point, it is important to underline the effort done for testing a very large number of human-centred low-cost countermeasures (18 of a total number of possible countermeasures identified in D2.3 equal to 89). with a focus on effects on road user behaviour and experience. Moreover, the extension of the time plan from M24 to M26 in most of the sites has allowed for collecting more data so providing more accurate and robust results. Finally, all the forecasted activities have been fully achieved without incidents, leading to a better understanding of situations, circumstances and measures for safer LCs.

6. REFERENCES

- SAFER-LC D1.3 (2018). Needs and requirements for improving level crossing safety. Deliverable 1.3 of SAFER-LC project.
- SAFER-LC D4.1 (2018). Implementation guidelines. Deliverable 4.1 of SAFER-LC project.
- SAFER-LC D2.2 (2018). Human Factor methodological framework and application guide for testing. Deliverable 2.2 of SAFER-LC project.
- SAFER-LC D2.3 (2018). Definition of new human-centred low-cost countermeasures. Deliverable 2.3 of SAFER-LC project.

ANNEX A. PROGRESS REPORT OF THE IMPLEMENTATION OF THE MEASURE

Progress report of the implementation of the measure
<Title of measure>

<Date of the latest version>

Table of contents

Abbreviations

Short name	Name

1. INTRODUCTION

This form is used to report the progress of the implementation and the execution of measures piloted in WP4 of the SAFER-LC project. The measures are meant to reduce level crossing accidents and/or to reduce the consequences of the collisions by minimising the impact of the collision to the road user or by decreasing the shut down time. The aim of performing pilot tests is to collect information for the evaluation of the effectiveness of the safety measures in their capacity to reduce such events, and to describe the implementation and data collection processes.

The information on this form is filled in by the pilot test leader before starting the piloting. After that the progress report is updated every three months (December 2018, March 2019, June 2019 and September 2019) by the pilot test leader in order to monitor the progress of implementation. The information reported on this form will provide the basis of the chapters describing the implementation and execution and data collection concerning this particular measure in Deliverable 4.3 (*Pilot operation report)* and in Deliverable 4.4 (*Results of the evaluation of the pilot tests*) of the SAFER-LC project.

2. PROGRESS REPORT

Country: <Country>
Responsible SAFER-LC organisation : <Organisation>

Description of the measure

- Description of the piloted measure. Include information on relevant details, e.g. pictures and relevant features of measures, type of level crossing (e.g. passive, active with light signals, active with barriers and light signals), expected safety effect (i.e. how the measure is expected to improve the safety of LCs), circumstances under which the measure is expected to be effective
- Objectives of the measure (incl. e.g. target group(s) of people, target incidents or behaviour; include these here if not already described in the previous bullet point).
- Description of the intended effect mechanism (possible effect mechanisms are listed in D2.2): How and why the measure is assumed to have desired effect?
- Previous experiences from similar measures: what, where, when? What were the effects?

<Write here>

Implementation of the measure

- Describe implementation site(s) including the equipment installed, eventual vehicles equipped and LCs involved in testing. Use maps and photos. If possible, include pictures of layouts and/or designs.
- Actual implementation schedule. Use Table 1 when implemented stepwise.
- Organisations and their roles (use Table 2)
- Notes on implementation process (e.g. difficulties encountered, deviations from implementation plans, assessment of overall success of implementation etc.)
- Compliance with the existing regulations and international standards

<Write here>

Table 1. Progress of implementation (add rows if needed).

When	Work done

Table 2. Involved organisations and their roles (main responsible organisation first).

Organisation	Role

Execution of the tests

- Describe test execution at the site(s) (e.g. start and closure of operations, status of sensors and equipment, vehicles and participants involved, etc.).
- Actual test activities schedule. Use Table 3 when implemented stepwise.
- Notes on execution process (e.g. difficulties encountered, deviations from activities plans, assessment of overall success of execution etc.)

<Write here>

Table 3. Progress of execution (add rows if needed).

When	Activity done

Evaluation data

- What are the safety effects to be evaluated (e.g. frequency of risky behaviours, frequency of near accidents, attitudes etc.)? If possible, refer to the KPIs listed in D4.2 and/ or examples of indicators listed in D2.2.
- Other evaluated effects (e.g. impact on railway operations or environment, acceptance) if any?
- Planned evaluation method(s), e.g. before-after study with control data.
- Data collection plan and actual data collection: variables and schedule. Reasons for deviations from the plan. In case of surveys and interviews, enclose relevant forms. Include also control data if collected (see Table 4).
- Provide table(s) summarising collected data that will be used in the evaluation of effects (see Table 5). As part of the evaluation be prepared for documenting the (expected and observed) changes in road user behaviour due to the introduction of the safety measure at the control and pilot test site both in the short and long-term.
- Include data on costs of the test implementations (see Table 6). Include at least the cost of the safety measure (i.e. the equipment), and its installation, operation and maintenance costs, but also other costs (e.g. planning) when relevant. In case the piloting concerns a prototype or a safety measure that is not yet on the market, try to

estimate the cost related to a possible future version(s) of the measure (including the operation, maintenance and other relevant costs).

<Write here>

Table 4. Description of data collection process (if necessary, modify to fit the case).

Data collection period		What (name variables), where, how, target quantity of data
Planned	Actual	

Table 5. Summary of collected evaluation data (if necessary, modify to fit the case). If possible, in 'Variables' column refers to the KPIs listed in D4.2 and/ or examples of indicators listed in D2.2.

Variable	Period	Results			
		Pilot test site		Control site (if available)	
		Short-term	Long-term[1]	Short-term	Long-term[1]
	Before				
	After				
	Before				
	After				
	Before				
	After				

[1]Long-term effects are probably only valid for 'After' -measurements

Table 6. Costs of the measure.

Cost component	Cost (€)	Source or explanation	Paying organisation

Lessons learned

Observations and suggestions for future improvements concerning the design of the measure and the implementation and data collection processes. Consider e.g.

- Encountered problems and solutions.
- Suggestions for improvements in the design or implementation of the measure: What should be done differently and why? Consider e.g. effectiveness and costs.

- Impressions on factors affecting the effectiveness of the measure: Circumstances where it probably works best; where or when it probably should not be used and why? Consider e.g. specific types of level crossing protection (passive / active)
- Ease of integration within the road and rail environment and the ease to implement and use the safety measure with other safety measures.
- Scale of implementation. Would this measure work better/worse if used more extensively (covering both short- and long-term effects)?

<Write here>

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3. CONCLUSION

4. REFERENCES

- List

5. APPENDICES

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