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Deliverable D4.4

Results of the evaluation of the pilot tests

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Authors:
Anne Silla, Ari Virtanen & Esko Lehtonen, VTT
Neofytos Boufidis & Josep Maria Salanova Grau, CERTH-HIT
Annika Dressler & Jan Grippenkoven, DLR
Virginie Taillandier, SNCF
Louahdi Khoudour, Chafik Bakey, Jean-paul Garrigos, Christian Françoise, Delphine Jacqueline, Raphael Antoine, Cerema
Fouzia Boukour, IFSTTAR
András Edelmayer, Commsignia
Clément Ruffin, NeoGLS
Ted Zotos, IRU Projects

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Consortium - List of partners

Partner No	Short name	Name	Country
1	UIC	International Union of Railways	France
2	VTT	Teknologian tutkimuskeskus VTT Oy	Finland
3	NTNU	Norwegian University of Science and Technology	Norway
4	IFSTTAR	French institute of science and technology for transport, development and networks	France
5	FFE	Fundación Ferrocarriles Españoles	Spain
6	CERTH-HIT	Centre for Research and Technology Hellas - Hellenic Institute of Transport	Greece
7	TRAINOSE	Trainose Transport – Passenger and Freight Transportation Services SA	Greece
8	INTADER	Intermodal Transportation and Logistics Research Association	Turkey
9	CEREMA	Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning	France
10	GLS	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 deliverable collects the main results obtained from evaluations of the piloted safety measures selected in earlier phases of the SAFER-LC project. This deliverable reports the descriptions of the piloted measures, method and data to evaluate the safety effects of the selected measures, as well as the results of evaluations together with their discussion. More detailed information about the implementation of the measures and execution of pilots can be found from deliverable D4.3 of the SAFER-LC project (Carrese et al., 2019). In some cases, deliverable D4.3 also reports details on the development of the measure.

The main inputs for this deliverable from other SAFER-LC activities originate from Work Package 2 (WP2), Work Package 3 (WP3) and earlier tasks of WP4. The earlier deliverables of WP4 produced implementation guidelines for the pilots (D4.1; SAFER-LC Consortium, 2018a) by providing an overview of the major testing environments that were available for piloting in the SAFER-LC project. The available pilot test environments ranged from simulation environments to real (or close to real) traffic circumstances. Deliverable D4.2 (SAFER-LC Consortium, 2018b) describes the proposed evaluation framework including a list of parameters from which the partners could select the most appropriate ones for the evaluation of their pilot. The identified Key Performance Indicators (KPIs) were arranged into five categories: ‘Safety’, ‘Traffic’, ‘Human behaviour’, ‘Technical’, and ‘Business’. Finally, the deliverable D4.3 (Carrese et al., 2019) describes the pilot activities carried out in WP4 by documenting the implementation and execution of pilots in various level crossing environments in different countries.

This deliverable reports the evaluation results of 21 safety measures that were piloted at eight pilot sites during the SAFER-LC project. The number of piloted safety measures varied by pilot site and the pilot test sites varied from simulation studies to controlled conditions and real railway environments. In some cases, the selected measures were not suitable for piloting in a real world experimental context and/or the implementation in real railway environment was not feasible, for example, due to financial resources, timing of our piloting period and/or lack of suitable pilot site(s). Therefore, pilot test sites in the SAFER-LC projects varied from simulation studies to controlled conditions and real railway environments. Some of the measures (‘In-vehicle warnings to driver’, and ‘Additional lights to train front’) were tested in two different environments to collect complementary information on their safety effects via two types of installation.

Due to the nature of the conducted pilots (small-scale pilot tests), it was hardly possible to calculate any quantitative estimates for safety effects of the measures in terms of annual reductions in the number of LC fatalities and/or accidents based on the results of the pilots. However, since numerical estimates of safety effects are needed for cost-benefit calculations (WP5 of the SAFER-LC project), the authors made an attempt to draw these estimates based on the applicability of safety measures to different LC types, road users and behaviours leading to LC accidents based on pre-existing information on the effects of LC safety measures. The authors acknowledge that many uncertainties are related to these estimates. However, the assumptions used in the calculations are clearly documented and hence the estimates can be easily updated if more detailed statistics or more information on safety effects become available. Therefore, a detailed documentation of LC accident data (information on additional variables and details) is highly recommended to enable drawing of these estimates.

Based on the safety potential calculations presented in chapter 5 the piloted measures that were estimated to have the highest safety benefits are:

- Additional lights at the train front, covering measures 'Additional warning light system at front of the locomotive (6.0–12.0%)' and 'Improved train visibility using lights (6.0–30.0%)'. This measure was estimated to have rather high effectiveness (prevention of 15–30% of relevant LC accidents) and target rather large share of LC accidents (19.9−96.3% depending on the approach).
- In-vehicle train and LC proximity warning (4.4–15.0%). It is important to be noted that the effectiveness of this measure depends on the usage of the in-vehicle devices. In practice, the car driver needs to install the application on a smart mobile device, and location tracking should be enabled on this device while driving. Furthermore, the driver needs to allow the application to run seamlessly on the background and also notice the visual or auditory warning in order to perform the required action on time (e.g. stop before the LC). However, these latter requirements are valid for all LC safety measures.
- Speed bumps and flashing posts (2.0–8.0%). This accident reduction estimate concerns the situation where the measure is implemented to passive LCs (where the highest safety effects were expected in Dressler et al. 2018).
- Blinking lights drawing driver attention (*Perilight*) (2.0–8.0%). This measure is targeted to passive LCs.

Some concerns on applicability of piloted safety measures in different railway environments are listed below:

- Written letters on ground and coloured road marking: Any road marking can only be applied on a paved road with an even surface. Thus, the message written on the road does not hold for road environments such as gravel roads, cobblestone, tracks etc. Furthermore, these measures are not perfectly suitable to countries with snow and long winter with darkness.
- Noise-producing pavement and speed bumps: These measures are not well suited to gravel roads. In addition, these measures are not effective in case of snow.
- Blinking amber light with train symbol and blinking lights drawing driver attention (*Perilight*): It is important to note that these measures are targeted to passive LCs and require power. However, in practice many of passive LCs no mains power is available and thus other alternative power sources need to be investigated. The effectiveness of these measures was estimated somewhat lower than active LCs with sound and/or light warning since the warning in these measures is linked to LC approach and not to actual arrival of train.
- In-vehicle train and LC proximity warning: This system may not operate satisfactory for LCs surrounded by roads on which Global Navigation Satellite System (GNSS) reception is poor.

Overall, the safety effect results of the piloted measures are promising. Therefore, it is recommended that some of most promising measures will be tested in larger scale real world experiments with well-planned research designs to obtain more information on their effects (also on long term) on road user behaviour and thus on road safety. This would also support the more exact numerical estimation of safety effects of the piloted measures.

The results of this deliverable will serve as input for WP5 that deals with cost-benefit analyses. The estimates of safety effects of each measure will be used in cost-benefit or cost-effectiveness calculations and the experiences collected during the piloting will support the drawing of final recommendations for the SAFER-LC project.

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1. INTRODUCTION

1.1. Objectives of SAFER-LC project

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

i. Road and rail decision makers to achieve better coherence between both modes,
ii. Effective ways to detect potentially dangerous situations leading to collisions at LCs as early as possible,
iii. Prevention of incidents at level crossings through innovative design and predictive maintenance methods, and
iv. Mitigation of consequences of incidents/disruptions due to accidents or other critical events.

The main output of the SAFER-LC project is a toolbox which will be accessible through a user-friendly interface integrating all the project results and solutions to help both rail and road stakeholders improve safety at level crossings.

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

Within the project, the objective of Work Package 4 (WP4) is to evaluate the positive and negative results of lab tests and field implementations executed within the SAFER-LC project, to draw recommendations and lessons learned from the piloting process, and where feasible, to discuss the results of evaluations for applicability in different circumstances. These impacts cover, for example, safety, 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), and environmental aspects of piloted safety measures.

1.2. Purpose of this deliverable

This deliverable reports the work conducted in Task 4.3 of WP4. This deliverable is a continuation to the previous deliverables produced in WP4. These earlier deliverables concerned:

1. Guidelines for the execution of the pilot tests from data collection and monitoring to the daily interaction with the testing partners (Deliverable D4.1),
2. Description of the evaluation framework to monitor and evaluate the pilot tests (Deliverable D4.2), and
3. Report on the implementation of the pilot tests describing the simulation, controlled and field tests (Deliverable D4.3)

This deliverable D4.4 collects the main results obtained from evaluations of the piloted safety measures selected in earlier phases of the SAFER-LC project. The measures were targeted to prevent LC accidents both at passive and active LCs. According to the EU DIRECTIVE 2016/798 passive LCs are *'without any form of warning system or protection activated when it is unsafe for the user to traverse the crossing'*. In active LCs (which can be either manual or automatic) the '*crossing users are protected from or warned of the approaching train by devices which are activated when it is unsafe for the user to traverse the crossing'*. The protection by the use of physical devices refers to half or full barriers or gates whereas the warning by the use of fixed equipment at LCs refers to visible devices (lights) or audible devices such as bells, horns, klaxons etc.

This deliverable reports the descriptions of the piloted measures, the methods and data used to evaluate the safety effects of the measures and the results of evaluations. At the end of the report, there is a discussion of the obtained results including aspects such as lessons learned during the piloting, a list of recommendations and discussion of evaluation results for applicability in different circumstances. More detailed information about the implementation of the measures and execution of pilots can be found from deliverable D4.3 of the SAFER-LC project (Carrese et al., 2019). In some cases, deliverable D4.3 also reports details on the development of the measure.

At the end of the document, the evaluation results are summarised and some preliminary findings on the numerical safety effects of the piloted measures are provided. These are followed by general conclusions about the piloting process and evaluation results together with some recommendations. The results and recommendations will be used as an input for the applied CBA of the deliverable D5.3 and especially in the valuation of the benefits of each piloted safety measure. At the end, the CBA results will be used to define the expected business output of each safety measure.

1.3. Interactions with other activities within the project

The main inputs for this deliverable from other SAFER-LC activities originate from Work Package 2 (WP2), Work Package 3 (WP3) and earlier tasks of WP4. Specifically, WP2 produced a list of new human-centred low-cost countermeasures to improve the safety of LCs (Dressler et al., 2018). This list of safety measures was used by the partners when selecting the measures for piloting in WP4 of the SAFER-LC project. Furthermore, during WP3, some of the selected technical solutions were further developed as part of the work package.

The deliverable D2.2 of WP2 (Havârneanu et al., 2018) reports on the methodological framework used for the assessment of selected measures from a human factors viewpoint. This framework and the related assessment tool will be developed and updated based on the experiences gathered during the WP4 piloting and the updates will be reported in deliverable D2.5. The safety effect estimation was drafted in cooperation with WP2 to align the results with the ones resulting from the evaluation of selected safety measures from a human factors perspective (deliverable D2.4 of the SAFER-LC project).

The earlier deliverables of WP4 produced implementation guidelines for the pilots (D4.1; SAFER-LC Consortium, 2018a) by providing an overview of the major testing environments which were available for piloting in the SAFER-LC project. The available pilot test environments ranged from simulation environments to real (or close to real) traffic circumstances. Deliverable D4.2 (SAFER-LC Consortium, 2018b) describes the proposed evaluation framework including a list of parameters from which the partners could select the most appropriate ones for the evaluation of their pilot. The identified Key Performance Indicators (KPIs) were arranged into five categories: 'Safety', 'Traffic', 'Human behaviour', 'Technical', and 'Business'. Finally, the deliverable D4.3 (Carrese et al., 2019) describes the pilot activities carried out in WP4 by documenting the implementation and execution of pilots in various level crossing environments in different countries.

The results of this deliverable (D4.4) will serve as input for WP5 that deals with the exploitation aspects of the SAFER-LC safety measures (or solutions, as they as called in WP5). The estimates of safety effects of each measure will be used in cost-benefit or cost-effectiveness calculations and the experiences collected during the piloting will support the drawing of final recommendations for the SAFER-LC project.

1.4. Structure of the document

This deliverable consists of six main chapters:

- Chapter 1 includes an introduction of the project and purpose of this deliverable together with the links to other work conducted during the SAFER-LC project.
- Chapter 2 introduces the guidance that was provided to pilot test leaders before the piloting of safety measure to support their data collection and analysis.
- Chapter 3 documents the descriptions of piloted safety measures and their evaluation results together with the used evaluation method.
- Chapter 4 summarises the main safety related evaluation results by piloted safety measure.
- Chapter 5 presents the calculations to estimate the safety potential of each piloted safety measure.
- Chapter 6 provides the main conclusions and recommendations.

1.5. Abbreviations and terms

Abbreviation	Description
AIM	Application Platform for Intelligent Mobility
ANOVA	Analysis of Variance
AV	Automated Vehicle
CAM	Cooperative Awareness Message
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Messaging
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communication
DTW	Dynamic Time Warping
ET	Encroachment time
ETA	Expected Time of Arrival
ETSI	The European Telecommunications Standards Institute
FCD	Floating Car Data
G5	Frequency band (5.9GHz)
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
HFAT	Human Factor Assessment Tool
KPI	Key Performance Indicator
LC/LCs	Level Crossing / Level Crossings
LTE	Long-Term Evolution
MAP	Mobile Application Part
MRU	Motorised road user
MQTT	Message Queuing Telemetry Transport
NDS	Naturalistic Driving Study
NLOS	Non line-of-sight
OBU	On-board communication Unit
ROI	A region of interest
RSU	Roadside Unit
SAE	Society of Automation Engineers
SDS	Smart Detection System
SPaT	Signal Phase and Timing
SSH	Secure Shell
STD	Standard Deviation
TTC	Time-to-collision
VACC	Instrumented vehicle (“Véhicule d’Analyse du Comportement des Conducteurs”)
VPN	Virtual Private Network
VRU	Vulnerable road user
V2X	Vehicle-to-everything

2. GUIDANCE FOR EVALUATION

2.1. Expected results

In line with the objectives of the SAFER-LC project, the main objective for piloting the safety measures in WP4 was to assess their effect on i) the number of level crossings accidents, and/or ii) the railway system recovery time after such incidents by reducing the consequences of the collisions and/or the shut down time of railway traffic. In addition, the piloting was done to demonstrate the integration of the selected measures (technological and non-technological) in a railway environment and to assess their performance in relation to the KPIs defined in deliverable D4.2 of this project (SAFER-LC Consortium, 2018b). The evaluation also focussed on the human factors perspective to collect information on short- and long-term behavioural safety effects, together with the user experience and social perception. These aspects will be investigated as part of the human factors assessment to be conducted in WP2.

In order to obtain all this information, the piloting partners were requested to develop implementation and evaluation plans associated with each pilot, including plans for the collection of the required data for the evaluation. These plans and the progress of piloting were presented to other partners during the SAFER-LC progress meetings and documented in periodical progress reports, which were to be updated and sent for review to WP4 task leaders before each progress meeting (every three months; September 2018, December 2018, March 2019 and June 2019). The most extensive effort by partners was writing the first progress report (September 2018). In the following rounds, the writing of the progress reports concentrated on adding complementary information on eventual changes to the plans and schedule. The periodic progress reports contained five main sections: 1) Description of the measures, 2) Implementation of the measure, 3) Execution of the tests, 4) Evaluation data, and 5) Lessons learned. The template of the report is included as part of deliverable D4.3 (Carrese et al., 2019). The first section of the progress report concerned the description of the measure. From the evaluation viewpoint, this was an important section, since here the pilot test leaders were requested to describe details about the piloted measure. This included:

- Pictures and relevant features of the measure
- Targeted groups of people (all road users or only some specific group of people such as children or elderly), targeted road user behaviour, and targeted LC accidents which could be prevented with the implementation of this system
- Expected safety effects (i.e. how and why the measure is expected to improve LC safety)
- Applicability of the measure to different LC types (e.g. passive LCs, active LCs with light signals, active LCs with barriers and light signals)
- Circumstances under which the measure is expected to be effective (e.g. during all weather and lighting conditions or only during some specific conditions such as during darkness)
- Previous experiences with similar measures

The collection and documentation of the above information was targeted to support the pilot test leaders in selecting the most suitable study design for the estimation of the effects of their measure.

2.2. Focus on the evaluation

In order to estimate the effectiveness of a specific measure, the pilot test leaders were recommended to carry out an evaluation: (1) in a real experimental context (i.e. units are assigned randomly to a treated and untreated group to control the potentially confounding factors) and (2) by collecting evaluation data both in 'before' and 'after' conditions. Specifically, the pilot test leaders were encouraged to collect control data whenever possible, especially, in before-after studies. The control data would allow the separation of the effects of the measure from other simultaneously affecting factors. The collection of data on long-term effects of the measure was also encouraged.

The partners were encouraged to join efforts and collaborate with other partners to pilot the same safety measure in different settings and/or countries. In addition, the pilot tests leaders were requested to provide information on the implementation process, e.g. what kind of problems were encountered and how they were solved, and give advice on issues that should be taken into account when planning similar interventions.

In some cases, the selected measures were not suitable to be piloted in real experimental context and/or the implementation in real railway environment was not feasible, for example, due to financial resources, timing of our piloting period and/or lack of suitable pilot site(s). Therefore, pilot test sites varied from simulation studies to controlled conditions and real railway environments.

2.3. Quantitative estimates on the reductions of accidents and fatalities

The pilot test leaders were instructed to aim to provide quantitative estimates on safety effects of the measures, preferably in terms of annual reductions in the numbers of level crossing fatalities and/or accidents. However, it was recognised that providing reliable estimates of annual fatality and/or accident reductions in small-scale pilot tests is hardly possible. Since some quantitative results are needed for the cost-benefit analysis, the pilot test leaders were advised to make an expert evaluation of the safety issue the implemented measure aims to address, and provide some estimates on the safety effects (on annual numbers of level crossing fatalities) if the measure would be implemented on a large scale (e.g. covering all potential implementation locations).

The list of KPIs, defined in earlier phases of WP4 (SAFER-LC Consortium, 2018b), supported the estimation of safety effects. The pilot test leaders could review this list and select the series of appropriate indicators in order to assess the effectiveness of the implemented safety measures. Taking into account that level crossing accidents are relatively infrequent, some indicators may be less meaningful to collect during the piloting.

In order to have a sufficient number of accidents for the evaluation, data from a period of several years is typically required. However, the differences in accident frequencies between the before and after periods cannot then be solely explained by the treatments implemented, but by other external factors as well. Consequently, alternative methods are required to evaluate the impact of these measures while avoiding the influence of unknown variables. For example, risky LC user behaviours are more frequent than accidents. Therefore, the investigation of risky LC behaviours provides more data for evaluating the effectiveness of implemented measures. Risky behaviour can be evaluated by field investigators' observations, but it is usually assessed through video recordings, which are less obtrusive and enable the replay of events.

The final list of piloted measures is presented in the beginning of chapter 3 of this deliverable.

3. EVALUATION OF MEASURES

This deliverable reports the evaluation results of 21 safety measures that were piloted at eight pilot sites during the SAFER-LC project (Table 1). The number of piloted safety measures varied by pilot site and the pilot test sites varied from simulation studies to controlled conditions and real railway environments. Some of the measures ('In-vehicle warnings to driver', and 'Additional lights to train front') were tested in two different environments to collect complementary information on their safety effects via two types of installations. An additional test site was planned in Turkey, but as the project developed, it had to be put on hold in April 2019 due to political reasons external to the consortium. In addition, the results of the pilot test on 'Monitoring and remote maintenance' conducted in Aachen test site by NTNU were not available for this deliverable due to a human resource issue.

Table 1. *List of piloted safety measures by pilot site.*

Pilot site	Safety measures
Driving simulator of DLR	• Blinking lights drawing driver attention • Improved train visibility using lights • Noise-producing pavement • Sign 'Look for train'
Driving simulator of SNCF	• Coloured road marking • Funnel effect pylons • Rings • Traffic lights • Speed bump and flashing pylons • Proximity message via in-car device
Two simulation environments (VTT)	• V2X messaging system between automated vehicles (AVs) and passive LCs
Aachen test site (multiple partners)	• Smart detection system • Early detection and hazard information • Smart communication system 1 • Smart communication system 2
CEREMA Rouen (CEREMA&NTNU)	• Monitoring and remote maintenance
Thessaloniki living lab (CERTH-HIT & DLR)	• In-vehicle train and LC proximity warning
Real rail environment (VTT)	• Additional warning light system affront of the locomotive
Real rail environment (DLR)	• Blinking amber light with train symbol • Road marking "← Is a train coming? →"

The following subchapters (3.1–3.8) present the piloted safety measures and their evaluation results together with the used evaluation method. The evaluation results are combined with a discussion on lessons learned, recommendations, applicability of results to different circumstances and conclusions. The results are reported by pilot test site in the same order as the pilot sites are presented in Table 1.

3.1. Driving simulator (DLR)

3.1.1. Piloted safety measures

All piloted measures share the goal of supporting the safe behaviour of traffic participants at passive level crossings. They are especially supposed to improve the probability that an oncoming train is detected by the road user by eliciting an early visual checking behaviour to the left and right 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 will be evaluated:

- Blinking lights drawing driver attention
- Improved train visibility using lights
- Noise-producing pavement
- Sign 'Look for train'

The measures are mainly targeting fast-moving road users, especially motorised road users, since they are involved in the 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.

<u>Blinking lights drawing driver attention</u>

The blinking lights were positioned stationary in the peripheral vicinity of a level crossing (*Figure 1*) and were activated whenever a road user was 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 et al., (2016) showed positive short-term effects of stationary peripheral blinking lights at passive level crossings on the visual orientation of drivers. In the pilot study, the implementation of the blinking peripheral lights (*PeriLight*) was adapted to the situation at the test LC that allowed free view on the tracks already at 240 m and more ahead of the LC. Three posts with blinking lights were implemented at the tracks at 40, 60 and 80 m distance from the road, to both the left and the right of the LC. The blinking was triggered when the participant's car was 250 m ahead of the LC. The blinking sequence started with the two inner lights being activated for 0.1 s, followed by the two lights in between being activated for 0.1 s and, finally, the two outermost lights being activated for 0.1 s. After a pause of 0.1 s with all lights out, the sequence started again, yielding an impression of the blinking "moving" from the center to the periphery on both sides of the road. The blinking continued for 15 s overall.

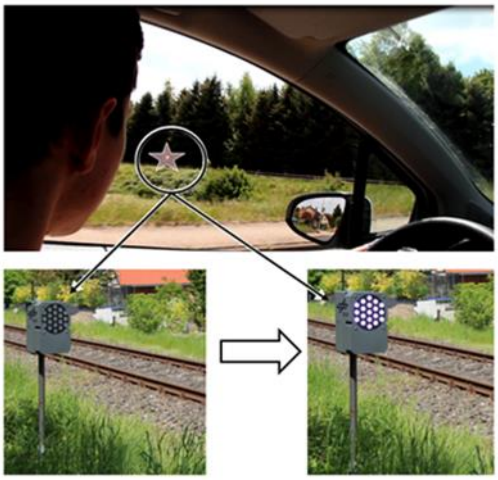

Figure 1. *Blinking lights located in the periphery of the level crossing to capture the visual attention of road users and increase the probability of detecting an approaching train. This measure relies on automatic responses of the human visual system.*

Improved train visibility using blinking lights

The improvement of the train visibility by using blinking lights relies on a facilitation of the detection by enhancing the salience of a locomotive (Figure 2). The additional warning light system was positioned at the front of the locomotive. 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). 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 headlights).

The analysis of additional light systems installed on locomotives was a joint initiative by DLR and VTT within the project. While VTT pursued the demonstration of the technical system in a real world level crossing context, DLR verified the capability of the system to positively influence road users' visual detection of trains in the context of an empiric simulation study.

Figure 2. *Additional blinking lights that complement the regular triangular lights of a locomotive are supposed to improve the detection by road users. This measure relies on automatic responses of the human visual system.*

<u>Noise-producing pavement</u>

The *noise and vibration producing pavement* elicits a rumble effect when it is driven over (Figure 3). It is assumed that this measure will firstly have an impact on motorised road users' 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), however, their effect on the visual search during the approach towards a level crossing has not been investigated sufficiently to date.

Figure 3. *Noise-producing pavement and other purposeful alterations of the road surface are supposed to influence the driving behaviour of motorised road users during the approach towards level crossings.*

Sign 'Look for train'

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 4 was written in German language. The text in the sign asks the road user "Kommt ein Zug?" (Is a train coming?). In a comparable setup, the effect of a *look for train* sign has been studied earlier (Noyce & Fambro, 1998). The sign was detected by more than half of the participants in their driving study. However, since other measures were studied 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 4. *The sign which asks the road user to check whether a train in approaching. Pictograms and arrows support the messages.*

3.1.2. Method and data to evaluate the piloted measures

All four measures were tested in the MoSAIC driving simulator of DLR[1].

A lot of effort was spent on the design of a driving environment the allows studying multiple measures in a within subjects experimental design, meaning that the same participant can be confronted with multiple measures without making them suspicious that the study is about level crossing safety. A long driving course was planned, consisting of both village sections and rural roads between them. To distract the participant from the level crossing focus of the study, a secondary task had to be completed once while driving through each of the villages in between the LCs. For this, participants received a message on a mobile phone, requiring them to execute a small task and send 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"). The secondary task was part of the cover story used to justify the purpose of the study in the initial instruction. Participants were briefed on the real purpose after the study.

A detailed procedure of the studies and the stepwise sequence of events is shown in Table 2. After a phase of introduction, explanation and calibration (A–D), participants started with a training course to get used to the simulator. The subsequent test course contained six LCs and was designed to take about 7 min driving time from one LC to the next. The first LC-passage always served as a baseline. A passive LC was crossed without a train approaching.

[1] https://www.dlr.de/fs/en/desktopdefault.aspx/tabid-11368/19984_read-46631/

Table 2. *Procedure and time plan of the driving simulation study.*

Trial / Phase	Duration	Contents	Factor 1 (within subj.):	Factor 2 (within subj.)	Factor 3 (between subj.)		
			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 <-> Noise-prod. pavement <-> 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	***Effect of train exposition*** *- additional LC traverse for testing the effect*	**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			**target n subjects**	18		18
Total duration	**90 min**			**target total n**	**36**		

The second to fourth LC likewise entailed a passage without a train coming, but with one of three different infrastructural safety-measures in place (*sign 'Look for train'*, *peripheral blinking lights* or *noise-producing pavement*). These three experimental conditions were encountered by all of the participants. The order of measures was balanced across participants.

At the fifth level crossing, each participant encountered a train that approached the LC. This train was a normal train for a half of the participants (baseline for the factor *train design*), and a train with additional blinking lights for the other half. While the other factors were varied within-subjects, a between-subjects design was chosen for this factor because a train encounter was expected to bias driver behaviour in any following LC passages towards more attentiveness and caution than would normally be observed at LCs. Therefore, each participant should only encounter a train once, and always at the end of the measure sequence. The direction of train approach from the left vs. right side was balanced across participants. The train was triggered when the participant's car was at

390 m ahead of the LC, with its trajectory to be on a perfect collision course in case the driver would continue to drive at the maximum allowed speed of 50 km/h.

To test for the effects of a train encounter on driver behaviour at LCs, a sixth LC passage was included, involving a LC without any supplemental safety measure and without a train, similar to the baseline condition.

After the test-drive, a questionnaire was administered to the participants in which they were first briefed on the background and focus of the study and then shown each of the measures again, along a with a short description of their proposed functions. Participants were subsequently asked to give their assessment of the measure on a number of scales (see results for items).

3.1.3. Evaluation results

Participants

A total of 52 participants (24 male, 28 female) took part in the study. The conduct of the study and the assessment of the driving, gaze and subjective data, respectively, was partially restricted due to simulator sickness (participants were instructed to abort the test immediately in this case), technical problems with gaze detection or calibration quality in eye-tracking, and, in one case, persisting failure to comply with the instructions. Participants who had to quit early because of simulator sickness, still filled in the user questionnaire if they felt ok to do so. Subjective assessments were collected of 49 participants (24 male, 25 female, aged 18 to 65, M = 35.3, SD = 13.1). A complete set of driving data could be obtained of 46 participants (22 male, 24 female, aged 18 to 65, *M* = 34.4, *SD* = 12.5), and a complete set of gaze data was obtained of 39 participants (18 male, 21 female, aged 18 to 65, *M = 34.4*, *SD = 12.7*).

Gaze behaviour

To assess the effect of the measures on visual search for a train, indicators of looking out for a train on the tracks to the left and right were computed and compared between the conditions. The necessary stopping distance at a speed of 50 km/h (including reaction and braking) is about 40 m with normal braking, or 30 m with hazard braking. Therefore, the analysis focused on gaze behaviour in the LC approach section from 140 to 40 m ahead of the LC, in which visual scanning for a train is especially important to determine whether there is a need to brake and give way to a train.

Figure 5 shows the regions of interest (ROI) that were defined as the left periphery and right periphery for the analysis. Fixations needed to last at least 120 ms to be counted. For the defined ROI and approach phase, the following indicators were computed: (1) number and percent of participants who fixated the ROI at least once, and (2) mean number of fixations on the ROI.

Figure 5. *Definition of the regions of interest (ROI) "left periphery" (L) and "right periphery" (R). The blue dot represents the participant's current gaze position in this screenshot.*

When looking at the proportion of participants who gave a given ROI at least one fixation, it first became obvious that there was a general bias to attend more to the left than to the right side. Across all LC conditions, about 75% of participants scanned the left peripheral region of the tracks at some point during the critical approach phase between 140 and 40 m ahead of the LC, while the mean proportion of participants who did the same on the right side was only about 51%.

In the baseline condition (passive LC without any additional safety measures), around 65% of participants fixated on the left side of the tracks, and around 45% fixated on the right side once or more often on approach (see Table 3). On the left side, this proportion increased in almost all of the test conditions, except the *noise-producing pavement* condition. The highest increase was observed with the PeriLight (+ 19%), followed by the sign *Look for train* (+ 15%). On the right side, the only measure that lead to a comparable increase was the *PeriLight* (+ 19%). The sign *Look for train* did not induce considerable changes compared to the baseline. Neither did the *noise-producing pavement.*

A considerable increase on the left side and somewhat smaller effects on the right side were also observed in the blinking train condition (left: +15%, right: + 9%), compared to increases of around +7 % on both sides in the normal train condition. However, the ROI fixation results for the conditions with a train present should be considered together with the results of the analysis of the first fixation on the train (reported below) which show that in all but one of these cases the approaching train had already been detected. What is more interesting in the conditions with a train present is the effect of the train approaching from one side on the inspection of the tracks on the opposite side. When a train approached from the right side, fixations to that side were increased (+18%), and there was also a small increase (+8%) on the left side in comparison to the baseline. When a train approached from the left side, there was an increase of fixations on this side, but not on the right side.

Notably, in the condition *After train encounter,* which involved approaching a passive LC without any additional safety measures and without a train after having encountered a train on the LC before, the proportion of participants who scanned the critical regions was also enhanced by around 20% on the left side and 10% on the right side.

Table 3. *Number and percent of participants who fixated the given ROI at least once between 140 and 40 m ahead of the LC. Note: n-Participants equals the number of available data of participants by condition. Row percent are based on this value.*

ROI		**Left Periphery**		*Participants*	**Right Periphery**	
LC condition		n	**%**	*n*	n	**%**
Baseline		31	**64.6**	*48*	22	**45.8**
PeriLight		36	**83.7**	*43*	28	**65.1**
Noise-producing pavement		30	**66.7**	*45*	18	**40.0**
Sign Look for train		36	**80.0**	*45*	21	**46.7**
Train		31	**75.6**	*41*	22	**53.7**
	Blinking	*16*	***80.0***	*20*	*11*	***55.0***
	Normal	*15*	***71.4***	*21*	*11*	***52.4***
	From left	*15*	***78.9***	*19*	*8*	***42.1***
	From right	*16*	***72.7***	*22*	*14*	***63.6***
After train encounter		33	**84.6**	*39*	22	**56.4**

Table 4 and Figure 6 show the mean number of fixations in the left and right periphery for each of the LC conditions. Complementing these descriptive statistics, a two-way repeated-measures ANOVA with ROI and LC as factors was run on the data of the 39 participants of whom observations of all LC conditions were available. The data again reveal the general relative neglect of the right side of the tracks. This observation is confirmed by a highly significant main effect of the ROI in the ANOVA, $F(1,38) = 15.68$, $p = 0.000$. The main effect of the LC condition was also significant with $F(2.44, 92.83) = 6.15$, $p = 0.002$ (Greenhouse-Geisser-corrected), indicating that some of the measures induced significant changes in the number of ROI fixations on LC approach. Simple contrasts with the baseline as the reference condition showed a pronounced effect of the *PeriLight*, $F(1,38) = 11.71$, $p = 0.002$, and some effects in most of the remaining conditions, sign *Look for train:* $F(1,38) = 12.51$, $p = 0.001$, *train:* $F(1,38) = 6.39$, $p = 0.016$, and *after train encounter*: $F(1,38) = 5.88$, $p = 0.020$. In the *noise-producing pavement* condition, the number of fixations was not significantly different from the baseline, $F(1,38) = 1.32$, $p = 0.258$.

Table 4. *Mean number of fixations on ROI between 140 and 40 m ahead of the LC.*

ROI	**Left Periphery**			**Right Periphery**	
LC Condition	*M*	*(SD)*		***M***	*(SD)*
Baseline	1.23	*(1.21)*		**0.88**	*(1.27)*
PeriLight	3.16	*(3.12)*		**2.53**	*(3.73)*
Noise producing pavement	1.71	*(1.52)*		**0.89**	*(1.42)*
Sign Look for train	2.36	*(1.87)*		**1.22**	*(1.76)*
Train	2.10	*(2.36)*		**1.34**	*(1.76)*
After train encounter	2.15	*(1.42)*		**1.15**	*(1.42)*

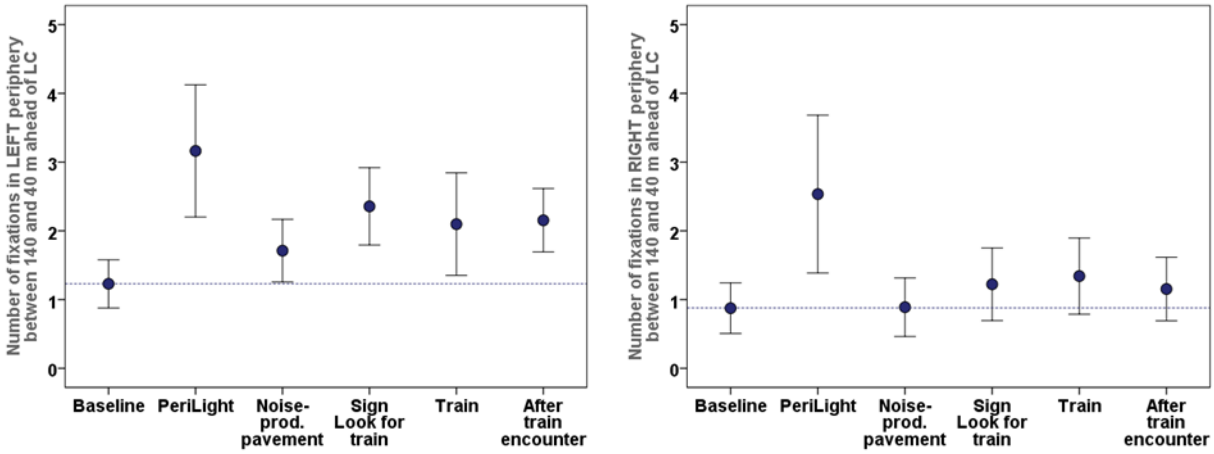

Figure 6. *Mean number of fixations on ROI (left vs. right periphery) between 140 and 40 m ahead of the LC.*

In the condition involving a train encounter, the train was triggered on the left or right side when the participant's car passed a fixed trigger point ahead of the LC. It first became visible on the screen on average when the participant's was at 250 m ahead of the LC. The trigger point was chosen to achieve a situation in which the participant's car would have to give way to the train when approaching at a speed of 50 km/h. Therefore, the train was already present on the screens and hence detectable before the participant's car reached the critical approach region that was analysed in the ROI analyses reported above. To test whether the blinking train was detected earlier than the normal train the *time of first fixation* on the train in terms of distance ahead of the LC was analysed for each participant.

The time of first fixation on the train could be determined for 36 participants (*blinking train: n* = 18, *normal train: n* = 18). All but one participant detected the train and let it pass before they crossed the LC. The one participant who did not fixate the train and passed the LC in front of it was in the *normal train* condition. Participants in the *blinking train* condition fixated on the train for the first time on average at 251.2 m ahead of the LC (*SD* = 23.7), participants in the *normal train* condition at 214.7 m (*SD* = 22.8), resulting in a statistically significant mean difference of 36.5 m (*Welch's t*(31.9) = -3.97, *p* = .000).

Analyses of the time that the train first became visible on the screen in the periphery also showed a significant difference between the two groups (*blinking train: M* = 258.8, *SD* = 23.9, *normal train: M* = 242.2, *SD* = 19.5, *Welch's t*(32.7) = -2.29, *p* = .029). Therefore, the *time to first fixation* was computed as another indicator of gaze behaviour. The *time to first fixation* describes how soon the train was fixated for the first time after it appeared on the screen, in terms of meters driven in that time. Participants in the *blinking train* condition detected the train soon after its onset, with a mean of 8.2 m driven in between (*SD* = 9.3). Participants in the *normal train* condition drove 30.5 m on average before they first looked at the train (*SD* = 27.6; *Welch's* t(20.8) = -3.24, *p* = .004). As implied in the standard deviations, the distribution of the time to first fixation was also broader in the *normal train* condition. The last participant to fixate on the train after it appeared drove a further 110 m before first looking at it, while in the *blinking train* condition, the maximum distance driven between train onset and its first fixation was only 37 m.

Driving dynamics

The analysis of drivers' speed choices on LC approach focuses on the 300 m ahead of each LC, i.e. it starts at the point at which the first sign of the respective LC infrastructure (three-striped post at 240 m ahead of the LC) becomes discernable, and ends at the beginning of the LC (0 m). To assess the effects of the different measures, we look at the velocity difference between each condition and the baseline – i.e., how much slower or faster did drivers go on average at a certain point with a certain measure compared to the situation without the measure –, and compare the resulting difference profiles across the measures.

Figure 7 shows the mean velocity differences to the baseline for the three stationary measures. For the *noise-producing pavement* and the *sign 'Look for train',* the mean speed profile is virtually the same as in the baseline condition. For the *PeriLight* measure, a speed reduction can be observed starting at around 160 m and reaching its maximum at around 50 m ahead of the LC.

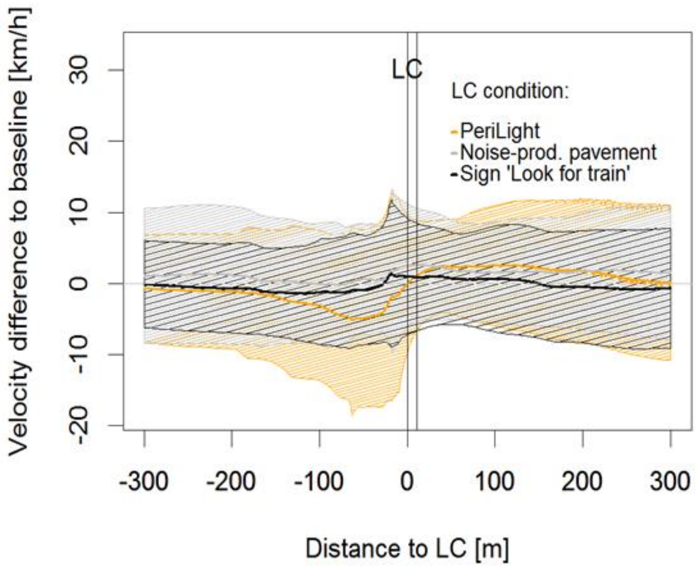

Figure 7. *Mean velocity difference to baseline for the three stationary measures PeriLight, noise-producing pavement and sign 'Look for train'. Error bands: +/- 1 SD.*

Figure 8 shows the mean velocity differences to the baseline for the two train conditions, normal vs. blinking. Visual inspection shows an obvious drop in the slope of both of the curves, where speed choice starts to deviate from the baseline condition. This is interpreted as the moment when the participants realised that a train is coming and that they need to adapt their speed to avoid a collision and give way to the train. In the blinking train condition, the drop appears on average at 240 m ahead of the LC, whereas in the normal train condition, it occurs at about 190 m ahead of the LC, i.e. 50 m later on average.

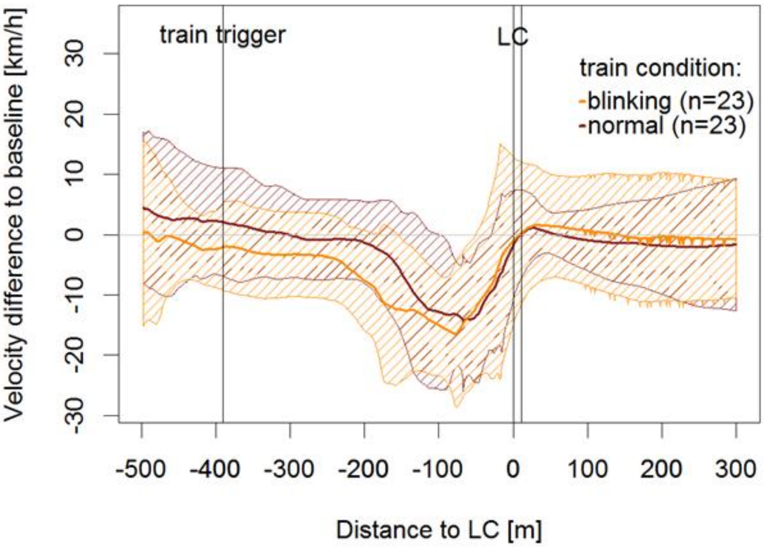

Figure 8. *Mean velocity difference to baseline for the two train conditions "normal" vs. "blinking". Error bands: +/- 1 SD.*

<u>Subjective data (user questionnaire)</u>

Effectiveness of cover story - notice of LC focus

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. 36 of the 49 participants indicated they had not assumed this before the debriefing (Figure 9). In total, 13 participants reported having had a hunch of this sort at some point during the drive. Only four participants expressed the idea of a LC focus already in the open item that was asked before the debriefing.

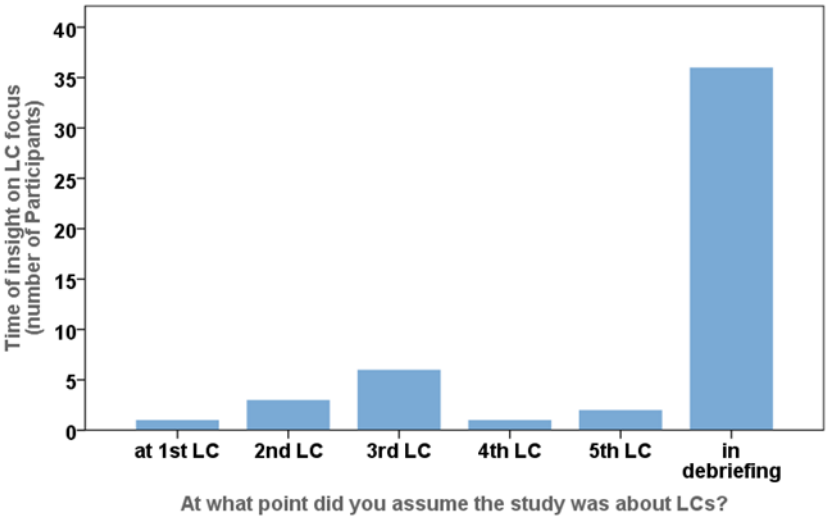

Figure 9. *Number of participants who expressed having had an idea about the LC focus of the study at a given point in time.*

Perceived usefulness of measures to prevent LC accidents

On the scale from *1 - completely useless* to *6 - extremely useful*, participants judged all of the measures to be rather useful for the prevention of accidents, as shown in the means in Figure 10. The *blinking train* (*M* = 4.51, *SD* = 1.69)*, PeriLight (M* = 4.80, *SD* = 1.23) and the *sign 'Look for train'* gained about equally high scores (*M* = 4.69, *SD* = 1.26), while the *noise-producing pavement* were perceived a little less useful to prevent LC accidents (*M* = 3.65, *SD* = 1.49).

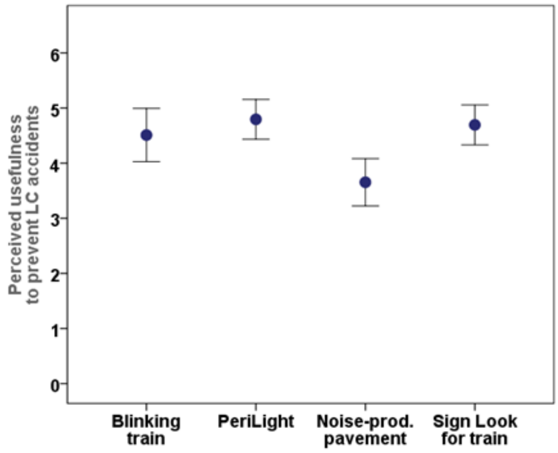

Figure 10. *Mean perceived usefulness of the four measures tested.*

Perceived usefulness of measures to support information processing at LCs

Four items of the questionnaire were to assess the participants' perception of the usefulness of measures to support different aspects of information processing at LCs. The scores are displayed in Figure 11 and Table 5.

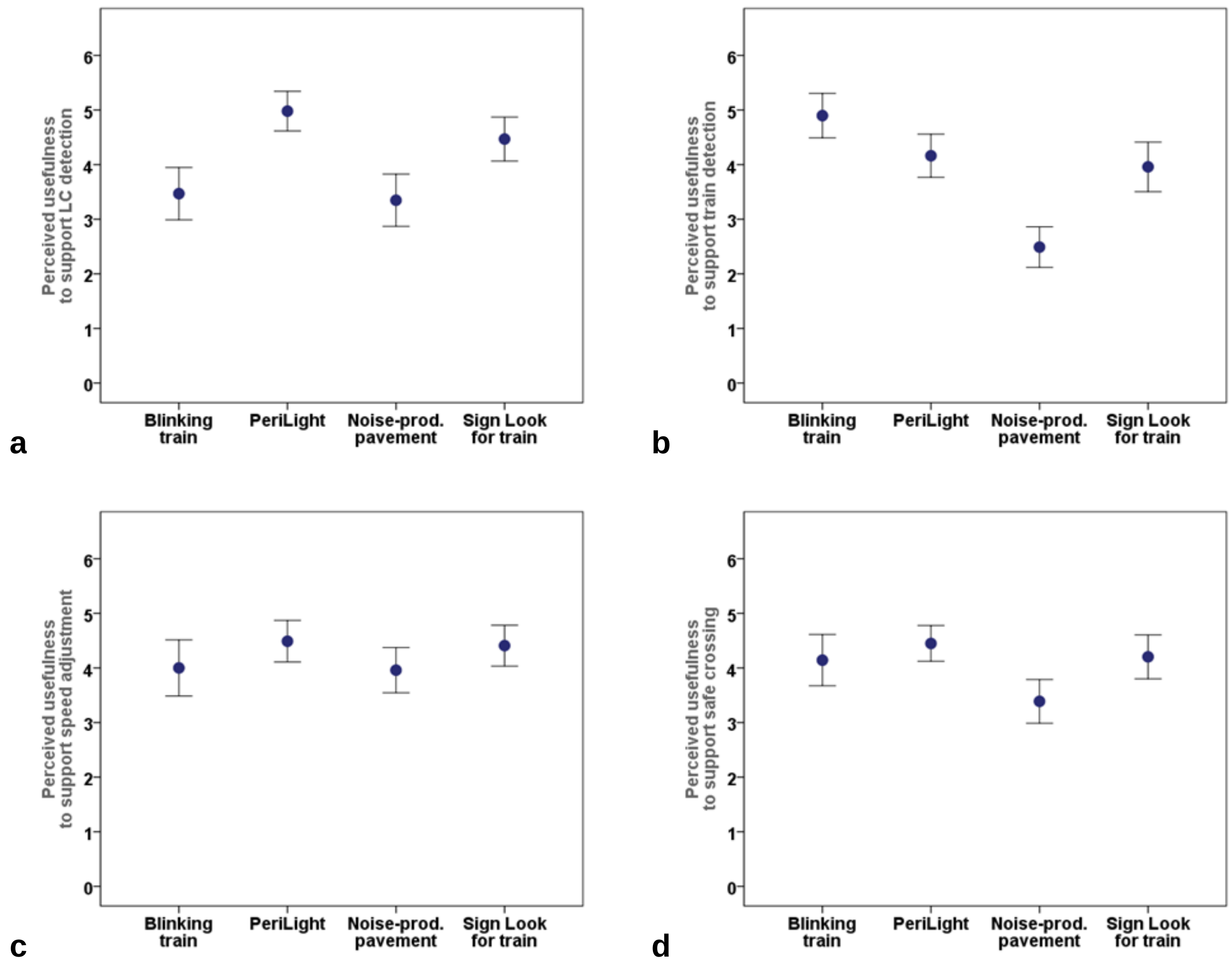

Figure 11. *Mean perceived usefulness of the measures tested to support information processing at LCs: a – to support LC detection, b – to support train detection, c – to support speed adjustment on approach to LC, d – to support safe crossing.*

Concerning the facilitation of LC detection (Figure 11, a), the *PeriLight* was perceived as the most useful measure on average, followed by the *sign 'Look for train'.* With regard to the facilitation of train detection (Figure 11, b), the *blinking train* reached the highest score, followed by the *PeriLight* and the *sign 'Look for train'.* Concerning the facilitation of speed adjustment (Figure 11, c), the differences are less pronounced: While all measures reached mean scores of approximately 4, there is a slight tendency for the *PeriLight* and the *sign 'Look for train'* to score better by around half a scale point. Finally, the perceived usefulness to support a safe LC traverse (Figure 11, d) appears to integrate the results of the three other dimensions, with a pattern resembling the one for the perceived usefulness to prevent LC accidents (cf. Figure 10). This pattern shows relatively high mean scores for the *blinking train, PeriLight* and the *sign 'Look for train',* and the *noise-producing pavement* scoring about one scale point lower on average.

Table 5. *Mean values and standard deviation of the perceived usefulness of measures to support information processing at LCs.*

	Blinking train		**PeriLight**		**Noise-producing pavement**		**Sign "Look for train"**	
	M	*(SD)*	***M***	*(SD)*	***M***	*(SD)*	***M***	*(SD)*
LC detection	**3.47**	*(1.67)*	**4.98**	*(1.27)*	**3.35**	*(1.67)*	**4.47**	*(1.40)*
Train detection	**4.90**	*(1.42)*	**4.16**	*(1.37)*	**2.49**	*(1.29)*	**3.96**	*(1.58)*
Speed adjustment	**4.00**	*(1.79)*	**4.49**	*(1.32)*	**3.96**	*(1.44)*	**4.41**	*(1.31)*
Safe crossing	**4.14**	*(1.63)*	**4.45**	*(1.14)*	**3.39**	*(1.40)*	**4.20**	*(1.40)*

Perceived ease of use

In the questionnaire after the drive, participants were asked whether they had noticed each measure in the simulation and whether they had understood its meaning. The results are displayed in Table 6. Three of the measures were assessed to be very easily detectable in general (Figure 12*,* a), with the *sign 'Look for train'* and the *PeriLight* reaching mean scores above 5 and the *blinking train* reaching a mean score of around 4.5 (Table 7). The medium mean score of the *noise-producing pavement* might partly be due a "visual" conception of the phrase *easily detectable* in the item text, i.e. participants might mainly have judged the visual discriminability of the noise-producing pavement on the road, rather than the ease of detecting the haptic stimulus of the vibration caused by the strips. The pattern concerning participants' subjective ease of understanding the measures' meaning (Figure 12*,* b) mirrors the results observed in the frequencies of understanding the measure in the simulation (Table 6), *with the* blinking train and sign 'Look for train' being judged as very easy, *the PeriLight* as a little harder and the noise-producing pavement as even harder to understand concerning their function related to the LC. Looking at participants' sensations if the measure motivates them to *drive* with caution in approaching the LC (Figure 12*, c*), the *PeriLight* and the sign 'Look for train' gained *the* highest mean scores, *followed by* the blinking train, while the noise-producing pavement were perceived as least suitable in comparison.

Table 6. *Absolute and relative frequencies of participants who reported (post hoc) to have noticed and understood, respectively, the measures in the simulation (Note: Total frequency is n = 24 for the blinking train, and n = 49 for the other measures).*

		Blinking train		***PeriLight***		***Noise-producing pavement***		***Sign 'Look for train'***	
		n	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Noticed measure in simulation	yes	23	***95.8***	43	***87.8***	42	***85.7***	49	***100.0***
	no	0	***0.0***	5	***10.2***	7	***14.3***	0	***0.0***
	no answer	1	***4.2***	1	***2.0***	0	***0.0***	0	***0.0***
Understood measure in simulation	yes	22	***91.7***	27	***55.1***	15	***30.6***	46	***93.9***
	no	1	***4.2***	22	***44.9***	33	***67.3***	0	***0.0***
	no answer	1	***4.2***	0	***0.0***	1	***2.0***	3	***6.1***

All participants reported to have noticed the *sign 'Look for train',* and virtually all who had encountered the *blinking train*, reported to have noticed it, too (one participant did not answer this item). Most of the participants reported to have noticed the *PeriLight* and the *noise-producing* *pavement* (88 %, and 86%, respectively). Looking at the understanding of the measure in the simulation, again, virtually all participants who answered this item reported to have understood the meaning of the *sign 'Look for train'* and the *blinking train.* Just over half of the participants stated they had understood the meaning of the *PeriLight*, and about one third reported to have understood the meaning of the *noise-producing pavement.*

In the section of the questionnaire concerned with how participants perceived the measures' usability, participants were instructed to imagine the measures in real traffic – i.e. beyond the concrete depiction in the simulator – and also to think of their deployment under different conditions – e.g. regarding traffic density, weather, sight, building development etc. – to give a general judgment of each measure.

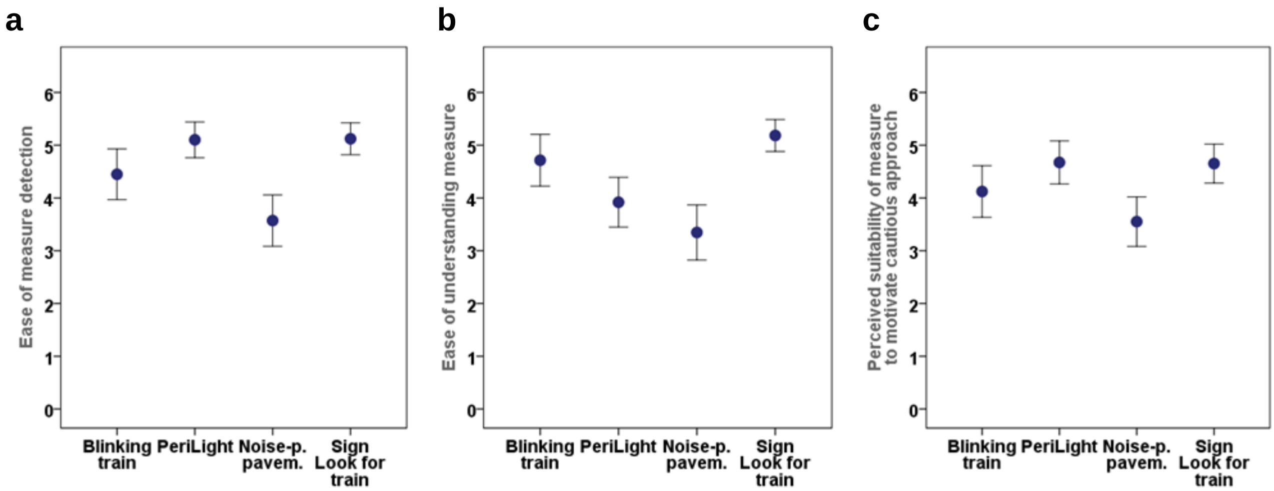

Figure 12. *Mean perceived ease of use of the measures tested with regard to (a) the ease of detecting the measure, (b) the ease of understanding the measure, and (c) the capability of the measure to motivate cautious driving on approach to the LC.*

Three of the measures were assessed to be very easily detectable in general (Figure 12, a), with the *sign 'Look for train'* and the *PeriLight* reaching mean scores above 5 and the *blinking train* reaching a mean score of around 4.5 (Table 7). The medium mean score of the *noise-producing pavement* might partly be due a "visual" conception of the phrase *easily detectable* in the item text, i.e. participants might mainly have judged the visual discriminability of the noise-producing pavement on the road, rather than the ease of detecting the haptic stimulus of the vibration caused by the strips. The pattern concerning participants' subjective ease of understanding the measures' meaning (Figure 12, b; Table 7) mirrors the results observed in the frequencies of understanding the measure in the simulation (Table 6), with the *blinking train* and *sign 'Look for train'* being judged as very easy, the *PeriLight* as a little harder and the *noise-producing pavement* as even harder to understand concerning their function related to the LC. Looking at participants' sensations if the measure motivates them to drive with caution in approaching the LC (Figure 12, c), the *PeriLight* and the *sign 'Look for train'* gained the highest mean scores, followed by the *blinking train*, while the *noise-producing pavement* were perceived as least suitable in comparison.

Table 7. Mean values and standard deviation of the three perceived ease of use dimensions for the measures tested.

	Blinking train		PeriLight		Noise-producing pavement		Sign "Look for train"	
	M	*(SD)*	***M***	*(SD)*	***M***	*(SD)*	***M***	*(SD)*
Is easy to detect	**4.45**	*(1.67)*	**5.10**	*(1.18)*	**3.57**	*(1.70)*	**5.12**	*(1.05)*
Is easy to understand	**4.71**	*(1.71)*	**3.92**	*(1.64)*	**3.35**	*(1.82)*	**5.18**	*(1.05)*
Motivates to drive cautiously	**4.12**	*(1.70)*	**4.67**	*(1.42)*	**3.55**	*(1.63)*	**4.65**	*(1.28)*

Perceived distraction by the measures was relatively low for all measures, with a tendency for *PeriLight* to be judged as slightly more distracting (Figure 13, a; Table 8). Concerning participants' expression of reservations against the measure, all measures gained comparably low scores that lie below the middle of the scale.

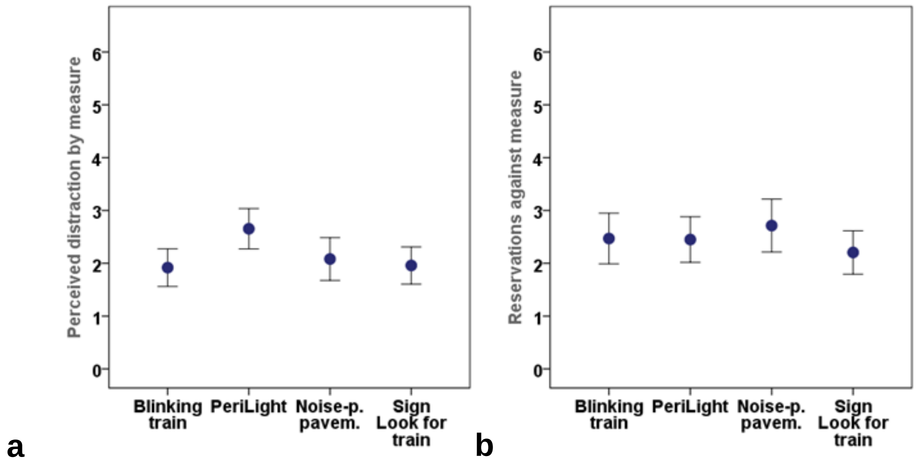

Figure 13. *Mean perceived (a) distraction by measures and (b) reservations against measures.*

Table 8. *Mean values and standard deviation of perceived distraction and reservations against the measures tested.*

	Blinking train		PeriLight		Noise-producing pavement		Sign "Look for train"	
	M	*(SD)*	***M***	*(SD)*	***M***	*(SD)*	***M***	*(SD)*
Distracts me from driving	**1,92**	*(1,24)*	**2,65**	*(1,33)*	**2,08**	*(1,41)*	**1,96**	*(1,22)*
I have reservations	**2,47**	*(1,67)*	**2,45**	*(1,50)*	**2,71**	*(1,74)*	**2,20**	*(1,43)*

3.1.4. Discussion

Summary of results

Four measures to improve safety at passive LCs were tested in a driving simulator experiment that involved a straight and flat approach to the LC with no other road traffic and very good sight conditions for scanning the tracks to the left and right to look for an approaching train. One measure focusing on train design, a train equipped with auxiliary blinking lights (blinking train), was tested at a passive LC against a normal train as the baseline. Additionally, three stationary measures focusing on LC design were tested at passive LCs without a train coming and compared to the baseline of a standard passive LC: blinking peripheral lights (*PeriLight*), a sign "← Is a train coming? →" including train symbols (sign *Look for train*), and *noise-producing pavement* on approach to the LC applied in combination with the standard LC signage at 240 m and 80 m ahead of the LC.

The *blinking train* was detected earlier and more reliably than the normal train, induced earlier speed reduction, and gained high subjective ratings on the usefulness and ease-of-use dimensions assessed. The *PeriLight* induced large increases in visual search for a train both to the left and the right side of the tracks as well as a speed reduction on approach to the LC. The measure gained high ratings on perceived usefulness and moderate to high ratings on the ease-of-use dimensions.

The sign *Look for train* induced large increases in visual search for a train to the left side of the tracks, while search behavior to the right side was hardly increased. No effect on approach speed was observed. The measure gained high ratings on perceived usefulness and ease-of-use dimensions. The *noise-producing pavement* did not increase visual search for a train, had no effect on speed and gained moderate ratings concerning their perceived usefulness and low to moderate ratings concerning their ease of use.

General discussion

The greatest effects on gaze behavior and speed choice were achieved by the two measures involving blinking lights: the blinking train and the *PeriLight*. Both work by using the mechanism of exogenous attention capture and thus do not require voluntary effort of the driver to attend to the relevant parts of the scene. In this, the *PeriLight*, although assessed to be very easily detectable and also motivating a cautious approach, was associated with some more uncertainty concerning its exact meaning – some participants reported they were unsure whether it could have meant a train was approaching. Therefore, part of the observed speed reduction might be based on this interpretation.

Of the other two measures that require the driver to voluntarily shift attention to scan the tracks for trains, the sign *Look for train* proved more useful than the *noise-producing pavement* to achieve the desired effect. The advantage of the sign is most likely because, unlike the noise-producing pavement, it provides specific information on the kind of hazard it refers to, as well as a direct cue to the adequate behavior. Complementing the results of the comprehensibility variables reported above, many of the participants stated in qualitative feedback that they did not relate the rumbling to the LC, although the strips appeared in combination with elements of the standard LC signage at 240 m and 80 m ahead of the LC.

One potential restriction to the generalizability of the results attained for the noise-producing pavement comes from their implementation in the simulation. The rumbling was conveyed via vibrations of the steering wheel. Although these were clearly noticeable and were also correctly attributed by the participants to be caused by the road pavement, the overall physical effect experienced through noise-producing pavement in a real driving environment is most likely stronger, due to the vibration affecting the whole of the car and driver's body. Therefore, there might be a stronger motivation to reduce speed in order to avoid unpleasant feelings and material stress to the car with noise-producing pavement in real environments.

Though the sign *Look for train* enhanced visual search for a train, the results observed suggest that it might not be as effective on the right side as on the left. The underlying mechanism leading to this imbalance is yet unknown. As it was also observed in the baseline condition, there might be an association with an overlearned gaze pattern prevalent in countries with right-hand traffic that favors the left side, as this is the side where a collision with crossing traffic would first occur on roads. However, other explanations might apply. Although the simulated track environment to the left and right was designed to be equally salient, the two sides were not perfectly symmetrically identical. Therefore, the possibility that some feature of environmental design drew more attention to the left side cannot be completely excluded.

<u>Lessons learned</u>

The *Hawthorne* or *observer* effect, a type of reactivity known in psychological and human factors research, involves study participants modifying their behavior in response to their awareness of being observed. In a study that explicitly focuses on behavior at LCs, it is likely that participants involuntary pay more attention at LCs than they would normally do or that their behavior gets modified in other ways just because processes that usually run highly automatically are brought into consciousness. To enable the valid observation of behavior at LCs, a cover story was used in the current study. Participants were instructed that the study was about coping with various traffic and stress situations in driving and were given a secondary task that involved answering short inquiries on a mobile phone and had to be completed while driving through the villages in between the LCs. Participants were briefed on the exact study purpose immediately after the drive.

From the experience gained in the study, the use of a cover story is recommended for further experimental research on behavior at LCs. The survey results showed that the cover story was reasonable to the majority of participants and suitable to distract from the LC focus. This corroborates the assumption that the behaviour observed in the study is largely free from bias and represents an ecologically valid sample[2] of how participants behave as drivers at LCs. The use of a cover story is also encouraged by the feedback of participants after the debriefing. They were often amused, and none expressed being upset after learning about the exact focus of the study. More importantly, participants expressed their agreement that it is sensible to design an experimental test like this to avoid unwanted effects on behavior.

Due to the framework conditions and regulations for the application of passive protection at LCs from a road user's view, the chances of not encountering an approaching train at a passive LC are much greater than those of actually encountering one. The resulting low expectancy of a train is part of the human factors safety issues at passive LCs because it lessens the motivation to visually scan the tracks to the left and right on LC approach (Wickens et al., 2015). Therefore, it was expected that a train encounter at a passive LC would exert an influence on behavior at a subsequent passive LC by increasing the expectancy of a train and thereby increasing search behavior and caution on approach. That is why, in the current study, the test condition involving a train encounter was always positioned last in the sequence of repeated LC encounters, to avoid an overestimation of the effect of measures applied at subsequent LCs. The train encounter hypothesis was tested by including a second "baseline" LC passage (i.e. passive LC without any additional measures) after the LC

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[2] Ecological validity refers to the extent to which the findings obtained in a study with a certain method can be generalised to real-life settings.

involving the oncoming train. The results confirm the expected effect of enhanced visual search behavior after a train encounter. Therefore, this effect should be considered in the design of future experimental research on behavior at LCs.

<u>Applicability of results to different circumstances and recommendations</u>

The road layout and environmental conditions in the study were chosen to allow an experimental test and comparison of the measures by creating an ideal LC: Starting at 500 ahead of the LC, the road was perfectly straight and perpendicular to the tracks. Sight on the tracks was extraordinarily good and there was no other road traffic. Therefore, the absolute values of the indicators of gaze behavior (e.g. time of first fixation on the train / the tracks, fixation probability on relevant parts of the tracks) are likely to be better than they would on average be in a real traffic environment, while the observed speed on approach might be higher on average than it would be feasible in a real traffic environment. However, keeping interfering factors constant or eliminating them allows for the isolation and comparison of the effect of the different measures tested.

Moreover, there are constraints to the situations in which passive protection can and will be applied at LCs in real traffic environments. These constraints create essential structural similarities that apply to both passive LCs in real environments and the ideal LC setup in the simulator study. Passive protection without any additional measure is only allowed to be applied at LCs where it is possible in principle to visually detect an approaching train in time to come to a stop if necessary – given that the driver pays due attention, which is the behavior that the measures tested mainly aim to enhance. Therefore, although the applicability of the measures tested is of course restricted by sight conditions (e.g. heavy vegetation, buildings etc. covering the tracks), these restrictions will typically not apply to a passive LC to an extent that would render the measures ineffective.

It should be pointed out that the use of an optimal approach in the simulator study does probably not make the test more liberal, but, on the contrary, more conservative. That means the simulator setup does not make it easier, but even harder for the measures tested to cause large effects in behavior, compared to a real traffic environment where visibility conditions are less optimal (e.g. due to approach angle, weather, vegetation etc.). The reason for this is that the optimal approach raises the overall rate of active visual search done by road users, including that of the baseline for passive LCs without any additional measures.

This assumption is corroborated by findings available from a real-traffic study of one of the measures involved in the simulator study. Grippenkoven et al. (2016) tested peripheral blinking lights in a field study involving the traverse of a passive LC in a day- and a nighttime condition. By day, the share of drivers who looked to the left and right at least once ahead of the LC, was increased by 47% on the left and 23% on the right side when the measure was active, compared to the baseline. At night, the effects were even larger with an increase of 59% on the left, 53% on the right side.

With regard to the angle between road and railroad tracks, measures to enhance peripheral attention should become even more effective when it deviates from 90°. Measures that rely on the exogenous capture of attention by blinking stimuli will still work as long as the blinking stimuli appear within the maximum field of vision that extends up to 110° to the left and right from the center axis of the visual field.

Additional lights designed to improve the early detection of a train need to be in line with the specifications given in EU regulation No 1302/2014. This regulation specifies the triangular head light constellation of locomotives and shall not be harmed by innovative light designs.

Concerning the application of noise-producing pavement, as explained above, the implementation in the simulation environment might contribute to an underestimation of a potential effect on speed reduction. However, what can clearly be inferred from the study results is that noise-producing pavement alone is not a suitable means to enhance visual search behavior on approach to passive LC. This is because drivers do not reliably relate them to the LC crossing even if applied in conjunction with elements of the standard advance LC signage and the necessity to look for a train. Therefore, noise-producing pavement should always be combined with additional measures that give clear hints to the relevant hazard and the recommended behavior.

The sign "← Is a train coming? →" proved to be one suitable solution to give such hints on the relevant hazard and the recommended behavior. Its applicability is mostly restricted by factors that reduce its visibility (e.g. fog, rain, snow, visual covering). Reading the text requires language and basic reading skills. However, the question mark, arrows and train symbols are expected to make the sign comprehensible even if the text cannot be read. As the measure increased search behavior and is very low-cost, its application will likely support safe behavior at passive LCs, despite an uncertainty remaining concerning its effect on the right side. Further research could investigate the causes of the observed differential effectivity on the right and left side and, in case the effect proves reliable, whether it could be overcome by adapting sign design.

No long-term effects were assessed in the simulator study. For the sign Look for train and the noise-producing pavement, some habituation effects can be expected in the long term, because, to be effective, both measures require a voluntary effort of the driver to initiate visual search. In contrast, the automatic capture of visual attention by flickering stimuli in the periphery of the visual field, as used in the blinking train and the peripheral blinking lights, is a hard-wired feature of the nervous system. This automatism evolved because it represented an evolutionary advantage. Therefore, this reaction is not expected to be subject to any considerable habituation effects.

3.2. Driving simulator (SNCF)

3.2.1. Piloted safety measures

<u>Coloured road markings</u>

The coloured road markings aim to improve the visibility and detectability of a LC to improve the vigilance of drivers when they approach the LC and to reduce their driving speed. They are aimed at urban active level crossings with barriers.

The road marking used in this study included fours stripes: 1) yellow band of 5 cm at 150 meters, 2) orange band of 10 cm at 100 meters, 3) train band 50 cm at 75 meters, and 4) 20 cm red band at 2 meters from the active LC (Figure 14).

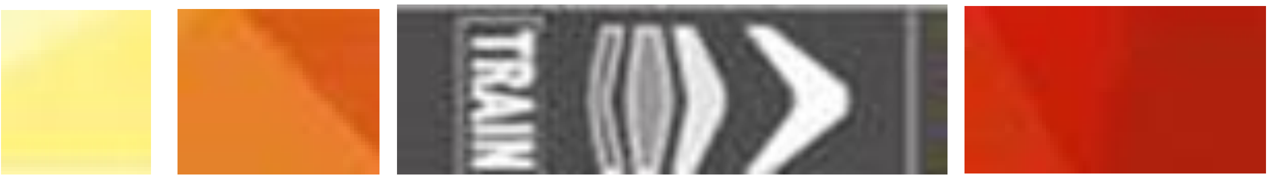

Figure 14. *Example of coloured road markings.*

Funnel effect pylons

The tunnel effect pylons aim to improve the visibility and detectability of an LC. The desired effect is to improve the vigilance of drivers as they approach and to reduce their driving speed. The measure consists of 10–15 pylons with a diameter of 20 cm to 5 meters upstream of LC creating a ‘funnel’ effect (i.e. gives a visual impression of shrinking. The pylons are overlaid with reflective stickers and are installed from the smallest to the tallest (Figure 15).

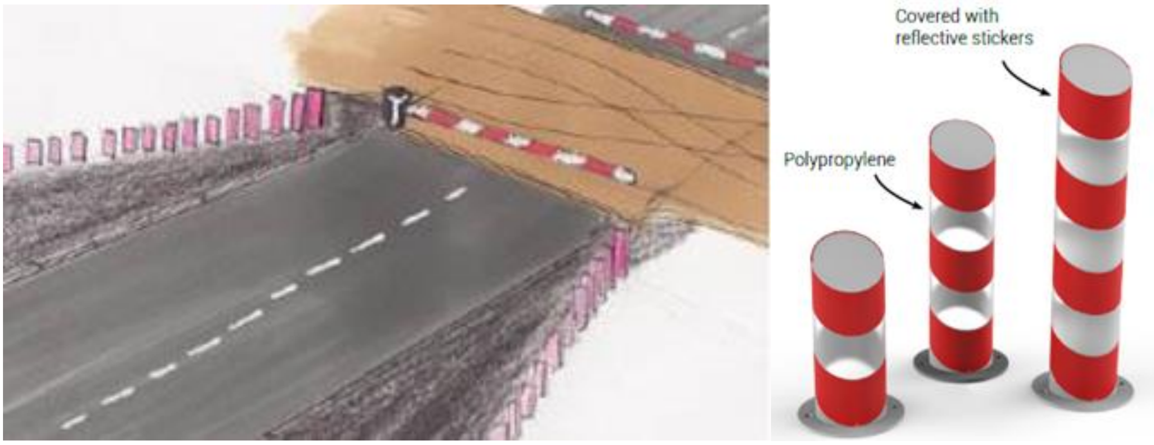

Figure 15. *Example of tunnel effect pylons installed before the LC.*

Rings

The rings aim to improve the visibility and detectability of an LC, improve the vigilance of drivers as they approach the LC and to reduce driver speed. The rings are intended for active level crossings with barriers that are located at rural areas. This measure consists of two rings which are located before the LC: one at 150 m and a second at 10 m before the LC. The rings consist of a set of LEDs and an orange light (diameter of 30 cm) (Figure 16). The second ring must not obscure the visibility of the red flashing light of the LC.

Figure 16. *Example of rings.*

<u>Traffic lights</u>

The purpose of the traffic lights is to encourage road users to respect the stop before the LC to increase probability of stopping upon activation of the LC. This measure is targeted to active level crossings with barriers located both at urban and rural areas. Two different configurations of this measure were implemented: 1) the flashing red light (R24) was replaced with a two-color light (22j) flashing orange, and 2) the flashing red light (R24) was replaced with a green traffic light (Figure 17).

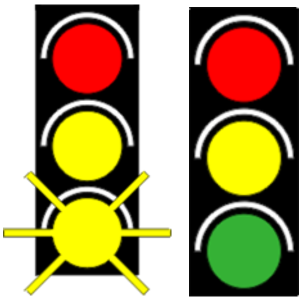

Figure 17. *Traffic lights.*

<u>Speed bump and flashing posts</u>

The speed bump and flashing posts aim to improve the visibility and detectability of an LC in order to improve the vigilance of drivers as they approach the LC and reduce driver speed. This measure is intended for rural active level crossings with barriers. The posts are equipped with a red LED lamp, and the three poles flash in alternating flicker located at 150, 100 and 50 m from the LC on the right edge of the roadway (Figure 18). The bumps are located 150, 100 and 50 m from the LC. The number of inner lines is different according to its location of the LC (1, 2 or 3 lines).

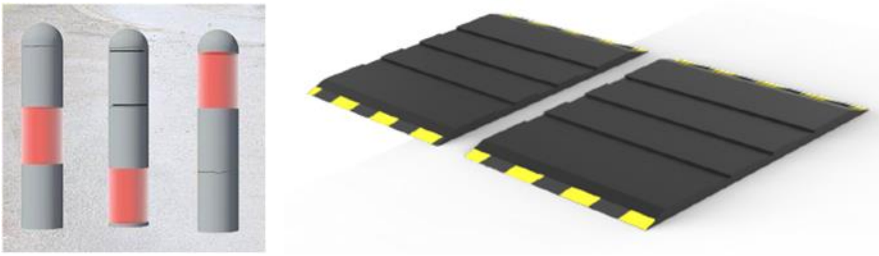

Figure 18. *Example of flashing posts and speed bump.*

<u>Proximity message via in-car device</u>

This measure aims to improve the safety of LCs by supporting car drivers to adapt their driving speed at the LC approach by providing different messages to their in-vehicle device. The content of these messages vary according to the status of the LC (LC closed, LC at 300 m, no crossings etc.) (Figure 19).

Figure 19. *Examples of messages provided to car drivers.*

3.2.2. Method and data to evaluate the piloted measure

All measures were tested in the driving simulator of SNCF. The main aim was to identify the effects of the implemented safety measures on driver behaviour by comparing driving behaviour at an LC before and after implementing these measures. The evaluation was conducted based on within subjects before and after measurements.

The baseline data were collected during a 3–4 minute drive in the city centre in a route without any LCs but with a STOP sign, traffic lights, a give way situation, a roundabout and a road outside an agglomeration with a different speed along both a straight line and a curve. In practice, this was a route beginning of the actual test drive in the simulator.

The actual test drives were 20–30 minutes long and the route included both open and closed LCs (seven situations with closed LC and six situations with open LC). The first three LCs in the route were 'classic LCs', which were considered as the control condition. After that, the participants began to encounter LCs equipped with different safety measures.

During the simulation tests and for all LC status scenarios (open-closed), two main sources of data were leveraged to enable the evaluation of safety measures:

- Speed sensor of the vehicle compared to speed limit
- Videos of driver in the vehicle and video of simulation (to compare the time lapse)

After the test drive, each simulation participant was interviewed for 30 to 50 minutes by a cognitive expert according to Vermesch's method. This qualitative explicitation interview allows the subjects to verbalise the mental or physical actions implemented in a situation. The main interview topics were:

- Perception
- Reasoning
- Action
- Comprehension

3.2.3. Evaluation results

In total, 58 persons participated in the simulator study. Of these, 33 persons participated in the safety course and 25 persons participated in the connected vehicle course. Out of all 58 participants, five were professional drivers.

The test subjects were selected based on various criteria for gender, age, occupation, number of years holding a driving license as well as typical trip purpose (work/home or professional appointments) and its frequency:

- 53% of subjects were women and 47% men
- 14 subjects were 14−24 years old and 19 were 25−35 years old (25 subjects were 35−50 years old (of which at least half of them had children)
- 30 respondents had a varying level of education
- Five were professional drivers (commercial, taxis, technicians, etc.)
- 10 subjects reported their annually driving less than 5000 km; 20 subjects 5000−20000 km and 10 subjects more than 20000 km
- In terms of the number of years holding a driving license, seven subjects reported less than two years, eight subjects between two and five years and 43 subjects reported between five and 30 years

Coloured road markings

Interviews with 27 subjects were conducted to evaluate the safety measures. In total, 20 subjects reacted upon seeing the road marking. Only two subjects saw the red “TRAIN” marking and the red line, and the rest only saw the white “train” marking. This reaction resulted in a deceleration at the approach of the LC.

Very scattered results were received when respondents were asked about their understanding of the road markings: i) for some, the marking was perceived as a repetition of the ‘LC ahead’ sign’ (A7 panel) and was perceived to have the same meaning, ii) for others, interpreting the simulator rendering was unclear: Some perceived the marking as a bump, and some focused their attention on reading the text and were subsequently surprised to encounter the LC so soon. Others interpreted the marking as a mandatory stop and others perceived the painted arrow as an instruction to accelerate.

It is likely that the rendering of the simulator did not adequately represent the quality hoped for in reality. Therefore, the results obtained are to be considered with caution, and the evaluation of this safety measure should be performed in a real road environment.

Funnel effect pylons

For this safety measure, 28 subjects participated in testing. Less than 10% of subjects reacted to seeing the pylons by decelerating upon approach to the LC. The safety measure was unseen by 60% of subjects. The remaining 30% saw the safety measure, but did not understand its purpose. Only 10% of subjects understood that the pylons represent a danger zone, and that the funnel effect aimed to reduce approach speed.

It is likely that the rendering of the simulator did not adequately represent the quality hoped for in reality. Therefore, the results obtained are to be considered with caution, and the evaluation of this safety measure should be done in real road environment.

Rings

To evaluate this safety measure, 29 subjects participated in testing. More than half reacted to seeing the rings and the rest approached the LC uninfluenced as they normally would. However, half of these uninfluenced drivers noticed the lights on the arc.

The safety measure was interpreted as a decoration or village entrance by 90% of subjects, and they assumed it had nothing to do with the LC. Some subjects were so concentrated on the safety measure that they missed some information such as the 'LC ahead' sign (A7 panel) or the approaching LC and were surprised at the sight of the LC being closed. Only 10% of the subjects understood that the rings announce the approaching train and closure of the LC. The subjects were often distracted by the rings and did not associate it with the LC.

Traffic lights (Orange flashing traffic light)

In this test, the flashing red light (R24) was replaced with a two-color light (22j) flashing orange. This safety measure was located on a straight road out of town. The (R22j) light flashes orange (lowest light) and is located in place of the flashing red light (R24).

All 32 subjects reported having seen the flashing orange light. Three subjects did not associate the traffic light with the LC and anticipated an intersection instead. Moreover, one subject thought the flashing light was green. Of the remaining 28 subjects, we observed the following:

- 23 subjects thought that the flashing light indicated that the light would soon display red and that the LC would close.
- Two subjects understood that the flashing light indicated that the LC was out of order
- Three subjects understood that the flashing light invited them to cross the LC, but to do so urgently.

Overall, all subjects slowed down at the sight of the flashing orange light, including those who misinterpreted it and anticipated a road intersection instead of an LC. The subjects largely reported being distracted upon encountering a flashing orange traffic light. Elements that drew subjects' attention in particular included the light's orange colour, the flashing itself and the fact that it was the lowest light.

It is worth considering that this safety measure and its attention drawing nature may also generate risks of its own, as drivers may suddenly brake or hesitate, which may increase the risk of being struck by another vehicle. For instance, one subject chose to drastically reduce speed and later reported that "*Well, right here, I practically stopped. Because I did not know exactly why it was blinking, so I thought the barriers would bend down ...* ". Moreover, it is possible that the first time the subjects encounter this safety measure, they will slow down due to habit. Behaviour risks may be further generated when drivers who understand how to appropriately respond to the safety measure are mixed with drivers who are unfamiliar with the safety measure. These risks make the safety measure seem ineffective.

Traffic lights (Green traffic light)

In this test, the flashing red light (R24) was replaced with a green traffic light. This safety measure was located on a straight road in a built-up area. The (R22) light is green and is located in place of the flashing red (R24) light.

All 31 subjects reported that they saw the green light. One subject failed to associate the safety measure with the LC, as they were accustomed to seeing a traffic light on the approach to a junction. Of the remaining 30 subjects, we observed the following:

- 26 subjects associated the green light with permission to cross the LC without precautions
- Four subjects noted a contradiction between the green light signifying a precarious crossing and the LC that they associate with a danger.

As a conclusion, the green light clearly reassured the subjects that the LC is safe to cross. In addition, it also encouraged them to cross the LC without precautions and at higher reported speeds. In some cases, the green light cancelled the caution induced by the 'LC ahead' sign (A7 panel) (lack of indication on the triggering of the LC). When the majority of subjects saw the green light, they assumed no train would pass, resulting in acceleration. Four subjects noted a contradiction between the green light and the LC, and reported some weaknesses of this safety measure. For instance, one subject indicated that: "*... I know that at a green light we have the right to pass but I also know that behind there is the barrier so ... Danger.* ".

Speed bump and flashing pylons

Of 28 subjects participating in testing this safety measure, over half reacted to the speed bumps by lowering their LC approach speed. Although the subjects understood that the bumps indicate nearby danger, few associated the speed bump with the LC directly. It is worth noting that because subjects were so concentrated on the speed bumps, very few noticed the side light beacons. Additionally, some subjects expressed their animosity regarding speed bumps. Speed bumps were considered dangerous for motorcycles and generally uncomfortable.

Proximity message via in-car device

Data were collected from 23 and 25 subjects for the different situations (two subjects were sick and could not attend all the tests). In total, 70% of subjects reacted to the message and associated notification sound (beep) providing information of LC status (LC closed, road works in LC or LC in xx meters). This allowed them to adapt their speed upon approach to the LC and to better prepare for the stop.

For situations in which no message was received, the subjects resumed their existing behaviour and were not worried about the lack of a message. The majority of subjects understood that the messages were sent in order to anticipate situations demanding attention on approach to the LC.

However, the interviews showed that some subjects preferred to concentrate on their driving behaviour instead of the messages. This was because reading messages on a screen was considered distracting and dangerous, as it forced subjects to look elsewhere from the road.

'LC closed' situation

We attempted to observe different reactions to subjects receiving the messages and associated notification sounds. This reaction generally differed depending on the information received by the subject (Figure 20):

- **When the notification sound and message were activated:** the subjects assumed that a train was arriving and that the LC was closed
- **When only the message was activated:** the subjects assumed that a train was arriving except for one subject, who misinterpreted the message

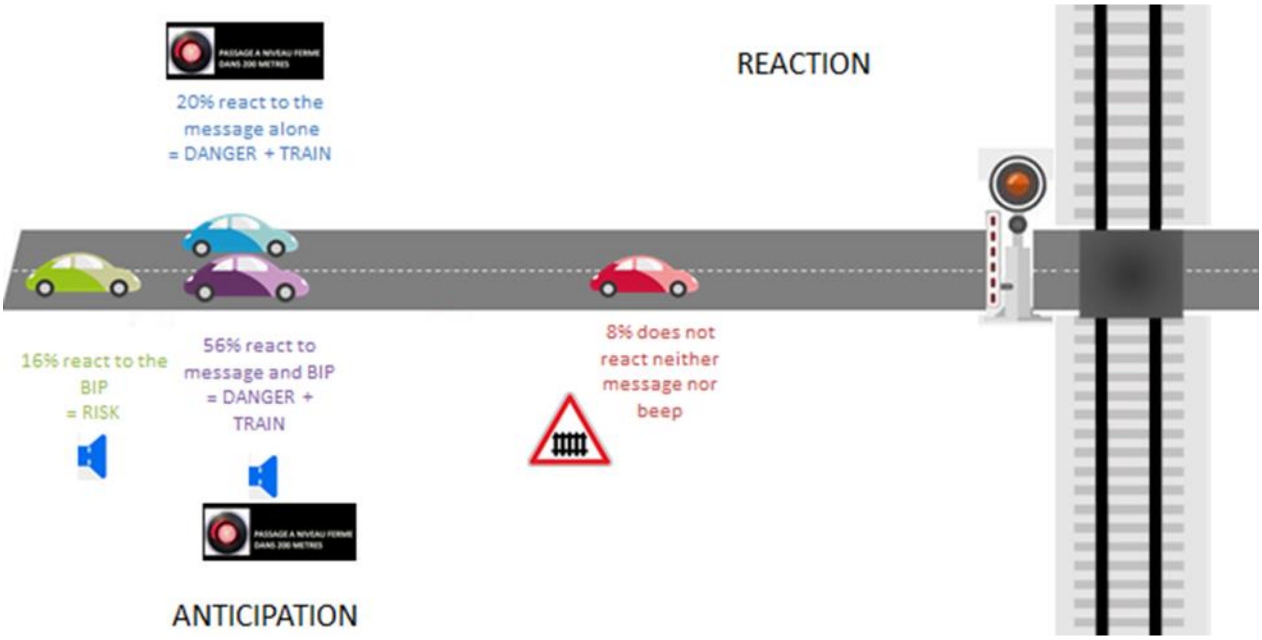

Figure 20. *Diagram of LC closed device.*

When only the notification sound was activated, the subjects received no explicit information regarding what to expect ahead. Two subjects assumed the sound warned of a danger, but they did not identify what it was. Two subjects did not consider the notification sound at all because they perceived it to relate to their existing behaviour. Additionally, the notification sound on its own was distracting for some subjects, and one of which stated that: "*it disturbed me. I said to myself: I do not see a sign and that's after I saw the sign*. ".

Of all subjects, 74% knew before arriving to LC that the barriers were closed. For 25% of the subjects, the information of the LC's closure only came from LC warning devices (bell, lights, barrier) and not via the in-car device.

Road works in LC

The message reminded subjects that they are approaching an LC with barriers and that they must turn left before the LC due to road works (Figure 21). A significant share (61%) of car drivers continued straight ahead despite the road works warning. This was either due to the bad positioning of the panels and/or the approaching vehicle traffic.

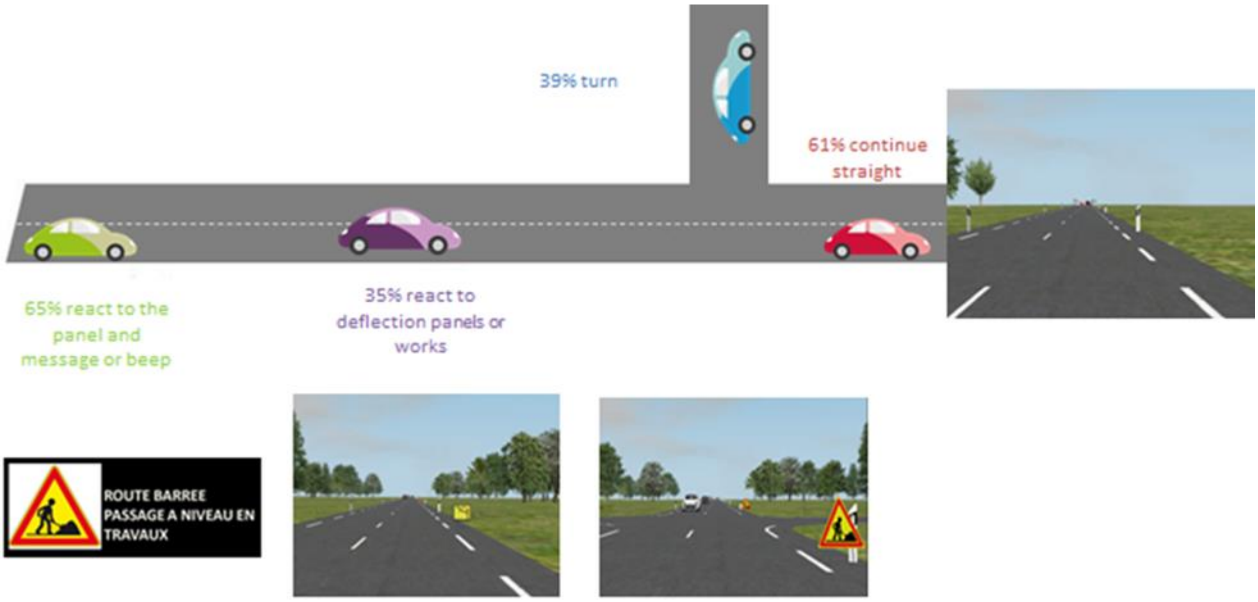

Figure 21. *Illustration of road works in LC.*

LC in xx meters

In this situation, we observed three phenomena shared with the other situations (Figure 22):

- Subjects reacted to the message
- Subjects reacted to the 'LC ahead' sing (A7 panel)
- Subjects waited to see the LC

We observed that although the message allowed the subject to anticipate the risks associated with the LC, it did not provide information of the state of the LC. Thus, at least three subjects considered the message irrelevant because the lateral signalling gave them the same information. Another subject even associated the message with an open LC. In general, this type of message is complementary to the 'LC ahead' sign (A7 panel), which was confirmed by four subjects who believed that it allowed them to anticipate the approach.

Figure 22. *Illustration of LC in xx meters.*

3.2.4. Discussion

It is also important to note that drivers who have experience with the safety measure, and those who discover it the first time, can behave very differently. This can lead to mismatching expectations between road users, who have a different level of experience with the system, creating risky situations.

No information on the cost of measures is available since the tested equipment are from reflections following a design study or a benchmark. Development, integration and maintenance costs were not studied.

3.3. Two simulation environments (VTT)

3.3.1. V2X messaging system between automated vehicles and passive level crossings

The *V2X messaging system between automated vehicles and passive level crossings* was developed with the aim of enabling automated vehicles (AV) to cross passive LCs safely. The detection ranges of sensors used in AVs 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 AVs of approaching trains. However, there are currently no standardised V2X messages for this purpose.

The aim of this measure is to improve safety especially at passive level crossings, as they are typically located far from the infrastructure required for traditional LC installations (safety measures, roadside units etc.), making them cost-intensive. This distance from infrastructure is also the reason why ITS-G5 roadside units (RSU) are unavailable in most cases. However, even with ITS-G5, based on IEEE 802.11p technology, the communication range is still too short for direct communication between the train and the AV. The only cost-effective solution to this problem is the use of a centralised server, which keeps track of train traffic, provides estimated arrival times and creates virtual barriers for all level crossings (Figure 23). The system is very flexible for information dissemination (not exclusive to a single technology or platform). The estimated train arrival time and the state of the level crossing can be delivered via information displays, as well as sent using ITS-

G5 messages either with DSRC (dedicated short range communication) devices or LTE/5G mobile networks. A client contacts the service interface and requests data for a specific LC. In this pilot, ITS-G5 unit was used to simulate a protected level crossing, and an RSU and LTE connection was used for data requests at an unprotected level crossing. The system is very cost effective, because it does not require any additional installations to the LC.

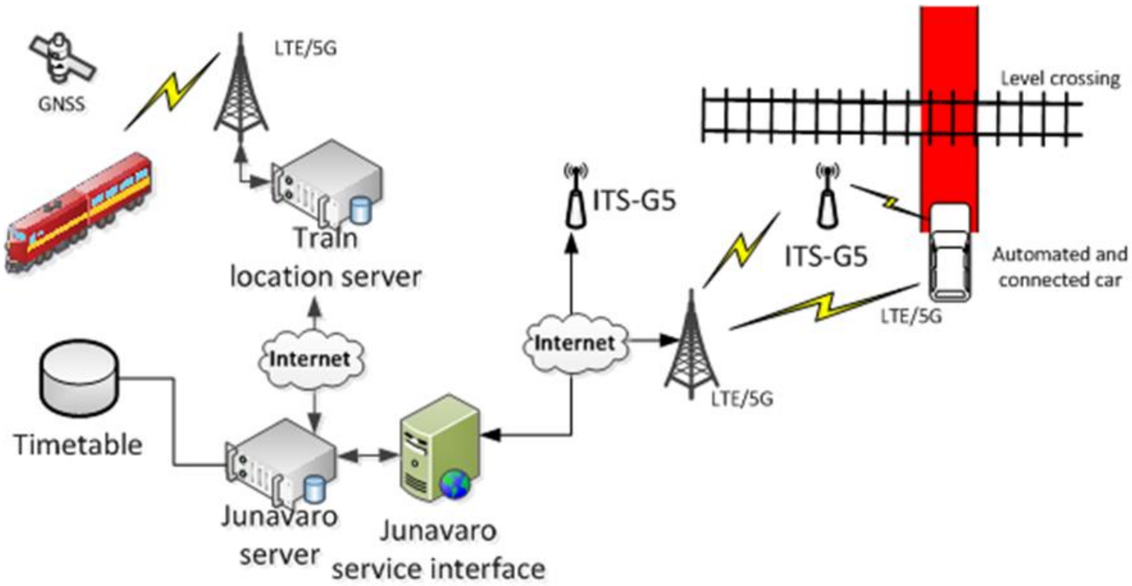

Figure 23. *System architecture to provide approaching train information to automated vehicles.*

SAE J3016 defines six levels (0−5) of vehicle automation (SAE, 2018). In this analysis, it was assumed that the automation level of the autonomous car is 4 or above. This means that the vehicle can drive without driver intervention, and that there can be passengers or the vehicle can also be completely empty.

3.3.2. Method and data to evaluate the piloted measure

The measure was implemented in two simulation environments: 1) In Junavaro data simulator which contains train and level crossing data from Finnish rail section 142 between Hanko and Karjaa and uses train traffic data recorded during May 2010, and 2) in road traffic simulator which utilises GIS information from OpenStreet Map.

Operation

The LC can be compared to a road intersection with traffic lights. However, there are two main differences:

- LC equipped with warning lights has no yellow light to indicate that the status of traffic lights is going to change. Further, in level crossing lights, the green light is replaced with a blinking white light.
- At LCs, cars always drive straight over and there are no right or left turns. Thus, if the LC is closed, it is closed for all road users. Passive LC is also either open or closed, because the train has the right of way for passing. Traffic regulations state, “*Passing the level crossing is forbidden if a train is approaching, traffic lights oblige to stop, a warning sound is heard or*

*the barrier is down or moving. One must stop at **safe distance** from tracks, before the barrier or semaphore*".

Autonomous car cannot determine a safe distance to stop before the LC. Machines are good at measuring things, therefore seconds and metres would be more practical for them. Therefore, a simple map of the LC including the defined stop lines is required. Figure 24 presents an example of such a map. As a minimum requirement, 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 otherwise it will be on the tracks. The length of the rectangle varies and depends on amount of tracks.

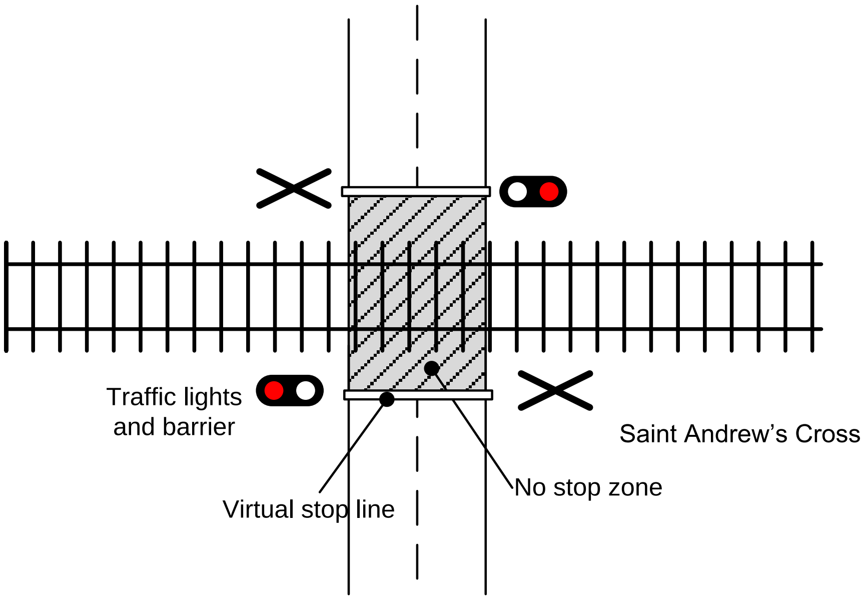

Figure 24. *LC from the autonomous vehicle point of view.*

<u>C-ITS messages</u>

Because protective devices require power, it is possible to install an ITS-G5 DSRC radio roadside unit to the level crossing. Usable messages 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, including 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.
- **SPaT** (SAE J2735) - Traffic light signal phase and timing information and the status of traffic controller. Prediction of duration and phases.

- **CPM** (ETSI TR 103 562 V0.0.17 (2019-08)) Collective Perception Message is a new V2X service under development which aims at disseminating sensory information about the current driving environment by letting vehicles and road infrastructure elements transmit data about detected objects (i.e., about the behaviour of other road participants, obstacles and dynamic road hazards) in abstract descriptions. These descriptions then will be included in broadcast messages called CP messages (CPMs).

Relevance of each of the above options:

- **DENM** message can be used to inform the autonomous car about the presence of a LC and where the area of danger starts and ends, but it does not contain information about LC status, therefore its usefulness for the autonomous car is limited. Autonomous cars use pre-planned routes and a routing algorithm can include LC data to the route. Thus, DENM contain redundant information.
- **CAM** messaging from the approaching train could provide train location information to the autonomous cars. The main problem is the communication range of the ITS-G5, which is only a few hundred meters (Gozalves et al., 2012). Therefore, a relay station is needed to achieve the required communication range. The second challenge is the reliability of the communication. The communication is not failure proof, since one does not know if a missing message means that no train is approaching or no message is transmitted.
- **SPaT** messages can send LC status information to the autonomous car and thus support sensor based recognition. However, since the state of LC is either "open" or "closed", the LC protection system cannot produce "time to green" or "remaining green time" values.
- **MAP** is very useful and contains required features to describe LC geometry precisely.
- **CPM**s carry abstract representations about the status of detected objects (both static and dynamic ones) which represent safety risk in the traffic situations and, therefore, are to be included in the CPM for information sharing, with the objective of warning other traffic participants. CPM messaging is relevant at active LCs where LC infrastructure can produce content to CPM messages.

In summary, using RSU that sends DENM, SPaT and MAP messages together with sensor-based recognition provides enough data for the safe passing of level 4 or level 5 autonomous cars. Concerning level 2 autonomous cars, the control can be passed to the driver who performs the crossing of LC manually.

SPaT and MAP messages are the best choice for autonomous cars, and the Junavaro system can be modified to produce and provide necessary phase and time as SPaT information for the passive LC. By using SPaT messages one can provide compatibility to road intersections' data messaging. The principle of the SPaT calculation is shown in Figure 25.

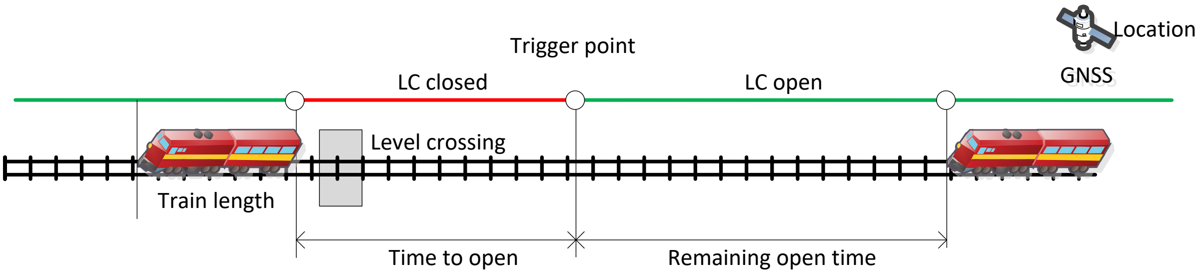

Figure 25. *Principle of the SPaT information determination.*

'Remaining open time' is the time taken for the train to arrive to the trigger point where the LC is set to the 'closed' state. 'Time to open' is the time from the trigger point to the moment where the last railway car passes the LC. Thus, data for train length is required. Fortunately, train composition data is available in the backend systems. If not, one can use some conservative value such as 450 m. Nevertheless, car sensors can detect the train and determine whether the LC is free or not. In a case where multiple trains pass the level crossing subsequently, SPaT messaging integrates all trains as one message. The Junavaro system can show arrival times and directions for all trains approaching the LC.

Additional tests

Additional tests were performed in May 2019 in co-operation with the AutoPilot project. This was done due to the challenges that occurred in the simulator exercises. Specifically, the train did not move fast enough in the simulator, and it did not manage to follow the location information from Junavaro. Because of this, LC opening and closing times did not match between the simulated train and Junavaro.

The test scenario involved a vehicle approaching a junction controlled by a traffic light. In the tests, the autonomous car known as Marilyn received the traffic light's phase data (SPaT), sent using a MQTT (Message Queuing Telemetry Transport) protocol, and would then perform the relevant required action. When the traffic light displayed red, the objective was that the car would stop before a virtual stop line (Figure 27). When the traffic light displayed green, the car resumed movement and continued on its route. The objective of the AutoPilot project was to measure the performance of the IoT-platform's communication capability, while the SAFER-LC project aimed to evaluate the performance of the car itself.

Figure 26. *Autonomous car stopped before a virtual stop line.*

Measured values included the accuracy of stopping at the correct point as well as the time taken for the vehicle to resume movement after the traffic light's change of state. The route was on a downhill slope and the vehicle's approach speed was 20 km/h. The vehicle was set to stop five metres (the length of the vehicle itself) before the virtual stop line. The test was repeated 16 times.

3.3.3. Evaluation results

Figure 27 presents an example of SPaT data produced by the modified Junavaro system from Kirkkotie level crossing which is located at railway section 142 in Finland (59,864443°, 23,075697°, WGS84). 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.

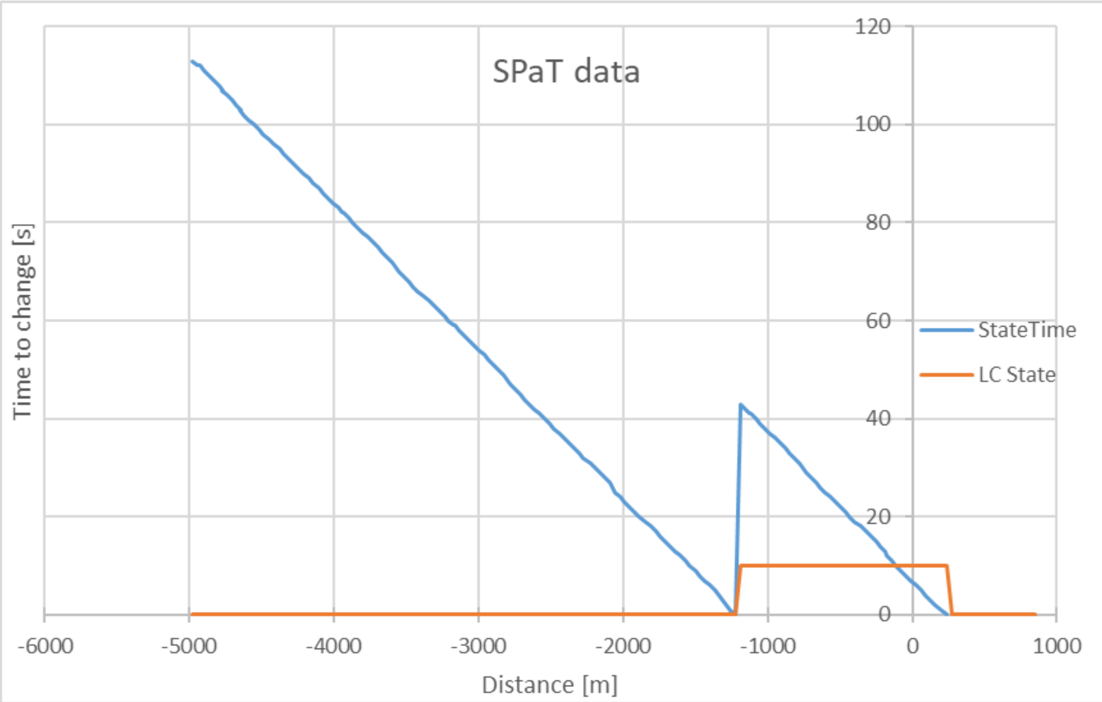

Figure 27. *Example of the SPaT data produced by the Junavaro system.*

The behaviour of an autonomous car is illustrated in Figure 28. 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 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. A virtual obstacle is set, if the analysis shows that LC is “closed” when the car arrives to the LC. Once the LC is again “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.

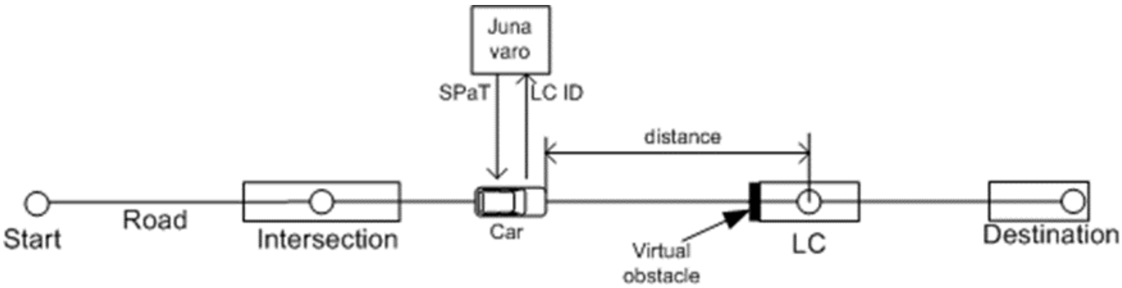

Figure 28. *Autonomous car behavior when approaching the LC.*

The average stopping distance of the car in the additional tests was 4.22 meters from the virtual stop line (Table 9). The length of the car from the rear axle (reference point) to the front bumper is 3.8 m.

Therefore, the average distance from the car front to the virtual stop line was 0.42 meters. In one case, the virtual stop line was overshoot by 0.86 meters. However, this overshooting was not severe.

Table 9. *Stopping distance from virtual stop line.*

Run	Longitude (WGS84)	Latitude(WGS84)	Distance [m]	Distance to car front [m]
1	23,8839392	61,45454267	2.93	-0.86
2	23,8839488	61,45455367	4.25	0.45
3	23,8839455	61,45454983	3.79	-0.00
4	23,8839497	61,45455567	4.47	0.67
5	23,8839492	61,4545545	4.34	0.54
6	23,8839478	61,45455283	4.14	0.34
7	23,883949	61,45455417	4.30	0.50
8	23,8839483	61,45455383	4.25	0.45
9	23,8839502	61,4545555	4.46	0.66
10	23,8839503	61,45455533	4.45	0.65
11	23,883949	61,45455417	4.30	0.50
12	23,8839493	61,45455433	4.33	0.53
13	23,8839492	61,45455433	4.32	0.52
14	23,8839485	61,45455383	4.26	0.46
15	23,8839497	61,45455583	4.48	0.68
16	23,8839492	61,45455483	4.37	0.57
		Average	4.22	0.42
		STD	0.38	0.38

The average duration from the traffic light changing its state to green to the moment when the car resumed movement was 908 milliseconds, with a deviation of 319 milliseconds (Table 10).

Table 10. *Time difference between the traffic light changing its state to green to the moment when the car resumed movement.*

Run	Time difference [ms]
1	508
2	674
3	744
4	743
5	733
6	747
7	1,248
8	1,494
9	1,176
10	1,261
11	1,254
12	782
13	758
14	652
15	478
16	1,273
Average	**908**
STD	**319**

Safety aspects

The detection of trains sufficiently early using sensors of the automated vehicle involves uncertainties depending on sensor setup, sensor location (especially installation height), weather conditions as well as unknown and variable visibility barriers like vegetation or snow banks. Fully autonomous vehicles no doubt require support for passing passive level crossings safely.

3.3.4. Discussion

Level crossings are an interface between road and rail environments. If an autonomous car needs to pass the LC and its automation level is less than 4 (SAE, J3016), the control of the car can be passed to the driver, who then manually operates the car over the LC. If the automation level is 4 or above this is not possible, since no driver intervention is required.

An autonomous car follows the planned route and therefore the presence of the LC along the route is known. The autonomous car can detect the protected LCs by using environment perception sensors. The protected LCs have mains power available, and hence a roadside unit can be used to send C-ITS messages. The most useful C-ITS messages for autonomous cars are SPaT and MAP messages, where the former provide information on the status of LC and the latter precise geographic presentation of the LC environment.

Today, the majority of level crossings are still unprotected. Train speeds can be up to 140 km/h, which require minimum visibility range of 840 meters to both directions from road to railway tracks. Today, the detection range of the sensors used in autonomous cars reach up to 250 meters in a good visibility conditions. However, the adverse weather conditions dramatically limit the available detection range. Therefore, the use of environment perception sensors alone cannot guarantee the safe passing of LCs.

The pilot tests demonstrated the importance of the communication system's real time nature. The MQTT-protocol used has been developed for IoT-platforms, in which the transmission of all messages is more important than delivering them on time. In real time systems, if a message cannot be delivered, new messages should overwrite it. This avoids message queueing and delivers the most recent data.

Message timestamping is highly important, and requires time synchronisation through the system. The required accuracy for timestamp comparison operations is achievable by using GNSS to record the time. However, it is important to consider that every operation in the chain increases transmission delay. Finally, when the data reaches the end user, one must know how old the data is and whether it is trustworthy. Delays and short communication breaks are manageable with estimation models.

Train location and velocity data serves as the base information which everything else depends on. On its own, GNSS is not capable of providing reliable location information in all circumstances (e.g. tunnels). This calls for a more integrated solution. Additionally, the availability of location data is more important than its accuracy. Arrival time estimation relies only on longitudinal location data. For example, a 10-metre error in the location data does not correspond to a great amount of time. However, if one wants to locate the train on for example parallel tracks, the accuracy requirement is stricter. The integrated location system requires the use of information from railway balises[3] and odometer of train to fulfil inaccuracies in GNSS-based positioning.

The reliability of system information may be improved by comparing detected train locations with signalling system and timetable information. All three information types should match each other. Thus, it is possible to detect broken equipment and rail sections where trains are moving and reliably adapt system information.

Summary of requirements for the system functioning:

- Integrated positioning system in train using high quality antennas and receiver
- Reliable low latency communication between train and back office system
- Up to date and accurate GIS information of the rail network
- All self-propelled railway equipment are included in the system
- Standardised information delivery protocols

To conclude, SPaT and Map C-ITS messages should be used to achieve compatibility with road infrastructure and traffic light intersections. As autonomous cars drive a predefined route, upcoming level crossings are already known. In order to use level crossing information, the crossing must have a unique identifier (Unique id). Map messages require accurate GIS information, which requires mapping the level crossing area (Map data and base information on LCs; name, location and is

[3] An electronic beacon or transponder placed between the rails of a railway as part of an automatic train protection (ATP) system (Wikipedia 2019).

protected or not). In addition, information must be geographically accurate (< 1m) to ensure that the autonomous car can stop at a safe distance from the level crossing.

3.4. Aachen test site

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

The system includes two main functionalities (Figure 29):

1. Detection of potentially dangerous situations (obstacles, vehicle stopped at LC, approaching train etc.) by cameras and/or vehicle to everything (V2X) communication
2. Wired communication between the cameras and level crossing (LC) unit, G5 communication between the roadside units (RSUs) and LC unit, and G5 communication between the LC unit and vehicles (road vehicles and/or train)

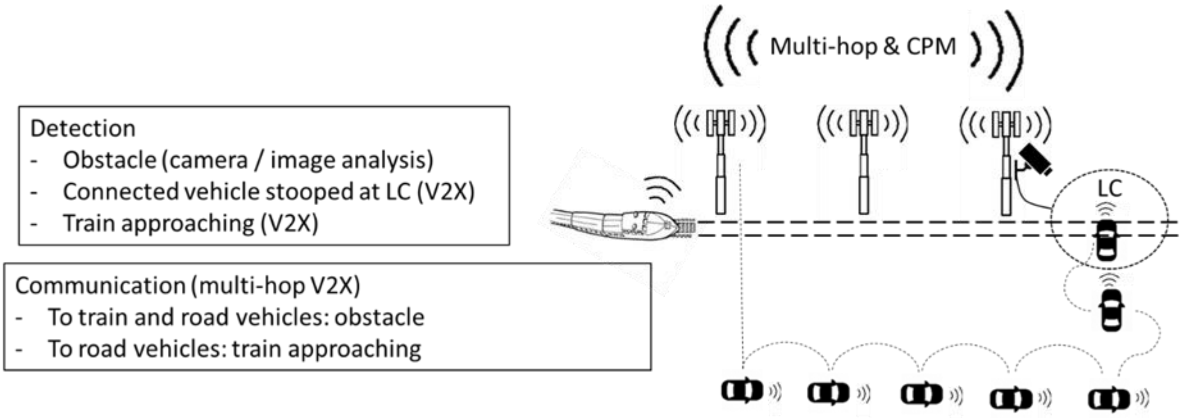

Figure 29. *Detection and communication scenarios tested in Aachen.*

The above functionalities can be used for the following safety purposes: 1) to close the barriers based on the estimated time of arrival (ETA) of the approaching train, and 2) to deliver in-vehicle messages and alerts to the control room about a dangerous situation using decentralized environmental notification messages (DENM) and collective perception messages (CPM) to cars equipped via a specific on-board unit.

The individual measures linked to this combined measure are presented in subchapters 3.4.1–3.4.4.

3.4.1. Smart Detection System (CEREMA & UTBM)

Piloted safety measure

The piloted safety measure is *Smart Detection System (SDS)* which supports the railway stakeholders in identifying the potentially dangerous situations occurring at level crossings and enabling them to act on time to prevent the potential accidents. The Smart Detection System will detect and classify the potentially dangerous situations occurring at LCs based on up-to-date video data. After detection, the Smart Detection System sends an alarm to the control room together with the up-to-date video images from that specific LC. The operator will then assess the situation and decide whether any action is needed to ensure the safety of LC.

Method and data to evaluate the piloted measures

The following aspects were tested during the piloting of this measure:

- The connection between smart detection system and smart RSU of NEOGLS
- The connection between smart RSU and communication unit (which can deliver information to trains or in-vehicle on board units carried out by IFSTTAR team)
- The connection between smart detection system, RSU and in-vehicle on board unit
- The connection with the control room and the possibility to provide up-to-date video data together with the alert messages in case of a detected event (i.e. potentially dangerous situation)
- The performance of the system in term of scenarios' recognition. In this study, a scenario is an event (e.g. a car is coming on the LC and stopped for a while) that is played by one or several actors. The scenarios can involve cars, pedestrians, train, or other objects. Based on this, also what we call as 'event' is a scenario automatically detected by the SDS. The evaluation of the SDS has been realised considering that in case it is installed at a level crossing with a high security context, its ability to **detect events** (stopped cars, pedestrians etc.), whatever their nature, is crucial. Further, every time an event is detected, an alarm is sent at least to the control room with the corresponding video. Therefore, it is very important that the system is able to **detect an event** from its beginning to its end and to send an alarm accompanied with the related video. In this case, the operator in his control room is warned, the video is displayed and it is up to them to decide on the appropriate actions according to the data received. The difference between detection and recognition is the following: detection means that the system detects an event without providing information on the nature of the event (i.e. there is something or somebody on the LC). Recognition means that the system has detected something and is able to qualify its nature (a car stopped, a pedestrian, etc.). For this purpose, we propose four different evaluation indicators:
    - **Perf_Detect** = (number of events detected by the SDS)/(number of the events correctly detected by the SDS + the number of events not detected by the SDS). This indicator measures the ability of the system to detect an event whatever its nature. This indicator is calculated for every video (41 videos) but we have decided to group the evaluation by distinguishing Cerema Datasets and Aachen datasets, as their contexts are quite different.
    - The indicator **Perf_Detect_Weather** is used to calculate the ability of the SDS to detect events according to the weather conditions. Among the 41 videos collected, seven different weather conditions were defined:
        - High sun with shadows created by objects, wind
        - Sun and shadow on the LC
        - Cloudy and low illumination
        - Snow and low illumination
        - Cloudy with low average illumination with small rain

- Snow with very low illumination
- Cloudy higher illumination

The same formula than that of **Perf_Detect** was used, but applied to sub datasets, each one corresponding to a specific weather condition. The indicator **Perf_Detect_Weather** was used to calculate the ability of the SDS to detect events according to the weather conditions.

- **Perf_Detect_recog** = (number of events recognised by the SDS)/(number of the events correctly recognised by the SDS + the number of events not correctly recognised). This indicator measures the ability to detect and recognise the nature of an event (car, train, pedestrian, etc.). This indicator is calculated for every video (41 videos) but we have decided to group the evaluation by distinguishing Cerema Datasets and Aachen datasets, as their contexts are quite different. In principle, it is enough for the railway operator that the event is detected and sent to the control room together with the corresponding video. However, in our case, it is also possible to detect and recognise the event (stopped cars, pedestrians, bicycles, etc). Hence, in this case it could be useful to calculate a second indicator that we call **Perf_Detect_Recog** (See deliverable D3.5; Bakey et al. 2019).
- The indicator **Perf_Detect_Recog_Weather** is used to calculate the ability of the SDS to detect and recognise events according to the weather conditions.

In order to have a complete and comprehensive evaluation, the performance of the system in terms of scenario recognition (means detect and recognise the nature of the event: car stopped, pedestrian, etc.) was evaluated by using two video datasets: one recorded at Cerema test site and another at Aachen test site. During the assessment, the scenarios recognition was compared with the ground truth (ground truth was obtained from manual annotation of initial raw video data and comparison with the automatic scenarios' recognition) which was directly provided by the raw video data (collected during piloting at Cerema test site and at Aachen test site). During the piloting, the system was operating constantly and thus it was possible to have several scenarios involving the same vehicle.

Many different scenarios were played at Cerema test site and at Aachen test site. These scenarios include cars, pedestrians, a small train, moving cars, stopped cars, moving pedestrians, stopped pedestrians, several cars at the same time constituting jams. At the beginning, a classification of all scenarios (events) was organised into different categories, but since the categories were not so different in terms of type during the evaluation, (for instance an atypical behaviour can be considered firstly as an obstacle and then as an atypical behaviour), it was decided to focus on the detection capabilities of the SDS. All scenarios were simulated with different barrier configurations (open and closed periods) with several dozens of repetitions to make the results statistically representative. For each scenario, the video data was stored, the detection was performed and information exchange between smart detection system and RSU was carried out.

The more specific variables included in the evaluation were:

- Detection performance (Perf_Detect and Perf_detect_weather indicators),
- Recognition performance (Perf_Detect_recog and Perf_Detect_Recog_Weather indicators)
- Processing time,

- Sample size, and
- Ability to transmit information

Evaluation results

The results of main variables evaluated during the testing are presented in Table 11.

Table 11. *Results of the main variables included in the testing.*

Evaluated variables	Results
The connection between smart detection system and RSU	During the tests, each scenario detected by the Smart Detection System was sent to the roadside unit (RSU). This exchange of data was done on exactly 1,038 events (scenarios played) for the two datasets Cerema and Aachen. No anomaly in the exchanges was identified.
The connection between RSU and communication unit (which can deliver information to trains or in-vehicle on board units).	This communication protocol is shared between NeoGLS and IFSTTAR.
The connection between smart detection system, RSU and in-vehicle on board unit	This global chain was tested in the third test phase in Aachen for a number of scenarios. When using a single vehicle to receive the event of the Smart Detection System, the range was about 80 meters. This was partly due to the test site location (several trees, buildings etc.). By using several vehicles to make multi-hop, a range of 180 meters was reached (with only one relay vehicle). With two relay vehicles this range can be reach to 500 meters.
The connection with the control room and the possibility to provide up-to-date video data together with the alert messages in case of a detected event (i.e. potentially dangerous situation)	The communication between the Smart Detection System and the control room was tested during the last test session. The Smart Detection System sent continuously image buffers of 5 s and when an event was detected, the operator in his room received a pictorial or audible warning and the video which corresponds to the event. The tests were conclusive. The duration of the buffer is configurable.
The performances of the system in terms of detection and recognition and during different weather conditions	The average performance of detection of the system is 84% (Perf_Detect indicator): 79% for Cerema datasets and 88% for Aachen datasets; the performance of recognition is 72% (Perf_Detect_Recog indicator): 75.5% for Cerema datasets and 68.5% for Aachen datasets. The difference in detection performance among cases with different types of weather is not considered significant. The worse performance was observed in cases with low illumination. Indeed, the performance of recognition during “Snow with very low illumination” is 38.8%. Nonetheless, the performance of detection for this weather situation is 93,7%. This means that the SDS is quite powerful for the detection performance (which is the most important) and could meet

	some difficulties for the recognition task during bad weather conditions. Much more data is needed to reinforce the results.
The classification of objects	In the retrieved bases, we are able to differentiate between pedestrian, car, train and two-wheel vehicles. We have evaluated the capability of the system to classify objects. To do that, we have used 24 videos among the 41 available. These videos contained 341 objects. The classification was correct for 268 objects and not correct for 73 objects. This lead to a classification rate of 78.6%. There was a very big variation for the objects classification. The classification errors were mainly linked to ambiguities cases: bicycle moving on the axis of the camera (this lead to a confusion between a person and a bicycle. It was also the case for some heavy vehicles (trucks, bus, train). Some occlusions were always present at Aachen test site because of the lack of room to locate the video sensor correctly. This affected a lot the classification rate. For pedestrians, cars in normal situations (no occlusions for example), the classification rate was close to 100%.

The smart detection system is a technical evaluation, a proof-of-concept and the functioning of the system was tested only during few days. The system addresses mainly situations where there are traffic disruptions on LC, such as stopped vehicles or traffic jams, by providing better situation awareness for the traffic management. Table 12 presents the numerical results calculated based on the pilot data.

Table 12. *Numerical results of the main variables included in the testing.*

Evaluated variables	Results
Detection performance (Perf_Detect indicator)	▪ Detection performance per dataset:Global datasets: 84% ▪ Cerema datasets: 79% ▪ Aachen datasets: 88% Detection performance per weather condition: ▪ High sun with shadows created by objects, wind: 80% ▪ Sun and shadows on the LC: 100% ▪ Cloudy and low illumination: 73.5% ▪ Snow and low illumination: 93.6% ▪ Cloudy with low average illumination with small rain: 87.7% ▪ Snow with very low illumination: 100% ▪ Cloudy with higher illumination: 88.9% The detailed formulas for the detection performance are included in deliverable D3.5 (Bakey et al., 2019).
Recognition performance (Perf_recog indicator)	Recognition performance per dataset: ▪ Global datasets: 72% ▪ Cerema datasets: 75.5% ▪ Aachen datasets: 68.5% Recognition performance per weather condition: ▪ High sun with shadows created by objects, wind: 68.5% ▪ Sun and shadows on the LC: 100% ▪ Cloudy and low illumination: 72% ▪ Snow and low illumination: 77.5% ▪ Cloudy with low average illumination with small rain: 70.2% ▪ Snow with very low illumination: 38.8% ▪ Cloudy with higher illumination: 100%
Processing time	The smart detection system is able to process data up to 25 frames per second. This is compatible with a real time implementation, which means that every entity crossing the LC will be detected, whatever its speed.
Sample size	In total, 41 videos that correspond to around five hours of video data, composed of 1,038 events (including cars, pedestrian, objects, etc.) detected by the SDS. Cerema and Aachen data consist of 523 and 515 events respectively, totalling to 1,038.
Ability to transfer information	100% between smart detection system and RSU, 100% between smart detection system and control room. This last functionality is based on a web platform (platform that enables to build solutions that enable delivery of content).

<u>Quantification of safety effects</u>

To estimate the safety effects of the current system based on empirical data, the system would need to be installed for a long time on one or more LCs to monitor how many accidents and incidents are avoided, which is out of the scope of this project.

From the literature and discussions with numerous domain experts we can conclude that the SDS is one important component of a global system which could be installed at LC premises. The global system could be called “An Intelligent Level Crossing”, as it integrates functions of advanced sensors, communications and information technologies in order to improve safety and operational efficiency at rail-road crossings.

The main benefits offered by a well-designed Intelligent Level Crossing system are (i) increased security and safety of the road users, train passengers and rail staff, (ii) improved efficiency of the rail and road traffic management by provision of real-time information to rail and road users on the status of the traffic network (for example, possible route alterations due to traffic jams at level-crossings).

Such system has the capability to detect the conditions at the level crossing, identify potentially hazardous situations, notify the local traffic management system, trigger the system response accordingly, and provide advanced warnings to the vehicle users and train drivers.

The purpose of obstacle detection systems is to prevent vehicle and train collisions at level crossings. They allow for the timely detection of objects caught within the level-crossing area and provide means for automated alert notification and activation of an appropriate network response (such as setting off the warning signs, lifting/closing the barriers, train route alterations, or partial closing down of the rail network). The main benefit of these systems is that they are potentially capable of fully automated performance, remote control and system failure diagnostic.

<u>Discussion</u>

The following challenges were identified during piloting:

- The transfer of video data to control centre was not as simple as expected. Some modifications to software configuration between the software implemented on the test site computer and the office computer were needed.
- The range (functionality tested only at Aachen test site) between the smart detection system and the in-vehicle on-board unit was not very high (around 300 m) because the Aachen test site was not open-air, and there were many obstacles such as buildings, trees, etc. The multi-hop testing (by using several vehicles) enabled us to reach 500 m as a distance range.
- According to experts, the operator is very busy at his control room and does not need to have details on a detected scenario. It is sufficient for them to know that something very trivial is happening on the LC (like car stopped on the LC for a given time) because they receive video data at the same time. For instance, in some cases they were not interested by a pedestrian crossing or stopping on the LC. They want to be notified only for critical events. To this end, the system’s evaluation focuses on detecting entire events and transmitting them to the control center, which is a more relevant evaluation.

Lessons learned

Some typical considerations linked to the SDS itself and to image processing techniques were noticed. A qualitative evaluation was carried out when comparing the ground truth and the automatic detection of scenarios.

Some scenarios were not taken into account, because of their limited duration.

The video's point of view is highly important. It was found that the system performs best when the sensor is installed at a vertical position.

Recommendations

The position of the video sensor is also very important and relevant to the scenarios the system is meant to recognise. The video sensor has to be located in such a way that it embraces all the vicinity of the level crossing in order to avoid problems linked to occlusions.

Applicability of results to different circumstances

The SDS was tested in two very different test sites and under changing weather conditions including sun, clouds, sudden illumination changes, rain and snow. Its performance was not degraded by the conditions.

Conclusions

The main performance of the SDS is its ability to detect and transmit events. It was measured on Cerema and Aachen datasets and the overall event detection performance is around 84%, while the scenarios recognition performance is around 72%. The detection performance is considered by far the most important.

There is no significant influence of the weather conditions on the ability to detect or recognise events, except for cases when illumination is very low which typically result in the detection being delayed.

The SDS evaluation was realised utilising two datasets, and therefore could be different if other scenarios were tested. The authors believe that an even more representative evaluation is indeed possible, but it would either require richer data sets recorded over longer periods, or testing under real world conditions, during normal operation of a LC.

3.4.2. Early detection and hazard information warning by means of Collective Perception Messaging (CPM) and driver's warning (COMMSIGNIA)

<u>Piloted safety measure</u>

The piloted safety measure is called as *Early detection and hazard information by means of collective perception messaging and driver's warning*. This measure consists of three safety vehicle-to-everything (V2X) communication-based applications, aiming to improve the safety of LCs:

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

The first application warns drivers of both road and rail vehicles about dangerous traffic events identified in LCs. This is achieved by issuing critical collision warning to road vehicles and trains whenever the train's collision with a V2X enabled road vehicle is imminent at LCs. The information supports the car drivers in avoiding collisions with trains (e.g. helps them to escape from the car in case of last second hazard situations) and supports the train drivers in mitigating the severity of collisions in LCs by reducing speed. The collision warning can also be delivered to the train in case a pedestrian (or any pre-specified type of object) blocks the LC and the collision with the arriving train is imminent.

The second application provides more accurate information on train arrival to active LC. This application identifies the presence of the approaching train by sensing and disseminating rail specific CAM messages by means of collective perception technology and CPM messaging. Train position information is made available in the LC that can be used in the calculation of the timing of safety actions such as barrier closing and opening.

The third application has the same objective as the second, however, instead of CAM messages, it triggers DENM messages on train upon arrival and disseminates these messages by means of multi-hop forwarding using the available V2X infrastructure and/or intermediate V2X capable vehicles' functionality.

The above scenarios demonstrate the capabilities of standard V2X use-cases in 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 collective perception and drivers' warning technologies.

These safety applications were developed in response to the need of cross-modal information exchange between road and rail vehicles drivers. The piloted V2X applications operate by collecting relevant environmental information and sharing this information among road and rail users/drivers in an attempt to support corrective actions.

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

<u>Method and data to evaluate the piloted safety measure</u>

During the piloting, the performance and capabilities of selected V2X safety applications were demonstrated regarding the clearance assurance and safety enhancement of LCs. Clearance assurance means the proper monitoring and processing of movement information of V2X capable vehicles around LCs, as well as last second warning of drivers in case of imminent hazard. The experimental applications were tested and operated in real traffic environments and hazard conditions.

The performance of the system in terms of scenario recognition was carried out using video data. Video data and interactive log files were used as input but also as ground truth utilised by this validation report. The applications realising the scenarios were verified by event logging and time stamp analysis of the safety messages and by measuring and evaluating safety parameters (e.g., target radius, dangerous closest distance, time to collision) which have direct influence on the performance and sensitivity of the communication.

The evaluation data consisted of information from message logs and HMI information evaluation. The evaluation included the following main use cases:

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

- Train detection range enhancement 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 perception service of V2X technology in LC environments in extending the perception range of the cars for several km. Cars wanting to cross the LC will be able to elongate their warning horizon in hazard situations.
- Another scenario demonstrates the capability of the multi-hop DENM forwarding technique in early train detection. The method is based on the Geonetworking protocol and fast forwards train position (arrival) information initiated by the train itself to a distant LC environment using the available V2X infrastructure.

<u>Evaluation results</u>

The evaluation was conducted for three main use-cases (UCs) which scenarios included different use-case scenarios. The total number of evaluated scenarios was six as they follows:

Use-case 1: Intersection assist safety applications in LCs

- LC intersection management from view of the ego (road) vehicle (use-case 1.1): Real time front-to-train and side-to-train collision monitoring and mitigation of the severity of collision hazards for road vehicles while in normal traffic speed.
- LC clearance management for train I (use-case 1.2): This scenario is a differently tuned Scenario #1 for rail vehicles. Train will use the intersection assist safety application with differently tuned parameter sensitivity.
- LC clearance management for train II (use-case 1.3): It warns car driver about the approaching train while the car gets in a dangerous situation inside, or in the dangerous vicinity of the LC (e.g., braked down vehicle) and helps to escape from the car in case of last second hazard situations.
- LC clearance management for train III (use-case 1.4): Collective Perception Message generation and distribution upon the detection of hazardous object in the LC.

Use-case 2: Detection range extension by means of collective perception

- Remote detection and monitoring of the approaching train (use-case 2.1): Large distance detection and sensing of the approaching train and dissemination of its changing position information towards LC by means of collective perception technology and CPM messaging.

Use-case 3: Perception range extension by means of multi-hop DENM forwarding

- Remote detection of the approaching train by means of multi-hop DENM forwarding with drivers warning (use-case 3.1): This is to advertise the presence of the coming train by triggering DENM messages on train upon arrival and disseminating these messages by means of multi-hop message forwarding.

Each of the above scenarios are presented in the tables (Table 13, Table 15, Table 17, Table 19 , Table 21, Table 23) followed by their corresponding evaluation data (Table 14, Table 16, Table 18, Table 20, Table 22, Table 24). The evaluation data to assess the safety effects covered the following variables: ‘Detection accuracy’, ‘Detection rate’, ‘Processing time’, ‘Sample size’, ‘General usability conditions’, ‘Stability and maturity of the solutions’, ‘Environment conditions for processing’, ‘Ability to work in hard conditions’, and ‘Ability to efficiently transmit information in the test scenario’.

Table 13. *Description of scenario 1.1.*

Scenario title	LC intersection management from view of the ego (road) vehicle
V2X application	LC intersection management safety application (LIMA)
Objective	The safety app issues critical collision warning to road vehicles and the train when the trains' collision with a V2X enabled road vehicle is imminent. The safety app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It helps car drivers to avoid front-to-train and side-to-train collision situations and mitigate the severity of collision hazards for trains.
Equipment	Car with OBU with LC intersection management safety application and HMI Train with OBU with LC intersection management safety application and HMI
Description	1: Car travels in a neutral direction regarding the LC geometry. This means either the car is (yet) outside of critical LC proximity or it travels in a neutral direction (presumably not wanting to cross the rail track). 2: Train is approaching the LC. 3: Car suddenly changes travel direction and heads for the crossing of the railway (or it gets in critical proximity to the LC) and the estimated movement trajectories of the train and road vehicle might have common points in the LC (i.e., the two parametric curves intersect) and as such, a probable collision with the arriving train can be confirmed. 4: The app triggers notification to both car and train drivers that the collision is imminent 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.
Enabling technology	CAM processing and sensor fusion
Measures to be evaluated	Application loading and reaction time, remaining time to collision
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	Target radius (the radius in which vehicle relative locations are evaluated), dangerous distance (the minimal distance between two vehicles which cannot be reduced any further without risking the collision).
Open issues	None
Notes	This application works in the very same way from view of the train (different ego vehicle). Sensitivity parameters, however, should be set differently for the train. Determination of the proper sensitivity setup and making proposition for a real application configuration is among the main the subjects of this scenario.

Table 14. *Evaluation data of scenario 1.1.*

Variable	Results
Detection accuracy	Standard V2X detection rate is 10 Hz. This sampling rate is sufficient and provide satisfactory event recognition resolution in LCs where the expected maneuvering speed of cars are less than 60 Km/h. Estimation of remaining time to collision is continuously updated during the dynamical scenario.
Detection rate	Standard V2X detection rate is 10 Hz.
Processing time	Processing time is within the limit of the detection rate i.e. it is less than 0.1 sec per one hit.
Sample size	The use-case was repeated 5 times with consistent evaluation results.
Usability	Usability of this use-case in real situations is well established based on Day 1 V2X safety applications. The scenario can be integrated in LCs without risk. High speed trains (over 80 Km/h) may pose safety challenges, however. The V2X parameters “target radius” and “dangerous distance” must be assigned dynamically with respect to the actual speed of the train. Further experimentation is needed.
Stability	The intersection management safety application is a quality assured, standardised V2X application that must be stable and providing repeatedly consistent results which can be used in LC environment.
Environmental conditions for processing	The approaching train is assumed to be in a microwave visible area.
Ability to work in hard conditions	No specific requirements over standard V2X operability conditions.
Ability to efficiently transmit information	Information exchange between various actors (i.e. road and rail vehicles) are performed on secured and coded information channels. Exchange rate of information is proportional to the V2X detection rate i.e., 10 Hz.

Table 15. *Description of scenario 1.2.*

Scenario title	LC clearance management for train I.
V2X application	LC intersection management safety application (LIMA)
Objective	The safety app issues critical collision warning to vehicles and the train when approaching LCs in the forward path of travel when a collision with a V2X enabled vehicle is imminent (dangerously approaching road vehicle towards LC). The app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It helps train driver to mitigate the severity of collisions in LCs.
Equipment	Car with OBU with safety application and HMI Train with OBU with safety application and HMI
Description	1: An unwary car approaches the LC (e.g., in dangerous speed or incautious behavior) presumably not intending to stop before of the rail track and its movement trajectory might have a probable collision point with the arriving train. 3: Train is approaching the LC 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.
Enabling technology	CAM processing
Measures to be evaluated	Application loading and reaction time, remaining time to collision
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	target radius, dangerous distance
Open issues	None
Notes	This scenario is a differently tuned Scenario #1 meaning that rail vehicles will run the safety application with different parameter setup. Sensitivity parameters should be set differently for the train and the cars. Determination of the proper sensitivity setup and making proposition for a real application configuration is among the main the subjects of this scenario.

Table 16. *Evaluation data of scenario 1.2.*

Variable	Results
Detection accuracy	Standard V2X detection rate is 10 Hz. This sampling rate is sufficient and provide satisfactory event recognition resolution in LCs where the expected maneuvering speed of cars are less than 60 Km/h. Estimation of remaining time to collision is continuously updated during the dynamical scenario.
Detection rate	Standard V2X detection rate is 10 Hz.
Processing time	Processing time is within the limit of the detection rate.
Sample size	The use-case was repeated 5 times with the same positive evaluation results.
Usability	Usability of this use-case in real situations is well established based on Day 1 V2X safety applications. The scenario can be integrated in LCs without risk. High speed trains (over 80 Km/h) may pose safety challenges, however. The V2X parameters “target radius” and “dangerous distance” must be assigned dynamically with respect to the actual speed of the train. Further experimentation is needed.
Stability	The intersection management safety application is a quality assured, standardized V2X application that must be stable and providing repeatedly consistent results which can be used in LC environment.
Environmental conditions for processing	The LC is assumed to be in a microwave visible area.
Ability to work in hard conditions	No specific requirements over standard V2X operability conditions.
Ability to efficiently transmit information	Information exchange between various actors (i.e. road and rail vehicles) are performed on secured and coded information channels. Exchange rate of information is proportional with the V2X detection rate i.e., 10 Hz.

Table 17. *Description of scenario 1.3.*

Scenario title	LC clearance management for train II.
V2X application	LC intersection management safety application (LIMA)
Objective	The safety application issues critical collision warning to both rail vehicle and the subjected car when train is approaching and the car is near stationary (or stopped) at the dangerous vicinity of LC and the collision with the V2X enabled vehicle is imminent. The app provides collision warning and hazard mitigation for car drivers and clearance assurance for train. It warns the car driver about the approaching train and/or helps to escape from the car in case of last second hazard situations. It also helps to avoid front-to-LC collisions for train drivers and/or mitigates the severity of collisions in LCs.
Equipment	Car with OBU with safety application and HMI Train with OBU with safety application and HMI
Description	1: Car crosses the LC in a very slow speed or stops suddenly (for any reason, e.g. due to traffic jam or technical malfunction. 2: Train is approaching the LC. 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. 4: Car moves away 5: Train HMI stops showing warning
Enabling technology	CAM processing
Measures to be evaluated	Application loading and reaction time, remaining time to collision
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	target radius, dangerous distance
Open issues	None
Notes	None

Table 18. *Evaluation data of scenario 1.3.*

Variable	Results
Detection accuracy	Standard V2X detection rate is 10 Hz. This sampling rate is sufficient and provides satisfactory event recognition resolution in LCs where the expected maneuvering speed of cars are less than 60 Km/h. Estimation of remaining time to collision is continuously updated during the dynamical scenario.
Detection rate	Standard V2X detection rate is 10 Hz.
Processing time	Processing time is within the limit of the detection rate i.e., 0.1 sec.
Sample size	The use-case was repeated 5 times with the same positive evaluation results.
Usability	Usability of this use-case in real situations is well established based on Day 1 V2X safety applications. The scenario can be integrated in LCs without risk, however, high speed trains (over 80 Km/h) may pose safety challenges. The V2X parameters "target radius" and "dangerous distance" must be assigned dynamically with respect to the actual speed of the train. Further experimentation is needed.
Stability	The intersection management safety application is a quality assured standardised V2X application that can be used in LC environment.
Environmental conditions for processing	The approaching train with respect to the LC location is assumed to be in a microwave visible area.
Ability to work in hard conditions	No specific requirements over standard V2X operability conditions.
Ability to efficiently transmit information	Information exchange between various actors (i.e. road and rail vehicles) are performed on secured and coded information channels. Exchange rate of information is proportional with the V2X detection rate i.e., 10 Hz.

Table 19. *Description of scenario 1.4.*

Scenario title	LC clearance management for train III.
V2X application	CPM generation and distribution upon detected object triggering
Objective	The safety app issues critical collision warning to the approaching rail vehicle when a detected pedestrian (or any pre-specified type of object) blocks the LC and the collision with the arriving train is imminent. The app provides collision warning and hazard mitigation and clearance assurance for train drivers. It helps to avoid front-to-LC collisions for train drivers or mitigate the severity of collisions in LCs.
Equipment	Smart object detection system connected with RSU located at the LC Train with OBU with safety application and HMI
Description	1: A pedestrian crosses the LC in a very slow speed (wandering) and/or stops suddenly from any reason. 2: Train is approaching the LC. 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.
Enabling technology	Smart Object Detection system with CPM processing
Measures to be evaluated	Application loading and reaction time, remaining time to collision, detection time and consistency
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	Detected object type identification according to vulnerable road users' categories, moreover the estimated size of detected object.
Open issues	Detected object type resolution is to be further developed and experimented with.
Notes	None

Table 20. *Evaluation data of scenario 1.4.*

Variable	Results
Detection accuracy	Detection accuracy depends on the accuracy of the video processing of the smart detection system. After receiving the detection trigger the start time of CPM processing in the RSU is immediate. CPM distribution is in accordance with standard V2X detection rate which is 10 Hz. Estimation of remaining time to collision is continuously updated for train driver during the dynamical scenario.
Detection rate	Detection rate is fundamentally based on the video processing capabilities of the smart object detection system. Upon request, standard V2X processing rate is 10 Hz.
Processing time	Processing time could be validated on the V2X side only, after the object detection trigger has been received from the smart detection system which was found within the limit of the 10 Hz detection rate of the V2X system.
Sample size	The use-case was repeated 5 times with the same positive evaluation results.
Usability	Usability of this use-case in real LC situations can be considered. CPM processing is conformant with the ETSI standard in preparation. The scenario can be integrated in LCs without risk. High speed trains (over 80 Km/h) may pose safety challenges, however, due to small time to collision parameters. Relaying of CPM information to far away trains is to be considered. Further experimentation is needed with this scenario especially regarding the CPM range extension which recently is the standard one hop distance (around 1 Km).
Stability	CPM messaging is a well-tested stable process that follows the rule of the standard in preparation. There is no risk with this application.
Environmental conditions for processing	Environmental condition compromising the visibility and event resolution capability of the video processor of the smart detection system represents limitation.
Ability to work in hard conditions	It is to be assured that the video processing system is always operated in good sighting conditions. Otherwise, there are no specific requirements over standard V2X operability conditions.
Ability to efficiently transmit information	Information exchange between the smart detection system and the RSU is ensured by the hard-wired communication link (ethernet), which is a secured link for data exchange. Exchange rate of information is proportional to the detection rate of the smart detection system. CPM processing in the RSU and the secured transmission of CPM packets over the air happens in 10 Hz frequency.

Table 21. *Description of scenario 2.1.*

Scenario title	Remote detection and monitoring of the approaching train
V2X application	CPM generation and V2X sensor fusion
Objective	This use-case is about to advertise the presence of the approaching train by sensing and disseminating rail specific CAM messages by means of collective perception technology and CPM messaging. Train position information is made available in the LC which information can be used in the calculation of the timing of safety actions such as barrier closing and opening.
Equipment	Car with OBU with safety application and HMI Train (emulated with a car) with OBU with safety application and HMI. The approaching train is emulated by a V2X capable road vehicle traveling in a quasi-parallel route along the railway track.
Description	1: Train approaches the LC in a faraway location. 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). 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. 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. 5: Car OBUs receive the CPM and displays the closing train location information on its HMI and generate warning for cars driver.
Enabling technology	CAM and CPM processing and distribution, V2X sensor fusion
Measures to be evaluated	Detection range, detection time, frequency of train location update
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	None
Open issues	None
Notes	None

Table 22. *Evaluation data of scenario 2.1.*

Variable	Results
Detection accuracy	Standard V2X detection rate is 10 Hz. This sampling rate is sufficient and provide satisfactory event recognition resolution in LCs where the expected maneuvering speed of cars are less than 60 Km/h. Estimation of remaining time to collision is continuously updated during the dynamical scenario.
Detection rate	Standard V2X detection rate is 10 Hz meaning that CPM messages carrying the position information of the arriving train contains position information in 0.1 sec resolution.
Processing time	Processing time is within the limit of the detection rate i.e. it is less than 0.1 sec per CAM hit.
Sample size	The use-case was repeated 5 times with the same positive evaluation results.
Usability	Applicability and integration of this use-case in real LC situations can be effectively considered. This scenario increases the detection range of the system by one RSU hop distance (approx. 1-2 Km). Further experimentation is needed with this scenario especially regarding the CPM range extension. In a real rail application, the detection range can be further extended by using a chain of RSUs around the railway and adjust system parameters to the speed of trains and geometry of railway. The actual solution is highly rail dependent and is to be streamlined on site. Final location specific antenna and radio configuration of the RSUs are to be determined by application request.
Stability	CAM to CPM generation and the corresponding sensor fusion process proved to be stable that provides ground for the standardisation process which is ongoing at ETSI. No stability risk with this application.
Environmental conditions for processing	No specific environmental conditions.
Ability to work in hard conditions	Electric rail environment represents a hostile environment for radio transmission devices because of the presence of high voltage trolley-wires and other metal objects. The effect is further amplified in case the line of sight condition of communication is obstructed by high voltage lines and/or large metal objects. The validation scenario, however, was still successful. The radio connection between the remote RSU (800 m away from the LC) and the RSU located in the LC were 100% reliable. The experienced radio disturbance patterns could be successfully eliminated by means of the application of a special radio configuration and special antenna architecture and arrangement applied to the RSUs. As a conclusion, it can be verified that the hostile rail environment did not pose any problem for the ETSI-G5-based V2X microwave radio technology.
Ability to efficiently transmit information	Information exchange between the remote and local RSUs, moreover the approaching train is safely and securely ensured via standard V2X communication. CPM processing in the RSU and the secured transmission of CPM packets over air happens in 10 Hz frequency meaning that the resolution of the approaching train position is calculated using the base time 0.1 sec, thus the distance resolution depends on the actual speed of the train.

Table 23. *Description of scenario 3.1.*

Scenario title	Remote detection of the approaching train by means of multi-hop DENM forwarding with drivers warning
V2X application	Multi-hop DENM messaging
Objective	This use-case is about announcing the presence of the approaching train by triggering DENM messages on train upon arrival and disseminating these messages by means of multi-hop forwarding using the available V2X infrastructure and/or intermediate V2X capable vehicles' functionality.
Equipment	V2X capable road vehicle with OBU and safety application emulates the approaching train. Remote RSU. Local RSU located in the LC. V2X capable road vehicles in LC vicinity with OBU and safety application and HMI.
Description	1: Train approaches the LC in a faraway 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 due time and distance. 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. 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. 4: Car OBUs receive the DENM and displays the closing train information on its HMI. 5: The train cancels DENM message after passing through the LC.
Enabling technology	Multi-hop DENM message forwarding is based on Geonetworking protocol and geolocation information triggering.
Measures to be evaluated	Detection range, detection time
Sensitivity parameters to be adjusted (both road and rail vehicles OBUs)	None
Open issues	None
Notes	None

Table 24. *Evaluation data of scenario 3.1.*

Variable	Results
Detection accuracy	Detection accuracy depends on various conditions. In case we can assume that a V2X capable transmission device is always available in the radio range then the arrival of the train triggered DENM to the LC depends on the minimal number of hops included in the GeoNetworking scenario between train and the remote LC. In cases when no intermediate V2X device is timely available, the message might be delayed. In the worst case, when there are no intermediate transmission units (a very probable scenario when traffic is low, e.g. in nighttime), the DENM will arrive to the LC as a "last minute" single hop message directly from the train.
Detection rate	DENM messages are processed upon request but still aligned to the standard V2X processing rate which is 10 Hz.
Processing time	Processing time depends on the ad-hoc geonetworking scenario (see detection accuracy considerations above).
Sample size	The use-case was repeated 5 times with the same positive evaluation results.
Usability	Usability of this use-case in real LC situations can be seriously considered. V2X equipped vehicles are capable to contribute to this scenario even if their traveling trajectory is neutral to the LC.
Stability	Multi-hop DENM messaging is a standard well-tested safety application of V2X technology. This is based on a secure transmission mechanism and the safety applications are standard-based and certified. There is no stability risk with this application.
Environmental conditions for processing	The approaching train with respect to other optionally located V2X devices and/or the LC location are assumed to be in a mutually visible area.
Ability to work in hard conditions	There are no specific requirements over standard V2X operability conditions.
Ability to efficiently transmit information	Efficiency of this scenario highly depends on the penetration rate of the V2X technology. The more V2X capable devices involved in the communication, the faster the DENM information will be propagated to the LC. In case the standard geonetworking routing from source (train) to destination (LC) can be secured, the transmission of DENM packets between train and the LC is ensured.

Discussion

Lessons learned

It was revealing to showcase that ITS safety applications of the V2X ecosystem can be effectively used in railway applications in a cross-modal setup safely and securely. The demonstrations convincingly exhibited that sharing a common communication technology standard between road and rail vehicles can provide railway operators with a means to control and manage the train traffic on their networks. This may contribute to make the traffic in the crossroads of the two modes of transportation safe and sustainable in the future.

Electric rail environment represents a hostile environment for radio transmission because of the presence of high voltage trolley-wires and other metallic objects. The effect is further amplified in case the line of sight condition of communication is obstructed by high voltage lines and/or large metallic objects. Therefore, not only the test scenarios but the performance and operation of the microwave radio communication system was subject of testing in Aachen. During the validation of the range extension scenario, we experienced electromagnetic disturbance which compromised the radio range of the RSUs significantly. This required the application of a special radio configuration, antenna architecture and antenna arrangement at the RSUs. As a general rule, the configuration of the radio parameters, moreover, the 5.9 GHz microwave antenna proved to be highly dependent to the scenario and location. RSU radio and antenna configuration, therefore, should be adapted to the environment of a given LC.

Recommendations

In electric rail environment it is always required to use high quality, high gain and well oriented RSU antennas. Sometimes, only directional antennas can satisfy the range and performance requirements. It is highly recommended that communication system deployments in electric rail environments are preceded by specifically designed communication tests verifying the range, fault tolerance and general communication performance of the system.

Applicability of results to different circumstances

DSRC V2X technology (ETSI-G5) was designed to be robust against a wide range of variations of environmental conditions. The basic set of safety applications developed for V2X systems are sufficiently rich to satisfy a wide range of applications for railway use. The Aachen test event showcased a selected set of applications and demonstrated a small set of possibilities of these applications.

Conclusions

As a general conclusion, it can be said that standard V2X technology with their standard safety applications (such as intersection assist safety applications) developed for road ITS use can be safely utilised in LC environments. The above characterised scenarios pointed out the importance and necessity of the use of cross-modal road-rail communications technology in hazard avoidance in LCs. The successful technology harmonisation is a precondition of the integration of the methods in rail environment and a key focus area for safe and sustainable transportation. It is important to note that the hostile rail environment did not pose unsolvable problems for the ETSI-G5-based microwave radio technology. However, the LC deployment of RSUs and their antenna and radio channel configuration needs special care and adjustment. With proper setup the visible range between two consecutive RSUs in electric rail environment can be safely kept around 1,000 meters that is not worse than in a standard highway environment.

3.4.3. Smart Communication System 1 (IFSTTAR & Geolog)

Piloted safety measure

This measure is *Smart Communication System* covering multi-hop communication of alerts through vehicle to everything (V2X) communication between roadside unit (RSU) and on-board communication unit (OBU).

The piloting included two scenarios:

- 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 the piloting, the smart communication system was installed and connected to the smart detection system (described in subchapter 3.4.1).

Method and data to evaluate the piloted safety measure

The evaluation focussed on identifying whether all detected events were correctly received by the vehicles and by the control room. This was investigated based on message logs (DENIM and CAM).

The investigated variables covered:

- Communication range
- Conformity
- Transmission delay
- End to end delay
- Event to vehicle distance

During the tests some logs were saved to calculate the relevant key performance indicators (KPIs) for this scenario.

Evaluation results

The smart communication was installed and connected to the smart detection system, and the first testing focussed on the communication between roadside unit (RSU) and OBU. In total, 229 DENMs were received in seven times (Table 25). The evaluation was done by comparing the cause code and subclass code for each received DENM with the ones sent at the same time interval.

Table 25. *Example of conformity.*

ID message emission (RSU)	Reception interval	Cause code	Subcause code
1309	14:58:02.27 to 14:58:17.32	94	0
1310	14:58:17.33 to 14:58:39.43	97	2
1312	14:59:17.04 to 14:59:40.12	98	1
1313	15:00:21.25 to 15:00:28.27	98	1
1315	15:03:55.07 to 14:04:04.10	94	0
1317	15:05:46.71 to 15:05:55.74	98	1
1318	15:06:11.44 to 15:06:33.52	98	1

The communication range was at least 40 meters. However, the maximal value of this range is not known since during the piloting there was not enough time to test the communication for varying ranges.

The latency should have been one millisecond or less because the accuracy is limited to milliseconds. However, some exceptional values of two milliseconds (twice), 998 milliseconds and

999 milliseconds (twice) were also identified (Table 26). These problems were due to the synchronisation and hence this problem was corrected for the second period of piloting.

Table 26. *DENM generation latency.*

Latency	Recurrence	Percentage
1 ms	138 times	60.27%
0 ms	86 times	37.56%
2 ms	2 times	0.87%
999 ms	2 times	0.87%
998 ms	1 time	0.43%

The second testing focussed on the connection between roadside unit and OBU in case of others scenarios, which were:

- Traffic jams at the level crossing
- Car blocked between the barriers
- Vehicle drives against closed barriers
- Pedestrian is detected at the LC

In this phase, the re-transmission between vehicle approaching LC and other vehicles far from the LC was also tested.

The DENIMs of all scenarios were well received. The tests were realised several times and the logs (DENIM and CAM) were saved in order to give some KPIs for each scenario.

Two problems were encountered in this phase:

- The transmit delay could not be measured because there was a shift between the time of the RSU and OBU. Thus, without knowing the exact value of this shift, it was almost impossible to have reliable transmit delay.
- KPIs could not be calculated for the multi hop scenarios.

These problems were solved for the last test session.

The last piloting sessions focussed on testing the multi hop scenarios. The objective was to evaluate the maximum communication range. The nearest vehicles sent the same received DENM to another vehicles coming to the level crossing.

<u>Discussion</u>

All scenarios were tested for the multi-hop schemas. All DENIMs were received correctly whenever the distance of OBU and RSU was lower than the maximum range of communication. In the case of line-of-sight, the maximum range is about 250 m. In case of 'Non line-of-sight' (NLOS), the maximum range in Aachen site (with presence of trees, buildings etc.), was about 60 to 80 m. With the multi-hop solution and two vehicles used, the maximum range was between 160 to 180 metres.

The following challenges were identified during piloting:

- The range values are very limit for smart communication ITS_G5 (around 180 m). These values are very much lower than the range proposed by the normalisation. This limitation is due to the Aachen test site. In this site there was no 'line of sight communication', there were many obstacles such as buildings, trees, etc.

- In frequency 5.9 GHz antenna positions are very sensitive, and the range depends on the propagation environment and number of equipped vehicles.

Lessons learned

Based on the evaluation, the multi hop scenarios are very important to increase the range (around 5km) of communication if all vehicles in an environment are equipped with the same technology.

3.4.4. Smart Communication System 2 (neoGLS & CEREMA)

<u>Piloted safety measure</u>

The *Smart Communication System* provides alerts about potentially dangerous situations to the control room. This system focusses on the interface between Smart Detection System (described in subchapter 3.4.1) and the smart roadside unit (RSU). This measure fetches and aggregates the video files from the camera of the Smart Detection System and transmits them to the control room to provide vision of the level crossing to the person monitoring the LCs.

Specifically, the Smart Detection System pushes the video files periodically to the smart RSU. Then the smart RSU chooses if the video file is relevant regarding the running events on the LC. If this is the case, the video files are sent to the control room.

<u>Method and data to evaluate the piloted measure</u>

The evaluation focussed on testing the video file chain between the Smart Detection System and the roadside unit (RSU) using a VPN connection and a test RSU.

Some challenges occurred during piloting since the system architecture of the Smart Detection System had changed between the pre-tests and second testing session. This caused encoding issues and thus the upload could not be tested during the second session. The encoding issues were solved for the third session and hence the video upload could have been tested.

<u>Evaluation results</u>

First, the Secure Shell (SSH) context was set up to send video files in a secured way between Smart Detection System and the RSU (using a key authentication). After that, the video upload was tested using dummy scenarios prepared for the Smart Detection System. At this point, the RSU received the complete video feed, in chunks of 30 seconds. The mechanism to upload videos to the control room also worked efficiently because it was also based on SSH. In addition, it had been tested before the piloting in the Aachen test site.

One issue encountered concerned the control room interface, where the video aggregation was initially not working. This issue occurred because the aggregation started when the file was not completely uploaded yet. To counter this issue, a MD5 sum was added to ensure that video files were complete before sending them to the control room.

Next, the complete chain with real scenarios was tested by using the Smart Detection System. After the modifications were implemented, as explained in the previous paragraph, the chain worked successfully, as expected. When an event was detected by the camera, the RSU uploaded it to the platform, and by clicking on the alert, the video files were aggregated, starting from the event detection until the event end. Figure 30 presents an example of a detected event and the corresponding video.

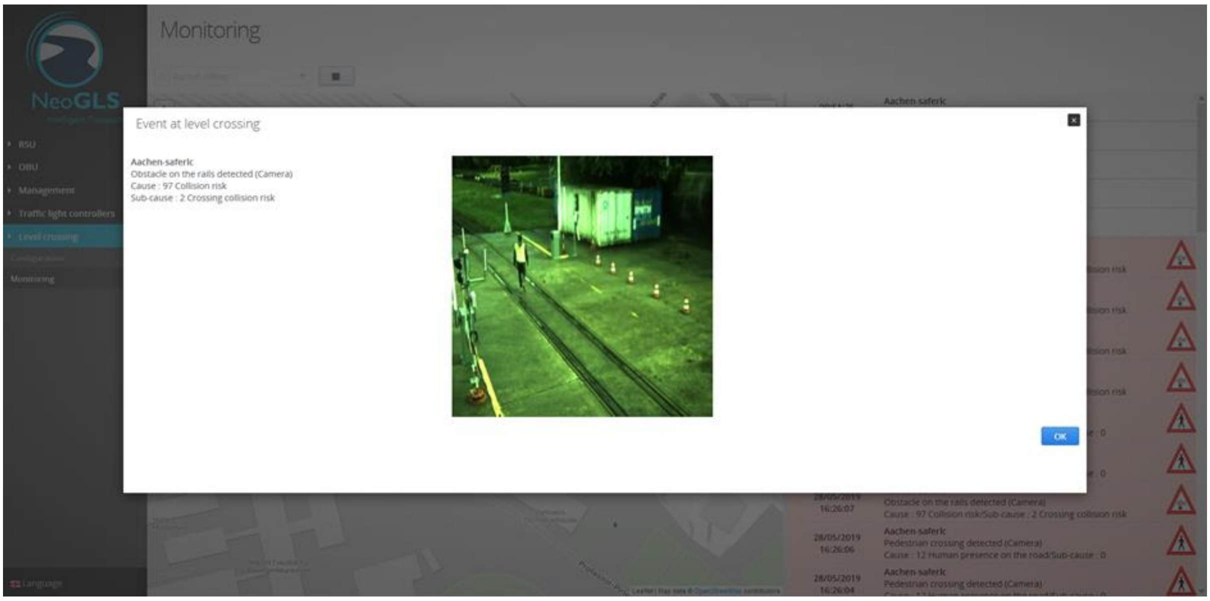

Figure 30. *Example of a detected event and the corresponding video.*

During the test, the video was displayed on-screen with an unsatisfactory delay, as a result of the different loop intervals on the different systems to process video files. Specifically, the delays were the following:

- Camera of the Smart Detection System: One file every 30 seconds
- RSU: Check for upload every minute
- Control Room: Aggregate on click.

To resolve this problem, the interval was reduced to 5 seconds on each system. By doing that, the video availability was very quick.

<u>Discussion</u>

No discussion was included.

3.5. CEREMA Rouen (CEREMA & NTNU)

3.5.1. Monitoring and remote maintenance

The purpose of *Monitoring and remote maintenance* is to monitor the condition of LCs and detect potential problems with rail infrastructure (e.g. any deterioration) by using sensors on the track and road (seismic sensors, photogrammetric system and thermal infrared method). This measure aims 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 already use topographic sections with a lower level of precision. The photogrammetric method will improve the detection of dangerous profiles.

3.5.2. Method and data to evaluate the piloted measure

The piloting of this measure was conducted at the Cerema experimental site in Normandy. The test site included a three-meter-wide experimental level crossing structure that was built for the SAFER-LC project (more details of the implementation can be found from deliverable D4.3, Carrese et al. 2019). The piloting aimed at testing the feasibility of different methods to detect degradation on level crossing.

Two different road configurations – bump and hollow – were used to reproduce the most common types of natural relief road configurations (Figure 31).

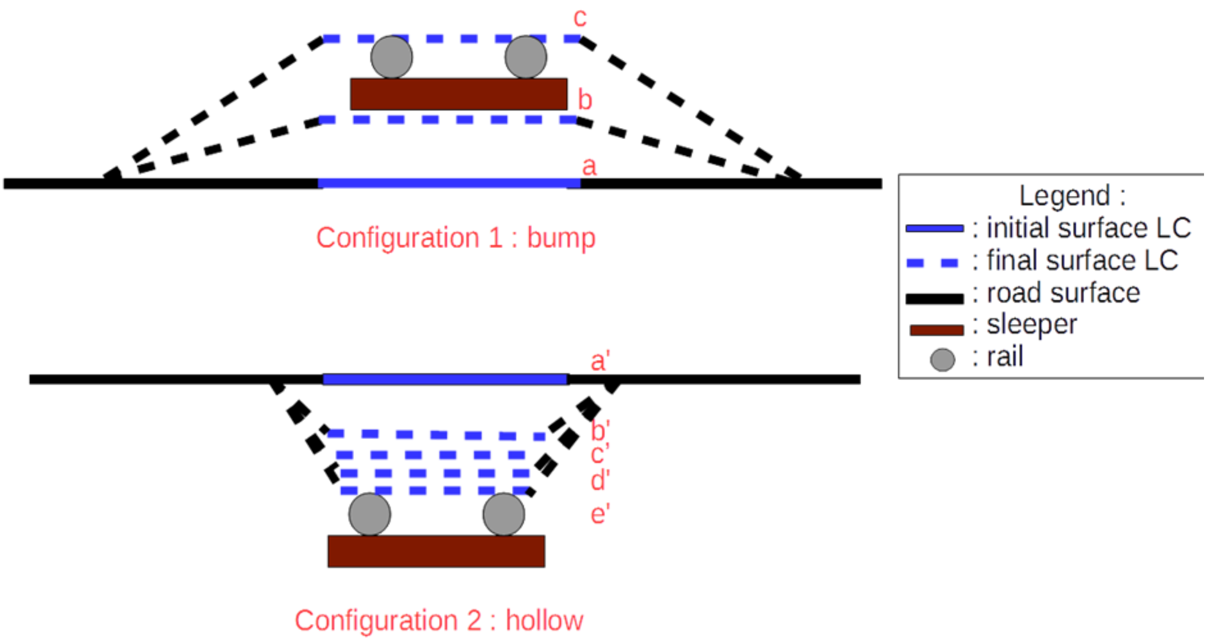

Figure 31. *Different configurations of the Cerema experimental test site.*

Bump configurations

The wood beams with two thickness were used in the bump configuration to generate three investigated configurations: 1a = 0 cm, 1b = 3.5 cm, and 1c = 7 cm (Figure 32).

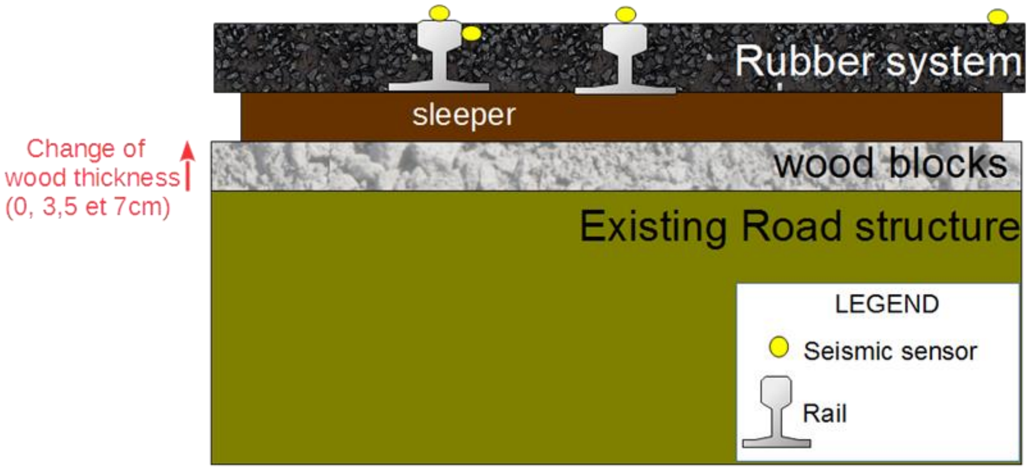

Figure 32. *Bump experimental LC – two thickness of wood.*

Hollow configurations

The hollow configurations were simulated by using water-saturated sand inside waterproof film in combination with the passage of trucks to produce deterioration of the infrastructure (Figure 33). The hollow configurations used in the piloting were:

- 2a' = 0 cm,
- 2b' = 1.9 cm, after 1 truck passage – 3km/h
- 2c' = 2.1 cm, after 1 truck passage – 12 km/h
- 2d' = 2.4 cm, after 1 truck passage – 12 km/h
- 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.

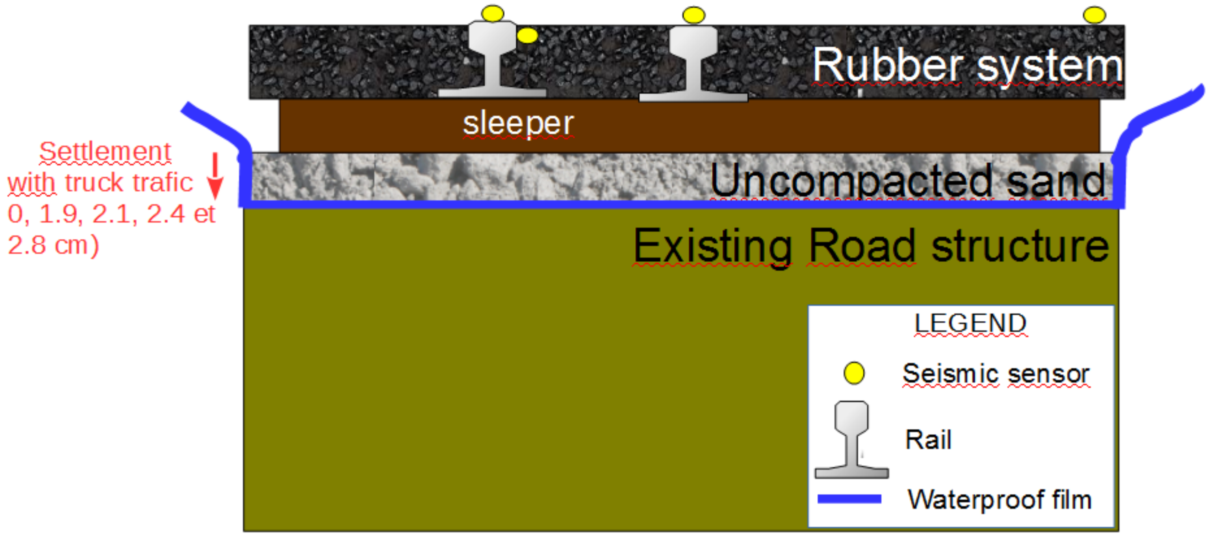

Figure 33. *Hollow experimental LC – three steps with truck traffic.*

The type of measurements used for different configurations to detect surface degradations are listed in Table 27.

Table 27. *Type of measurements used to detect surface degradations by configuration.*

Configurations	Measurements
Bump 1a, 1b, 1c	Vibration, photogrammetric, VACC (instrumented vehicle)
Hollow 2a', 2b', 2c', 2d', 2e'	Photogrammetric, thermal infrared, vibration, VACC

Four methods were tested on the experimental LC site.

Vibration
Two loads were used for the seismic measurements: a truck (6,5t/wheel, a deflectograph) and a van (1,5t/wheel). Three different speeds were used for each vehicle type:

- Truck (6.5t/wheel): 3 km/h, 12 km/h and 25 km/h
- Van (1.5t/wheel): 15 km/h, 25 km/h and 30 km/h

The accelerometers and their positioning used in the testing are presented in Figure 34.

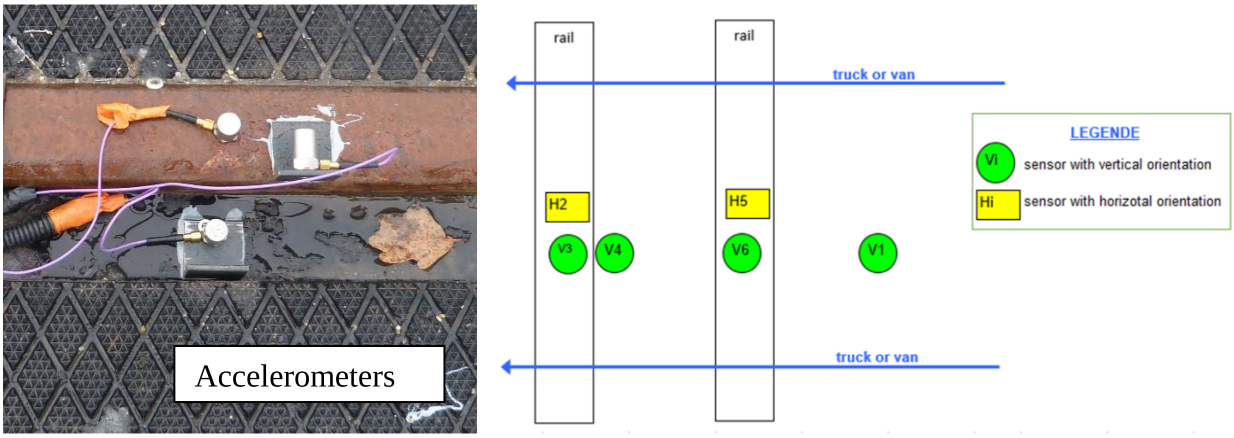

Figure 34. *Accelerometers and their position.*

Photogrammetric
The model was referenced with landmarks (Figure 35).

Figure 35. *Photogrammetric measure.*

In total, eight photogrammetric references were used (Figure 36). Furthermore, a stabiliser was used on an instrumented ramp to keep horizontal movement stable.

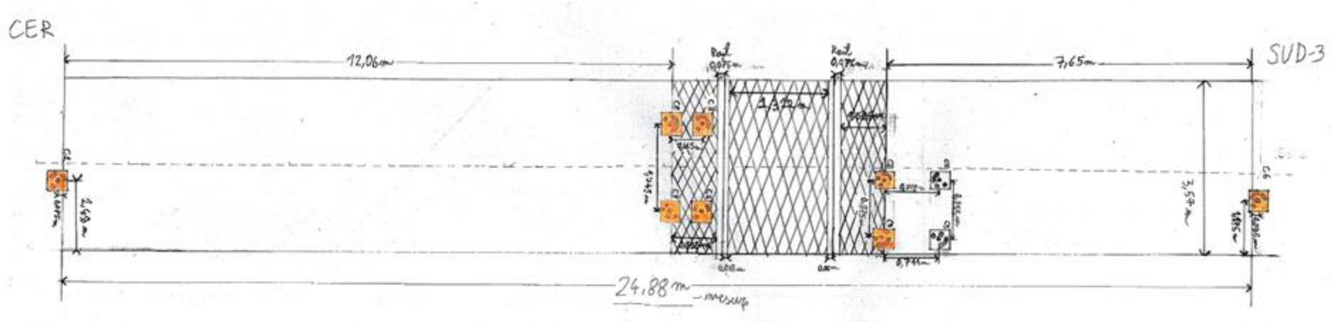

Figure 36. *LC representation with photogrammetric references.*

Instrumented vehicle (VACC "Véhicule d'Analyse du Comportement des Conducteurs")

An instrumented vehicle recorded all the data passing through the A/D converter bus of the car; that is, data on the dynamics of the vehicle (used by the different safety devices) and the actions of the driver. This data was associated with shooting video (front, back, steering wheel, pedals, driver) and GPS positioning.

Thermal infrared

The collection of thermal infrared data required a high-resolution thermal imaging camera.

<u>Scenarios used in the measurements</u>

Below, you will find the different scenarios for configuration 1a, 1b, 1c, 2a', 2b' 2c', 2d' and 2e':

- Scenario 1: instrumented vehicle crossing the LC (moving at 8.5 km/h) for photogrammetric measure - moving forward
- Scenario 2: loaded truck or van crossing the LC (speed 1) - moving backward
- Scenario 3: loaded truck or van crossing the LC (speed 2) - moving backward
- Scenario 4: loaded truck or van crossing the LC (speed 3) - moving backward
- Scenario 5: instrumented vehicle crossing the LC (VACC)

Complementary scenario for configurations 2a', 2b', 2c', 2d' and 2e':

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

For each configuration (1a to 1c and 2a' to 2d'), a levelling on rail was realised to compare photogrammetric results with full station measurement (Figure 37). Four points (R1D, R1G, R2D and R2G) were realised in total, and the result is the mean of these points (Table 28).

Figure 37. *Rail levelling and reference measure of the full station.*

Table 28. *Levelling results by configuration.*

Configuration		Thickness average (cm)	Std
Bump	1b	4.4	0.3
	1c	8.9	1.0
Hollow	2b’	1.9	0.5
	2c’	2.1	0.8
	2d’	2.4	0.8
	2e’	2.8	0.6

3.5.3. Evaluation results

Photogrammetry

Some mock-up tests were conducted and they revealed an issue to detect moving objects with photogrammetric method. Therefore, a photogrammetric model was created to compare two dates. The object was moved between two states (see Figure 38).

Figure 38. *Mock-up with object detection.*

A 3D model was obtained to compare two sets of pictures (Figure 39). The green areas represent stable zone, yellow depressions and red elevations. These results are consistent with our expectations. A yellow zone of depression can be observed at the old location of the object, and a red zone of elevation at its new location. Although centimetre precision is not enough to show the movement of sand under the object, it would be sufficient for LC application. It was necessary to calibrate camera with photoscan software to improve distortion correction on the edges of the model (Figure 39).

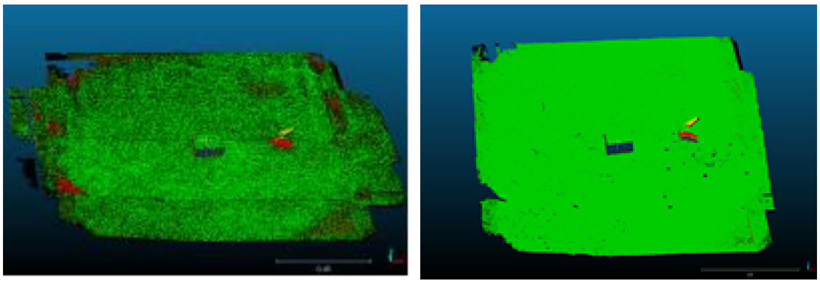

Figure 39. *3D photogrammetric models comparison with object detection. Centimetre precision without calibrate (left) and millimetric precision with calibrate (right).*

Seven photogrammetric models were obtained from a batch of photos. In order to limit the processing time and to prevent software crashes, 260 photos converging towards the surface were used, as seen in the green rectangles in Figure 40, to calculate 3D models with around 25 meters of roadway with adapted focal to obtain a strong density of points.

Figure 40. *Example of camera device layout for scanning model.*

Different photogrammetry software can be used to generate a cloud with photos game. Micmac has been used (Pierrot-Deseilligny et al. 2016) for full model because of the possibility of calibrating the cameras. Three photos are needed to perform the calibration of each camera, in our case photos of geometric shapes were used.

Point clouds must be recalibrated with common repository. The first configuration (1a and 2a') was defined as a reference and therefore must be georeferenced. Two methods were used: GPS points (GCP point in micmac), and the distances method, where the cloud is georeferenced to an absolute reference by similarity.

Figure 41 and Figure 42 present models (with s top of view presentations) obtained with two types of configuration (Figure 41 for bump and Figure 42 for hollow). Each model includes about 25.2 million of points. The geometric dimensions of the study area are 3.57 m by 24.88 m which leads to 25 points per cm².

Figure 41. *Photogrammetric model − Bump configuration (left to right 0, 3.5 and 7 cm).*

Figure 42. *Photogrammetric model – Hollow configuration (left to right 0, 3, 5 and 5.7 cm).*

Each model was then compared with CloudCompare against each other in order to obtain a 3D comparison model and thus quantify the degradations encountered on the crossing. An example model is presented in Figure 43. It shows a typical cloud of the surface change with depth. The direct cloud-to-cloud comparison with the closest point technique does not require gridding or meshing of the data, and is the simplest direct 3D comparison. Each point can be defined in both clouds. The surface variation is estimated as the distance between the two points (M3C2). With the length of the measuring area, cutting to three zones is necessary in order to obtain a coherent result.

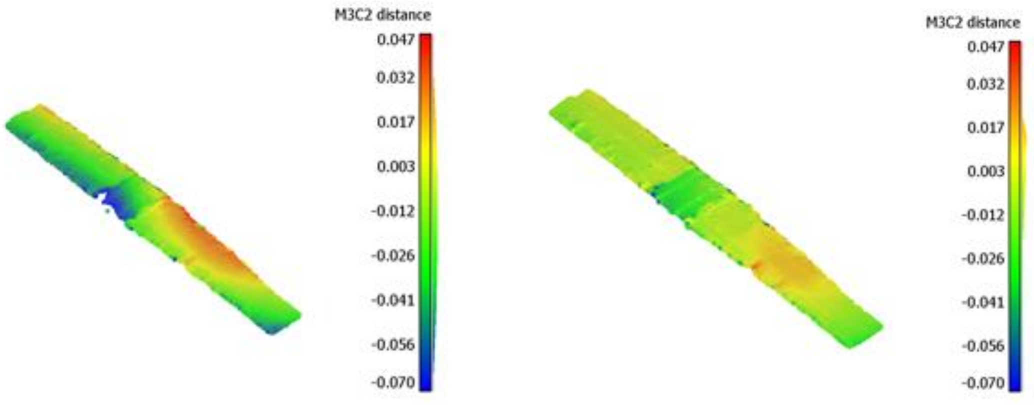

Figure 43. *Incoherent results full treatment M3C2 (left). Coherent result with cutting and merging zone treatment M3C2 – hollow configuration 2a'–2d' (right).*

According to Figure 44, the measured distance is sensitive to the cloud's roughness. So this technique is used to change LC surface on dense clouds. This figure also shows a distance around 8.6 cm on level crossing. It is similar with levelling results.

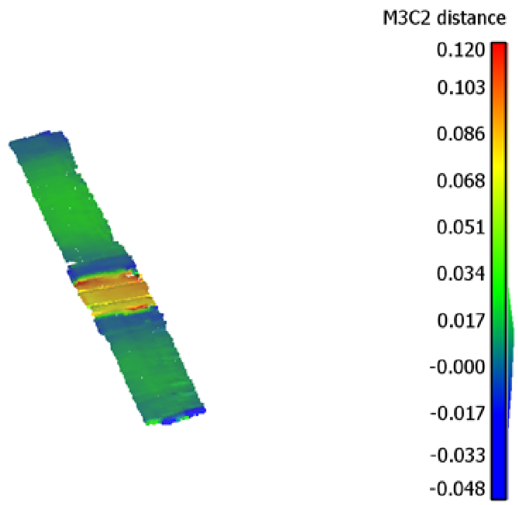

Figure 44. *Example of 3D photogrammetric model comparison – model bump 0 and 7 cm.*

Figure 45 illustrates the depression of the level crossing comparing configuration 1a and 1c.

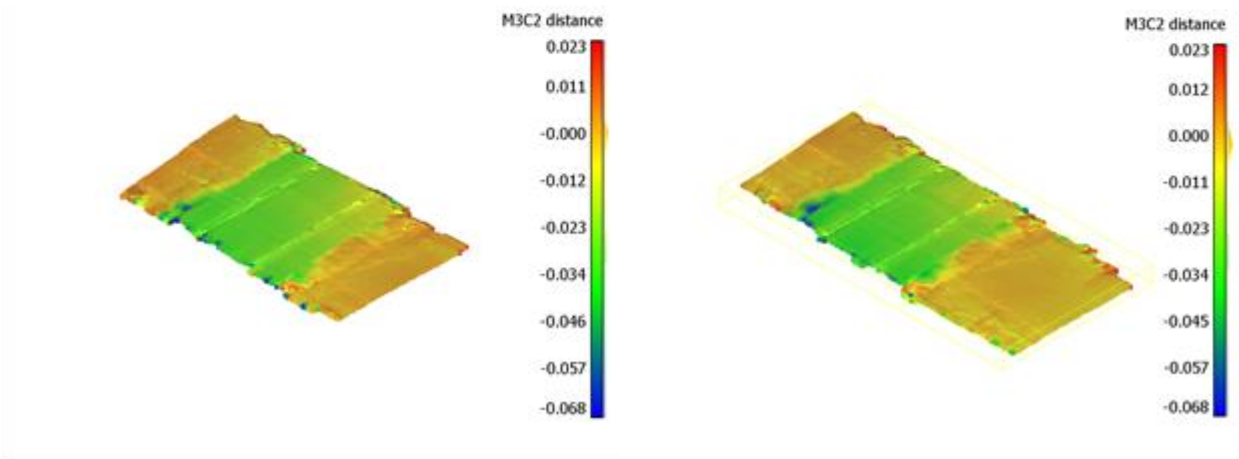

Figure 45. *Comparison model hollow 2a'–2b' (left). Comparison model hollow 2a'–2d' (right).*

From a computer development, we can obtain geometric profile data. The graph below (Figure 47) shows a difference between model bump 0 (blue curve) and model bump 7 (red curve) representative of values obtained with levelling.

Results obtained on the LC central zone for hollow configuration (Figure 45) show more deformation on configuration 2a'–2d' with greater truck passages with a depression marked in wheel passage.

This technique is satisfactory for detecting deformations on level crossing. Application of this technique in the level crossing context is suitable. These results are similar to Lague et al. (2013).

With cloudcompare it is possible to recover manually a geometric profile as shown in Figure 46.

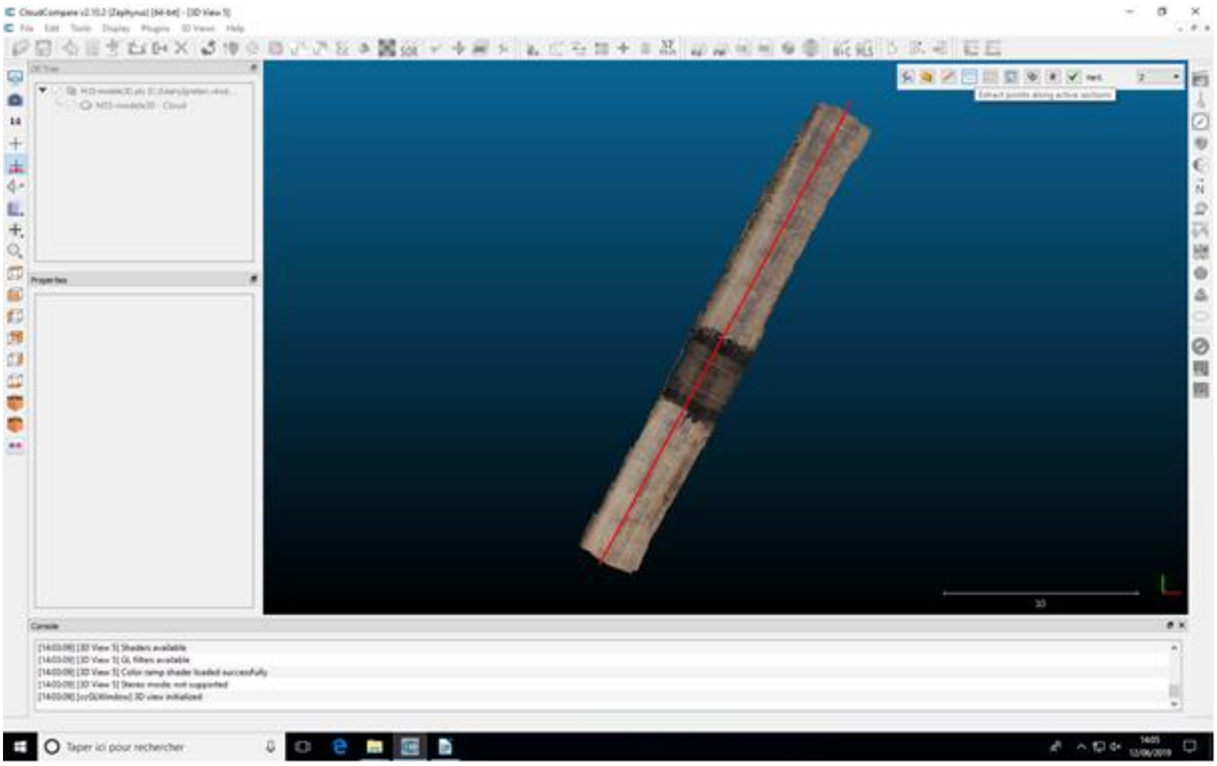

Figure 46. *Geometric profile recovery with cloud compare.*

To complete this treatment, the data of geometric profile recovered were leveraged by an algorithm developed in Python programming language. Figure 47 represents the modality in bump with the configuration at 0 cm in blue and at 7 cm in red. Figure shows a difference between model bump 0 (blue curve) and model bump 7 (red curve) representative of values obtained with levelling. A similar photogrammetric example with another application was described in Fauchard et al. (2013) and Chanut et al. (2017).

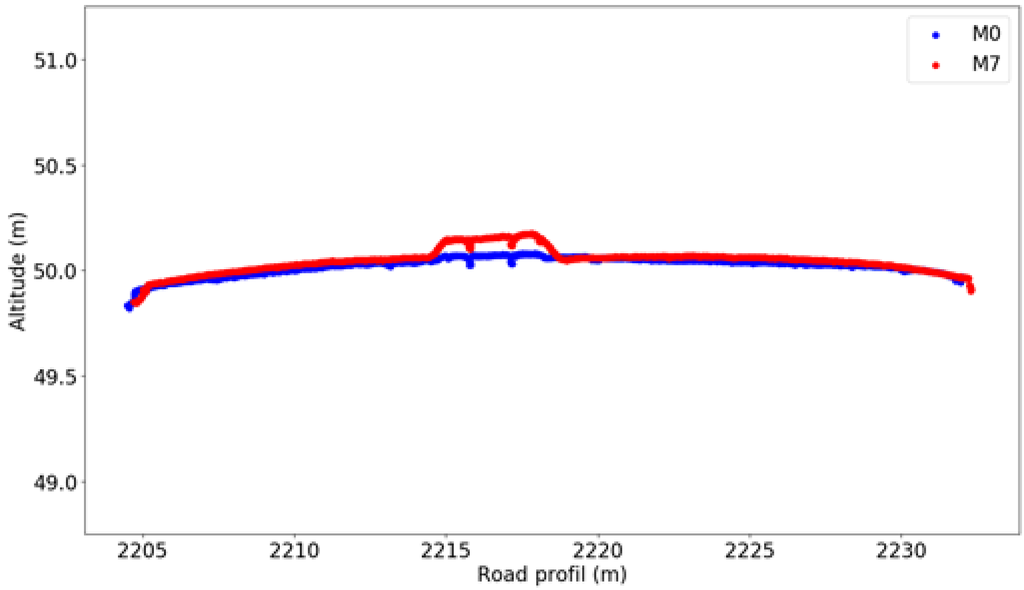

Figure 47. *Example of geometric profile – model bump 0 and 7 cm.*

An approximate surface profile is displayed, with the dangerous areas pointed out in red colour (Figure 48). These figures show that between two different trucks appears a conflict point with a different holder false. The photogrammetric method is used to efficiently detect and locate conflict points according to the characteristics of the truck.

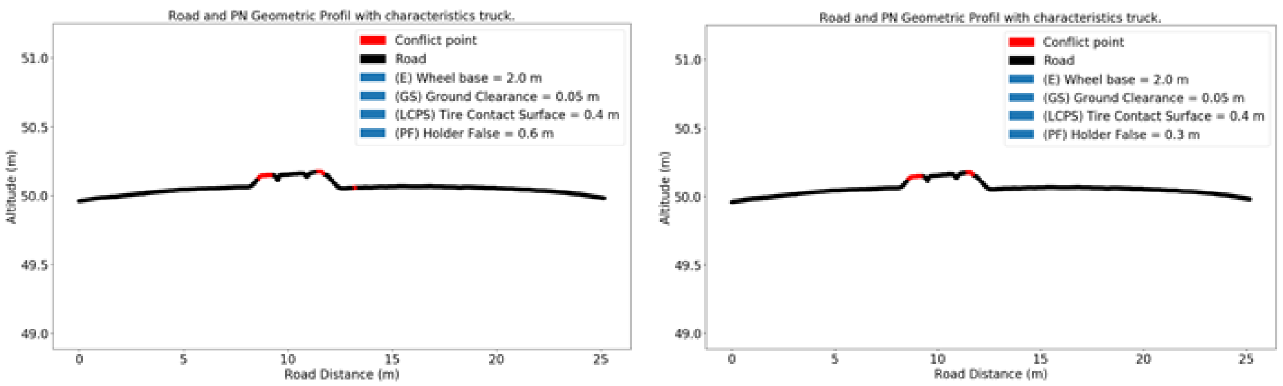

Figure 48. *Approximate surface profile with conflict point in red – model bump 7 cm.*

This surface profile depends on truck characteristics as shown in Figure 49.

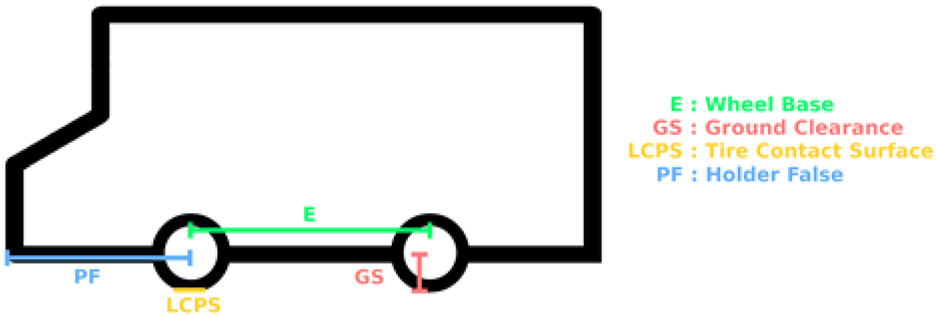

Figure 49. *Truck characteristics – surface profile.*

<u>Vibration</u>

We recorded four passages with VACC vehicle to average for each configuration. Figure 50 presents an example of VACC record average.

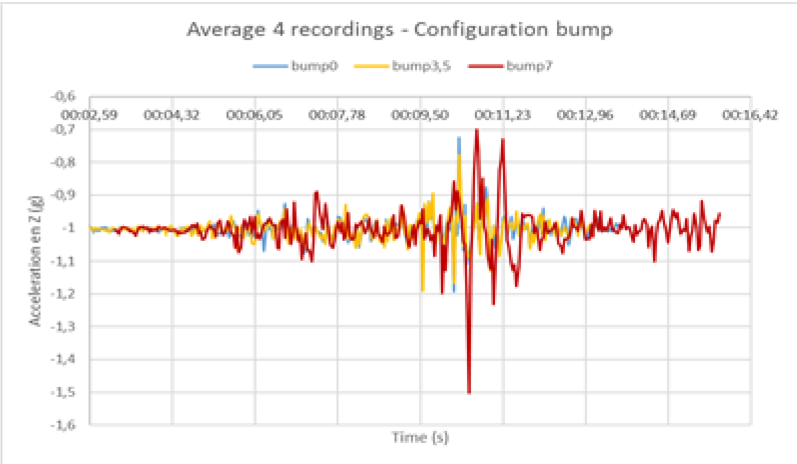

Figure 50. *Example VACC average - bump configurations.*

We record an increase of the acceleration with the increase of the height of the bump or the hollow (Figure 51 and Figure 52).

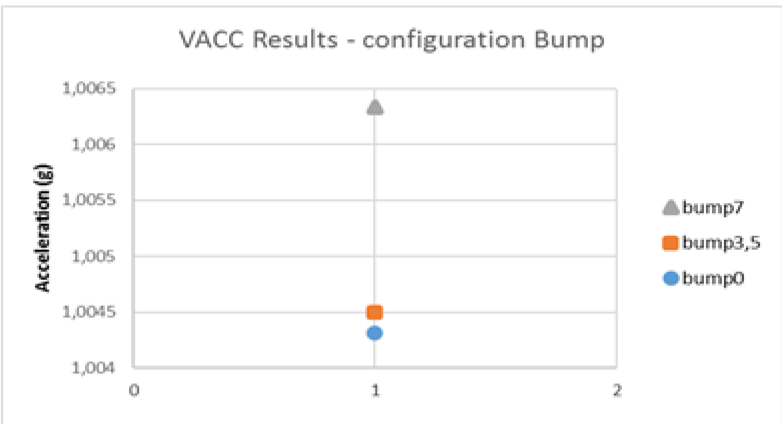

Figure 51. *VACC results - bump configuration.*

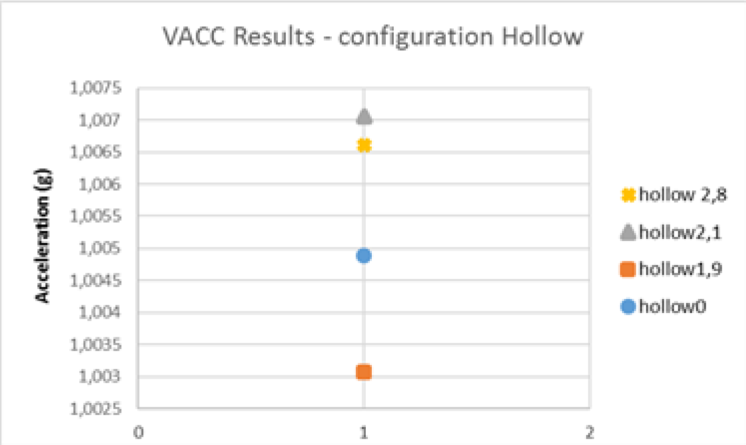

Figure 52. *VACC results - hollow configuration.*

Nevertheless, the variation remains very small and the result can probably vary according to the lateral deviation of the vehicle on the roadway.

The variation of the acceleration according to the speed and the height of the LC is presented in Figure 53 for a van and in Figure 54 for a truck. For the van, the variation of acceleration increases when the speed and the height of the level crossing becomes greater. For the truck, results are not representative, as the 3 km/h speed could not be correctly realised. Figure 54 shows anomalies as the acceleration should be variated with a higher value when speed and height of the level crossing increase.

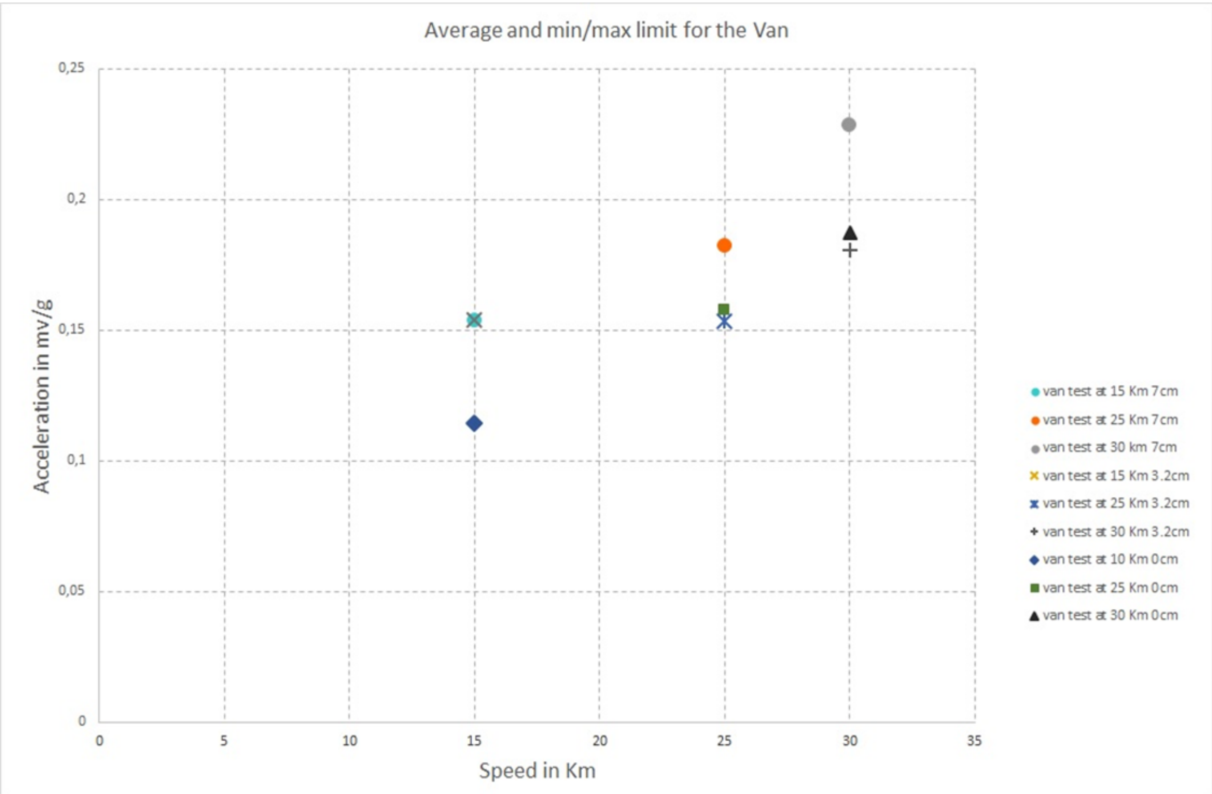

Figure 53. *Acceleration according to the speed and height of the LC for the van.*

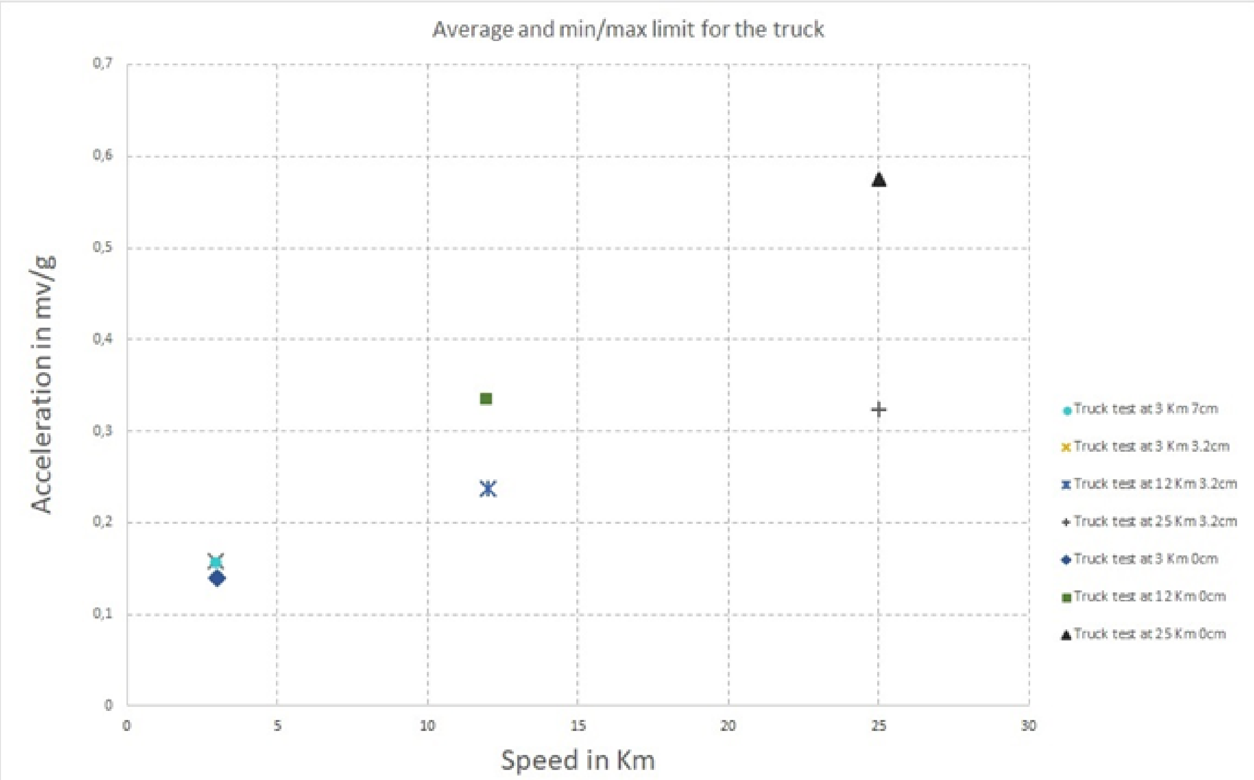

Figure 54. *Acceleration according to the speed and height of the LC for the truck.*

<u>3D thermal behaviour of the experimental LC and crack detection during deformation using the thermal infrared method</u>

This study aimed to detect potential cracks appearing in asphalt in contact with an LC, if the LC structure has deformed. Our hypothesis was 1) this asphalt may be subject to cracking at the contact of the deformed LC and 2) the cracks may be detectable using the thermal infrared method during daytime. The experiment (discussed in the photogrammetric section) consisted of triggering deformations of the LC by repeated passings using a car and a truck. After each passing, the thermal infrared method was applied on the two asphalt bands in contact with the LC. The methodology consisted of acquiring thermal images and photos using a high-resolution thermal camera (Variocam HD 800, 1024*768 pixel) at 1 m height. The 8 megapixel visible camera is directly present on the thermal infrared camera. These data were then used to obtain 3D visible and temperature maps calculated using the photogrammetric method. In this case, the 3D modelling enriches the data, bringing a topographic (depth) information in addition to the temperature and visible reflectance. Here, we only present preliminary results (general model + one passing after fracturation), as the CER experiment was performed in June 2019. It would be of interest to continue this type of experiments of another measure on a different test site. Figure 55 displays the 3D general temperature map of the LC obtained using the thermogrammetric method (developed in our team) and obtained at 10 a.m., i.e. during the warming of the structure. Due to their high thermal inertia (important thermal conductivity, density and heat capacity), the railways are 7°C colder than the surrounding environment during the morning (while it may appear warmer during the night). It is of note that the two asphalt bands in contact with the LC do not have the same temperatures. The asphalt band A1 is clearly warmer than A2 during the morning (contrast of 3°C). This observation should be associated to a difference in thermal inertia and thus to a contrast in the compaction degree of the bands: these structures were built just before the experiment, but within an interval of several days for A1 and A2.

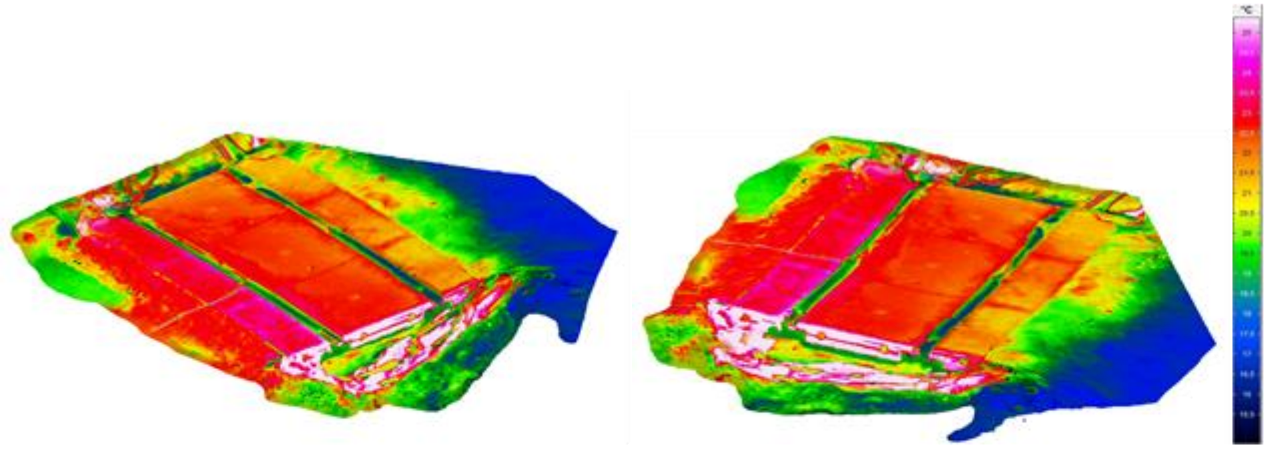

Figure 55. *Different views of the general 3D temperature map of the LC using the thermogrammetric method.*

Figure 56 exhibits an example of a 3D thermal and visible map on A1 (view from the top) after three passings (car + truck). First, a crack is induced within the asphalt band A1 (white square, Figure 56, a), due to the subsidence of the LC. Second, a temperature variation is detected in this area, associated to the recent crack formation (Figure 56, b). In this case, the temperature contrast is 2°C between the fissure and the surrounding area, while the crack may be highly difficult to detect with semi-automatic segmentation algorithms in the visible wavelength. More work will be obviously done in the next months to characterise the thermal behavior of the fissure for all the passings. However, from all these results, we plan to combine the visible, thermal and depth information to enhance some crack detection algorithms. The work will have to be continued in another time.

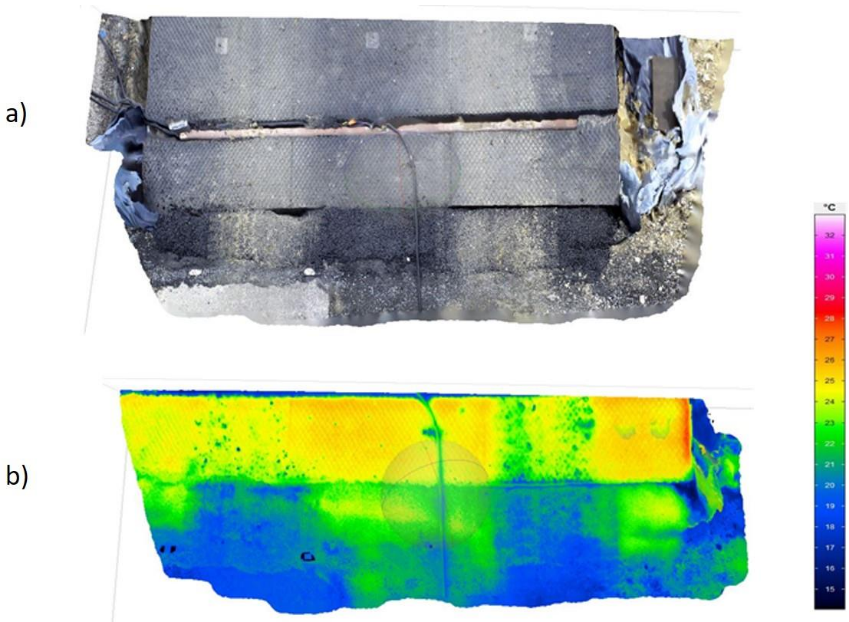

Figure 56. *a) 3D visible model of A1 (view from the top) and formation of a crack due to the LC deformation (white square) and b) 3D temperature model (view from the top) of the A1 Asphalt band. Note the presence of the thermally distinct crack recently formed during the deformation of the LC.*

3.5.4. Discussion

This measure was applied on a level crossing mock-up installed on Rouen test site. The mock-up represented an LC in which different scenarios of infrastructure were played. The monitoring system ensured the safety performance of the LC through the continuous and real time monitoring through two approaches:

- The use of smart and embedded wireless sensor networks. Vibration and temperature sensors were installed on the relevant track/road components and data was transmitted with an alert threshold to the LC operator. The system enabled to send alerts to LC users. To measure the vibration, it was necessary to use a truck.
- A photogrammetric device was used to monitored 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, the visible information combined to thermal infrared data to enhance the interpretations of the potential disorders as fissuration. High permeability zones generated a thermal anomaly of several degrees.

The methods tested at Cerema aims to provide infrastructure managers an efficient means in monitoring structural and geometric LC state to ensure preventive maintenance and safety for level crossings. These methods have shown their effectiveness in detecting and quantifying a geometric evolution. However, they need to be improved and industrialised to be easily used by infrastructure managers.

The advantages and disadvantages of each method are described below:

Photogrammetric method
Six high-resolution cameras were used which led to very long time computation. For ease processing, and with light profile need, two cameras with reduced resolutions would be sufficient.

- Advantages: Geometric modeling with realistic rendering of the LC to determine possible evolutions. Low cost of the measurement device.
- Disadvantages: The measurement should be carried out preferably in cloudy weather and on dry pavement. The processing time can be significant depending on the quality of the result sought. Programming of measurement campaigns.

Vibratory method
We tested two types of vibratory measurements: 1) sensors implanted inside the LC, and 2) sensors embedded in a vehicle (VACC).

The first technique (fixed accelerometers) monitors the structural state of the LC by measuring the intrinsic accelerations and therefore the elastic deformations undergone by the structure. It provides a permanent monitoring system.

- Advantages: Permanent real-time LC monitoring allowing an alert for the maintenance department or blocking traffic with detected danger.

- Disadvantages: Need to instrument the LC and to set up a communication device with a control post. Relatively high cost of deployment

The second technique (accelerometers included inside vehicle) allows monitoring to several LCs with light vehicle. The accelerations measured by the on-board sensors evaluate the LC geometric evolution.

- Advantages: Only one vehicle is necessary for periodic monitoring of the evolution of LCs in a network. Vehicle not specifically dedicated.
- Disadvantages: It is necessary to set acceleration thresholds beyond which geometry measurements must be made on the LC in order to confirm the level of evolution of the LC. Programming of measurement campaigns.

Infrared thermography

This method allows early detection of cracks in the transition zone between the railway structure and the road structure and therefore anticipates the need for maintenance of the structure.

- Advantages: Early detection of a structural evolution of the LC. Low cost
- Disadvantages: Rapid detection of deformation can lead to the appearance of a conflict zone. Programming of measurement campaigns.

Conclusions

Different techniques implemented on full-scale Cerema test site LC can be implemented to ensure LC safety in the area of conflict prevention between the structure and a vehicle. However, each technique has advantages and disadvantages. The implemented technique should be selected depending on budget, dangerousness of the LC, and the evolution speed according to the geometric structure:

- Photogrammetry allows periodic monitoring, the measurement accuracy of which can be adapted as required.
- Fixed accelerometry with a relatively high implementation and exploitation cost is justified when it is necessary to monitor the evolution of a LC in real time.
- Mobile accelerometers, which is cheaper than photogrammetry, allows periodic monitoring but requires additional measurements after detecting threshold overshoot.
- Infrared thermography is justified only by the need for early detection of the degradation of the transition zone to the railway structure.

3.6. Thessaloniki living lab (CERTH-HIT & DLR)

3.6.1. In-vehicle train and LC proximity warning

The *In-vehicle train and LC proximity alert,* is a mobile application aiming to enhance road user safety around level crossings. The application can be installed on any common mobile device such as a smartphone or tablet, and it warns road users about the presence of a LC through a dedicated pop-up window and a short audio alert, whenever they approach a LC. The warning also includes the estimated time of train arrival, whenever an incoming train is expected to reach the LC within one minute (Figure 57; static visual LC warning in the left and dynamic warning in the right).

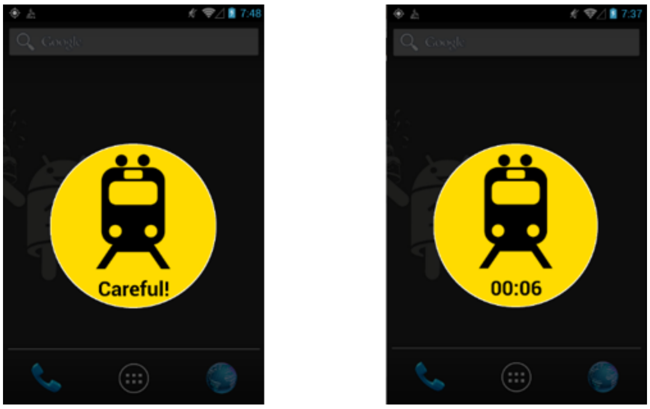

Figure 57. *The static visual LC warning (left) and the dynamic warning when the train is estimated to reach the LC in six seconds (right).*

The alert system can be used for all types of LCs (e.g. passive, active with light signals, active with barriers and light signals). In fact, the application is independent of LC and train type or state of other variables and circumstances (e.g. weather conditions). The only requirement of the system is sufficiently accurate location tracking by the mobile device and a predefined polygon area of interest around the monitored LC, in which road users should receive the warnings.

The system is expected to mainly contribute to increasing safety at passive crossings, which are unprotected, often difficult to spot and thus more dangerous. It is also expected to assist drivers who do not anticipate a level crossing while driving on an unfamiliar road or region, or while driving without being properly concentrated on the road and 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.

3.6.2. Method and data to evaluate the piloted measure

Before–after study was used to assess the safety effects of this measure. The before data consisted of 1.5 months of baseline data (situation before the application was in use). During this period, the application was installed and logged spatiotemporal data for the floating taxis near LCs included in the pilot, without producing alerts (‘inactive’ mode). The data collected in inactive mode were used for assessing the behaviour of drivers around LCs without the safety warnings.

The length of after data collection period was eight months[4]. During this period, the service was fully operable (‘active’ mode), and data analysis for this period focused on two differentiated cases: static alerts for the proximity of the LC and dynamic alerts for the proximity of a train, issued when a train is expected to reach a LC within a minute.

More than 600 taxis (out of approximately 1,000 taxis operating for the same taxi association) used the application in the city of Thessaloniki, Greece. Taxi drivers were allowed to withdraw from the pilot and have all the data recorded for the vehicles erased, by uninstalling the application at any time. According to the taxi association, some taxis use rather basic tablets with low-end

[4] In deliverable D4.3 (Carrese et al., 2019) the data collection period was planned until the end of July, but it was decided to extend this period until mid-September in order to collect evaluation data spanning over a longer period.

specifications (e.g. 1GB RAM) which struggle to cope with the existing dispatching software and they were expected to not install/use our application, which was a limitation for the testing of the service and it has reduced the performance to lower levels. However, at the same time these have become more representative of a large-scale implementation, in which various users may not have high-processing devices.

The drivers that participated in the program were provided with a written instruction form during the process of application installation. Its purpose was to highlight that application users should never fully entrust the system about the dangers and proximity of trains and that they are fully responsible for taking all necessary safety precautions when driving close to level crossings. On a technical level, the geolocation tracking, data transmission and popup alerts operate autonomously after the mobile application is installed, therefore no further training was required for the application users.

In total, 29 level crossings and various trains in the line Athens–Thessaloniki were included in the pilot. The trains were equipped with GNSS devices monitored by the Greek national train operator TRAINOSE and CERTH-HIT was granted real time access to the train location and speed data.

Besides the safety impact assessment by means of Floating Car Data (FCD), the piloted measure was evaluated in terms of operational performance and user's experience, utilising operational data automatically recorded by the system and questionnaires answered by test vehicle drivers before and after their experience with the piloted measure, respectively. In addition, three taxis were equipped with Naturalistic Driving Study (NDS) equipment to collect data for analysing the drivers' reaction to the safety service in the context of the approach to level crossings. The NDS platform consisted of a set of four miniature cameras. It monitored the environment as well as the driver's behavior and facial expressions during November and December 2018. In addition to the cameras, a GPS sensor was implemented in the NDS system to detect driving parameters such as speed, acceleration and position of the taxis. Four different drivers drove these NDS equipped taxis.

In summary, the datasets recorded and utilised in the evaluation of this measure are the following:

- Vehicle location and speed data generated by trains and taxis
- Data recorded by the safety system backend server
- Questionnaires answered by the drivers of the test vehicles (taxis)
- NDS data

In the following subsections, those datasets are described in higher detail, along with the analysis methods applied to each.

Vehicle data

Location data regarding circulating taxis and trains were recorded for the evaluation of the tested safety measure. The raw data is FCD composed of vehicle id, location (in the form of longitude and latitude coordinates), timestamp, speed magnitude (m/s) and orientation (as an angle to the North direction). All the data was generated by the respective fleet management equipment (tablets in the taxis and GNSS receivers in the trains) and collected by CERTH. The data was anonymised in order to respect the privacy of the drivers and can be only processed by staff of CERTH, following the ethical framework/guidelines defined in WP8.

More specifically:

- Taxi probe data were recorded whenever the vehicles entered the LC polygons at a 1Hz frequency. They were transmitted to CERTH-HIT in near real time, utilising wireless internet connectivity, where they were stored for future processing and analysis.
- TRAINOSE provided GNSS data for moving trains. Tracking devices were installed in SIEMENS DESIRO locomotives, operating the suburban railway of Thessaloniki. These devices were 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 data from these locomotives for more than six months, until June 2018. TRAINOSE then started the installation of more tracking devices and switched to a new IT service provider, as a result the data transmission was temporarily offline. A web-service providing with the data recorded by those new sensors in real time was online and accessible by CERTH in January 2019, monitoring some of the passenger and freight trains operating in Greece. These are ADTRANZ, SIEMENS 120 and MLW500 locomotives. Ever since, TRAINOSE was gradually installing more tracking devices to track a larger part of its fleet.

The evaluation datasets recorded by the on-board sensors on taxis and trains were collected from December 2018 to September 2019. During April, the quality of data recorded up to that date was assessed, leading to minor refinements and updates to the data logging mechanisms and polygon definitions. Probe data from the trains were gradually available and recorded from January onwards.

The Key Performance Indicators (KPIs) defined and calculated for the driving behavior around LCs, utilising the FCD were:

- Driving behavior based on trajectories of the taxis when approaching a LC including driver speed profiles with respect to temporal and spatial distance to the rail, number of stops for safety checking, temporal duration of stops, and distance of stops from LC.
- Kinematic indicators including vehicle speed and acceleration-deceleration functions around LCs.

During the baseline period the application was installed in 32 taxis, a relatively small percentage of approximately 3% of the whole fleet, to evaluate the application performance on a technical level and ensure that it does not disrupt the navigation and dispatching application that constantly runs on the fleet tablets. Three of those taxis participated in the NDS, and for those vehicles the application was set to ‘active’ mode in December, prior to the rest 29 taxis, in order to produce video recordings in cases when drivers receive alerts. As a result, the baseline dataset was generated by 29 taxis, with the app set in ‘inactive’ mode. In total, 4,303 unique vehicle trajectories through LCs were discovered during the baseline period, in a dataset of more than 133K GNSS pulses. In our analysis, a vehicle trajectory was defined as the set of all FCD records generated by the same vehicle each time it entered any of the polygons defined around the 29 LCs.

In the following paragraphs the data recorded during the regular period and until the 15th of September 2019 are presented. The application was installed in 635 unique tablets which were planted on taxis typically driven in shifts, by more than one driver. The number of professional drivers exposed to the ‘in-car train and LC proximity alert’ system was estimated to exceed 1,000.

Almost 7.2 million GNSS pulses have been recorded inside the 29 LC polygons, from a total of 257K unique vehicle trajectories around LCs (Figure 58). For all those cases, the application was in active mode and produced the static or dynamic alerts. Furthermore, almost 496K requests were posted to CERTH servers for train proximity status and estimated time of train arrival. A train was detected close to the corresponding LCs 167 times, and in those cases the dynamic message with the countdown was also generated for the driver.

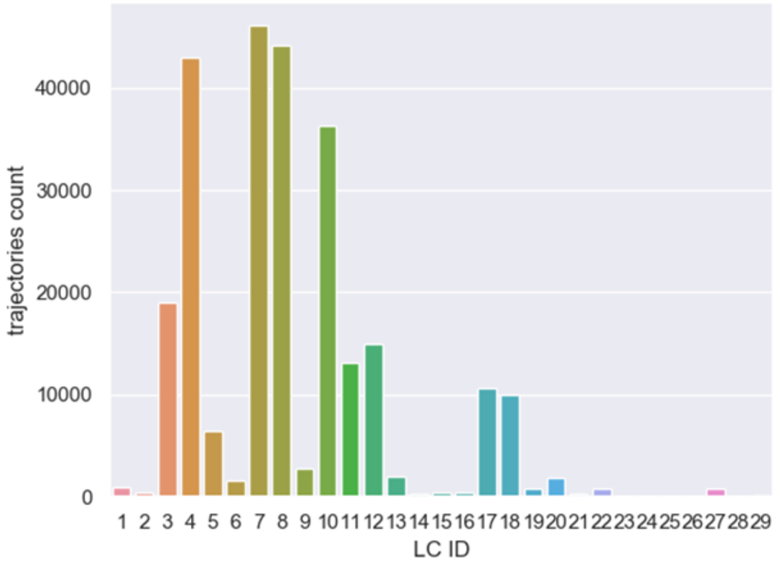

Figure 58. *Vehicle trajectories to LCs.*

Further analysis on the FCD revealed that several taxis were stopped for prolonged periods inside two polygons in close proximity to Thessaloniki intercity bus station, while queueing up for passengers (Figure 59). An algorithm was designed to confirm such events and differentiate them from cases of vehicles temporarily stopped behind closed barriers. The FCD from taxis waiting in the queue where excluded from further analysis.

Figure 59. *Taxis queuing in close proximity to a LC. Screenshot taken using Google Street View application.*

With regards to the number of FCD pulses (records) produced by each vehicle trajectory, there is a clear decreasing pattern meaning that fewer vehicle trajectories produced larger number of pulses. Almost 45% of vehicle trajectories produced up to 10 FCD records (Figure 60).

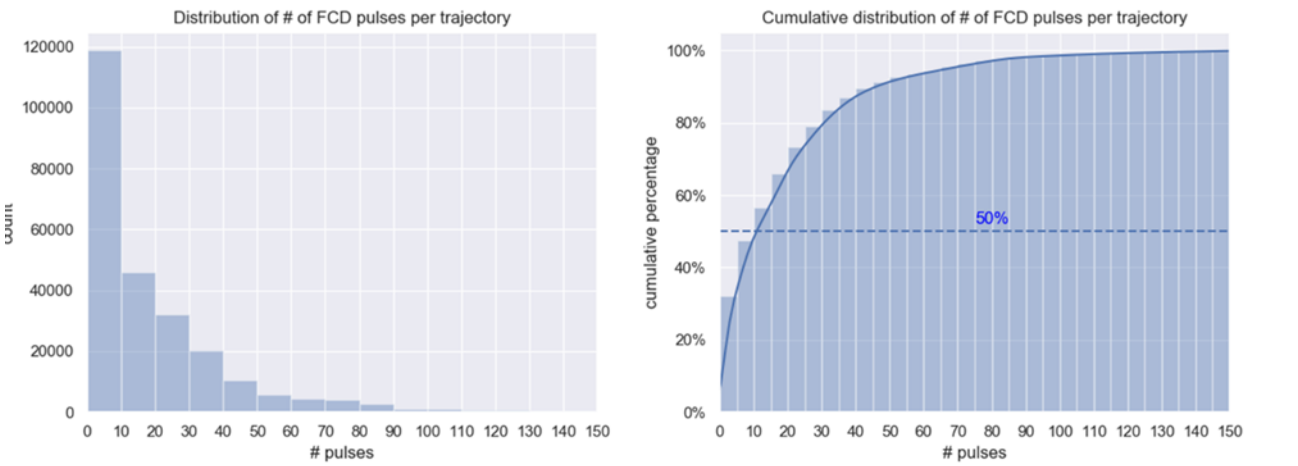

Figure 60. *Histogram (left) and cumulative distribution (right) of number of FCD pulses per vehicle trajectory through a LC.*

In detail, the high signal density and variety of observed variables allowed the development of geolocation data processing algorithms which were applied on the raw data. The rest part of the analysis focuses on the FCD which were recorded in the polygon areas around the two busiest LCs out of the three LCs where trains were tracked, and the dynamic message was available. Those LCs lie at coordinates 40°40'07.4"N 22°53'09.4"E and 40°39'45.7"N 22°53'49.3"E and hereinafter will be referred to as LC1 and LC3 respectively, following the same labels used in Figure 58. The polygon areas defined around those LCs are presented in Figure 61.

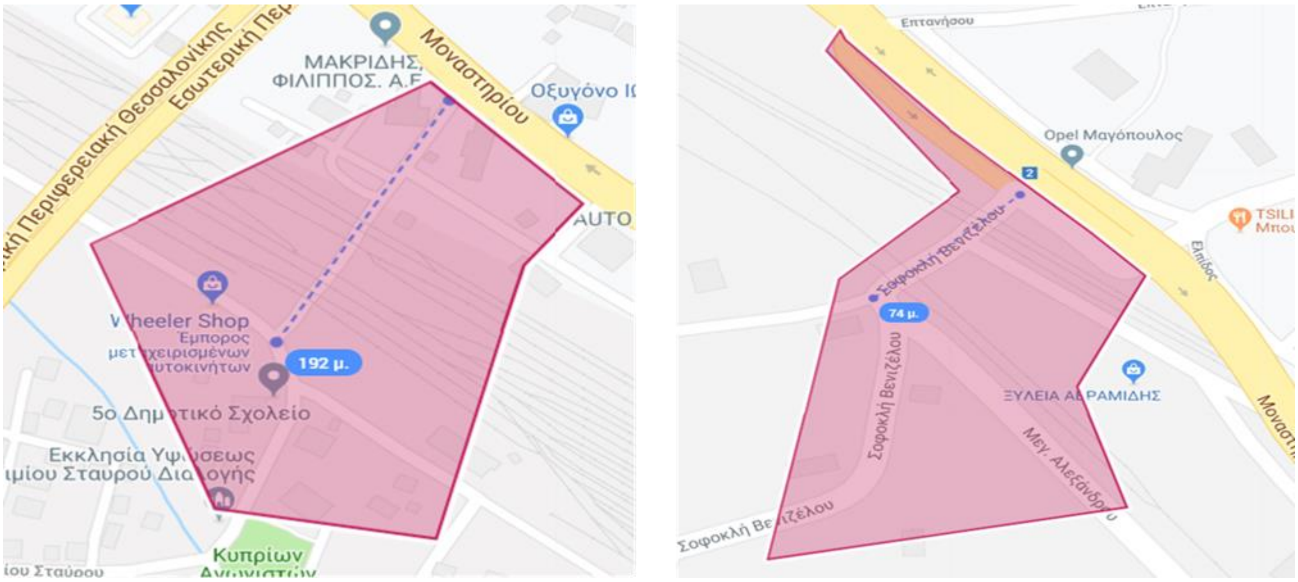

Figure 61. *Polygon areas around LC1 (left) and LC3 (right). A straight section with its corresponding length (192 and 74 meters) is plotted inside both polygons for reference. Screenshots captured from Google My Maps application.*

The number of FCD pulses and vehicle trajectories recorded in LC1 and LC3 are presented in Table 29.

Table 29. *Count of FCD records and vehicle trajectories at LC1 and LC3.*

LC	# FCD records	# vehicle trajectories (baseline / not baseline)
LC1	52,129	48 / 873
LC3	397,363	285 / 17,854
Total	449,492	333 / 18,727

A certain limitation of this real-world, large-scale pilot test is the quality of recorded data. The mobile application was designed to record data each second while the vehicle moves inside any of the polygons, however, the database contains several trajectories with FCD recorded in lower frequency and/or very few pulses. The quality of each trajectory was assessed in terms of duration and recording frequency, in order to process meaningful trajectories for further analysis. and exit the polygons without crossing the rail tracks and was separated from the main data table.

The speed values at each second, measured by the tablet’s sensor, typically contain noise and fluctuates in extraordinary ranges from second to second. In order to reduce noise, a smoothing function was applied to the speed time series of each trajectory, which corrects the speed value computing the mean speed value utilising the previous and next measurement. An original and its corresponding smoothed speed time series is presented in Figure 62.

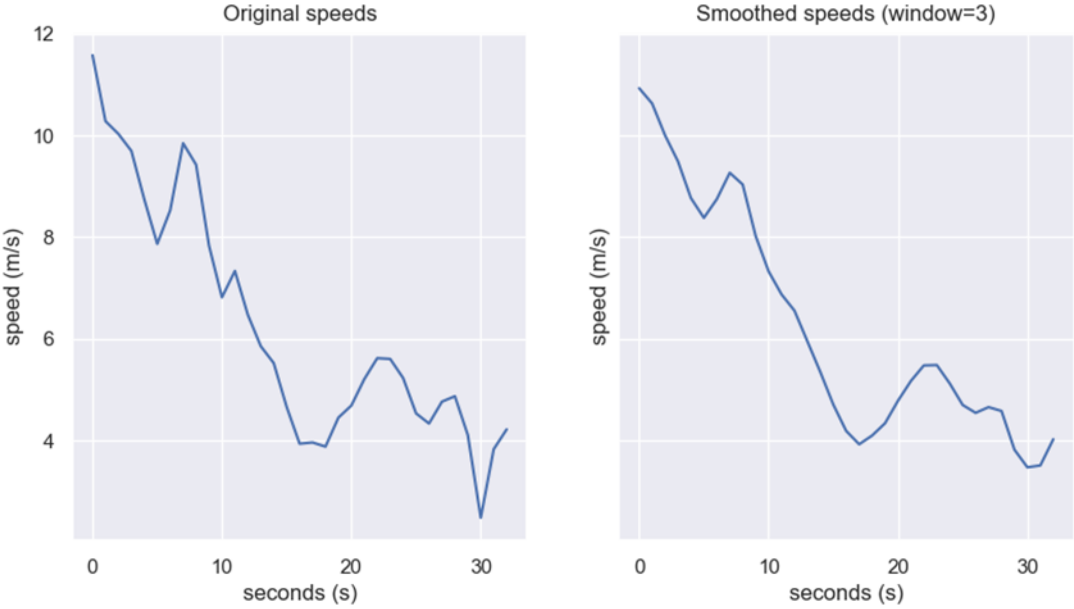

Figure 62. *A trajectory's speed time series, with original (left) and smoothed values (right).*

Another function was applied to each trajectory to classify the pulses before the vehicle meet the rail track as 'approaching', and 'not approaching' otherwise. This was achieved by labelling the different areas separated by the rail tracks with different identification labels. LC3 is also accessible from the road section between two rail tracks, therefore 3 areas were defined, area 1 North of both tracks, area 2 between the tracks and area 3 South of the tracks. For each datapoint, the corresponding area was identified and the distance to the first rail track was computed. Furthermore, each trajectory was assigned a label, according to the entry and exit road of the vehicle. A web-based interactive dashboard was developed to visualise taxi trajectories on a map, along with data for each point (area, speed and distance to track). This tool supports filtering of trajectories with respect to their type, and the user may choose any of the trajectories of the selected type for visualisation and exploration. A screenshot of the tool is presented in Figure 63, where the trajectory with identification label '25' of type '123' (meaning that the vehicle enters from area 1 and then moves to areas 2 and 3) is visualised.

Choose trajectory type:
Choose specific trajectory:

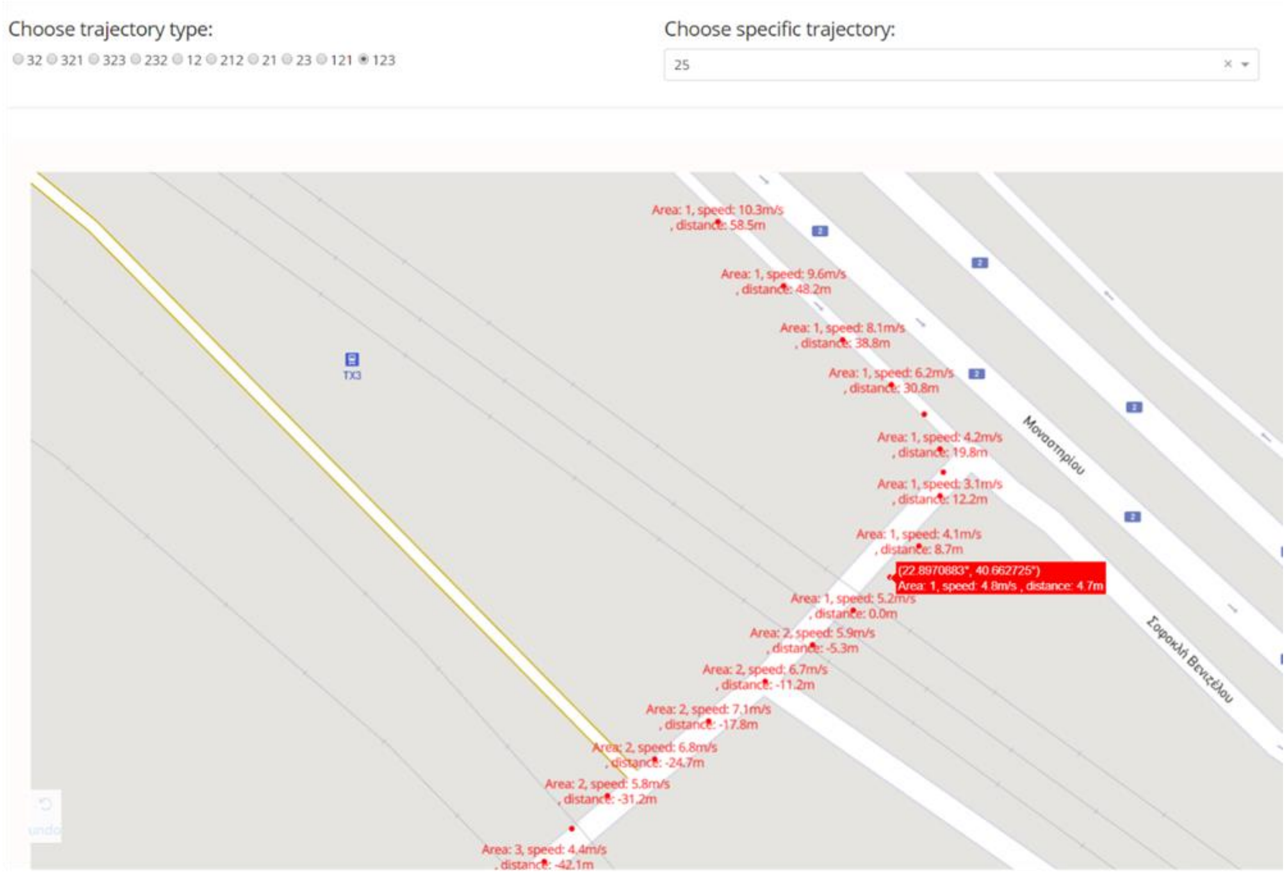

Figure 63. *Screenshot from the interactive tool for visualisation and exploratory analysis of unique trajectories, when trajectory '25' of type '123' is visualised.*

In an attempt to study the speed profiles of vehicles approaching LCs and explore patterns from the drivers, clustering was applied to the speed time series. Initially, the trajectories were grouped with regards to the road from which a vehicle approaches each LC, in order to utilise speed time series recorded in the same road sections. Four unique cases were defined for LC1 and five for LC3. The distance between each pair of time series was calculated utilising the Dynamic Time Warping (DTW) method, which attempts to optimally align time-dependent sequences of observations, even in the presence of deformations, noise and unequal length in the series (Müller, 2017). After computing pairwise distance of the speed sequences, four agglomerative clustering algorithms were utilised, namely ward linkage, complete linkage, average linkage and single linkage.

Additional functions and methods were applied on each taxi trajectory to classify and distinguish trajectories with respect to LC, system operational status ("baseline" or "after" period), current LC status and driver decision. Statistics and safety-related KPIs were calculated for those categories to quantify the safety impacts of the warning application before and after its deployment.

<u>Backend server data</u>

The backend server was designed to log operational data since the first day of the pilot tests. Two significant events were registered, namely the alerts and requests. An alert event was recorded when a vehicle entered any polygon and the warning pop-up was generated. A request event was registered to the database whenever a device has successfully posted a request to the server to acquire train proximity and its estimated time of arrival (ETA), after entering any LC polygon area. The logged data contained details for each safety warning message issued by the system including the vehicle ID, the event's timestamp, the ID of the corresponding LC polygon, the type of the warning (static or dynamic), the version of the application, the server's response to request, and the way the pop-up message was closed. Only 22% of pop up alerts were force-closed by users and the rest timed-out without intervention after the predefined 15-seconds period, indicating that the visual and audio alert are adequately discreet. Message force-closing is achieved by tapping anywhere on the tablet screen, to prevent or minimise the duration of "eyes off the road" events.

The backend server data were fused with the taxi generated FCD for the same temporal period to verify and cross-check the safety service operation and actions with the geolocation of taxis. One limitation of both the taxi FCD and backend server data logging was that data batches were transmitted to the server via 4G mobile communications network right after each taxi exited a polygon. According to the taxi association and their software services provider, most on-board tablet devices had low hardware specifications and run several applications including navigation and taxi dispatching, thus the more robust option of storing the data on the tablets was not feasible during the pilot tests. Transmitting data via mobile communication network is less reliable and may fail in cases of low quality or unavailable internet connectivity, or when the tablet or mobile application crashes. Consequently, it is possible that a warning message was indeed generated for a test vehicle circulating around a LC, although the event was not recorded in the database due to packet loss.

The backend server data analysis focused on the identification and examination of critical cases, including:

- False positive cases, when dynamic and static alerts were generated in appropriate distances.
- False negative cases, when dynamic and/or static alerts were incorrectly not generated.
- Estimated time of train arrival deviations and errors.

<u>Questionnaires</u>

Questionnaires were created to collect feedback from system users, and are presented in Annexes A and B. They were handed to the taxi drivers in three phases, in order to monitor their opinion and experience before, during and after using the system. Each version of the questionnaire was different, and adjusted to the pilot testing phase, as some questions were relevant in specific periods of the pilot implementation. The questions included in the forms are typically composed in order to target one or more of the criteria to assess:

a) the behavioral safety effect of the measure on road users and

b) user experience and social perception of system users

as defined in the Human Factor Assessment Tool (HFAT), presented in Deliverable D2.2 of the SAFER-LC project (Havârneanu et al., 2018). Processing of answers is directed towards a twofold aim: to generate input for the HFAT and also provide insights regarding the pilot evaluation procedure on a more general basis.

Both the traditional paper questionnaire and the more modern web-based, digital format were considered for this survey. The latter was preferred after discussions with taxi association representatives and the navigation software providers. All taxi drivers are familiar with the dispatching application interface; they have been using it for years and they receive business and operations related messages regularly. The web-based format ensures that the questionnaire targets all the fleet drivers with same probability without favoring the ones familiar with technology.

The link to the digital questionnaire was sent to all drivers as a short message through the navigation application. It was posted to both morning and afternoon shift drivers within the same day. The invitation was sent again to the vehicles from which the drivers did not initially respond. Analysis on the questionnaire answers provided statistical indicators about the end users of the safety service. The results from those surveys are considered highly important, as most of the taxi drivers who tested the safety system have huge driving experience, based on their answers regarding age, years of professional driving experience and distance driven the previous year. The first phase questionnaires (before the pilot period initiation) focused on user behavior and experience related to driving through LCs, and their opinion on the significance of an in-vehicle warning system. The next two phases focused on collecting information and feedback related to the significance, general user's experience and ease of use of the application. Some questions focused on the behavioral change after using the application.

Naturalistic driving data

The NDS was installed in three taxis between October 2017 and January 2018. NDS videos were recorded whenever the NDS system's power supply was plugged into the in-car socket and the car's electric power supply was activated (typically when the motor was running). The system creates a new video file each time the power supply gets switched off and on again. This way, between 0 and 134 video files were recorded per taxi per day (mean M = 3.8, SD = 12.1). Drivers were free to decide whether to plug in the system and thus whether to participate in the video recording or not. The recordings from the NDS system yielded 3,050 videos overall, sorted in folders by the taxi from which they

3.6.3. Evaluation results

In this section the evaluation results are presented, organised in four subsections with respect to the dataset utilised in analysis, namely a) evaluation of driving behavior, b) system's operational performance evaluation, c) questionnaire analysis and d) naturalistic driving study data evaluation.

Driving behaviour

The behavior of drivers was studied in the last 70 meters before reaching the rail track and data points outside this area were not considered for the results. The data quality filters introduced in subchapter 3.6.2, regarding each trajectory's duration and data recording frequency were applied. As Table 30 depicts, the initial sample size of 18,727 trajectories around LC1 and LC3 was decreased to 6,730 trajectories, after the exclusion of the trajectories that did not cross the rail tracks and application of the data quality filters. It is important to mention that trajectories not crossing the rail track have occurred for multiple reasons, for instance when a driver did not intend to cross the rail track or when the driver decides to make a U-turn to avoid waiting behind closed barriers. As seen in Figure 61, both LC1 and LC3 polygons might be entered and exited without driving through the rail track.

Table 30. *Trajectories sample size.*

Trajectories types	LC1 (baseline / after)	LC3 (baseline / after)
Total # of trajectories processed	48 / 825	285 / 17,569
# of trajectories after the duration and frequency filter application	27/ 253	160 / 7,904
# of trajectories not crossing the rail track (U-turn/other)	21 / 107	41 / 1545
# of trajectories crossing the rail track	6 / 246	119 / 6359

The vehicle trajectories that did not cross the LC were not considered for the rest of analysis. The remaining ones were classified in two categories; trajectories with open or closed LC protection barriers. In the absence of data about barriers shutdown period, the closed barriers cases were identified when a vehicle's pulses were stationary for at least 10 seconds. The purpose of this classification is to distinguish cases with inherently different speed profiles and extract appropriate statistics and safety-related KPIs adjusted for each category.

On a coarse-grained level of aggregation, where all trajectories are grouped with respect to the road from which vehicles enter the polygon, exploratory analysis does not reveal significant differentiations. In Figure 64, the aggregated functions of speed and acceleration with respect to vehicle distance from LC3 are plotted, for the case when vehicles enter the polygon via "Μεγ. Αλεξάνδρου" street.

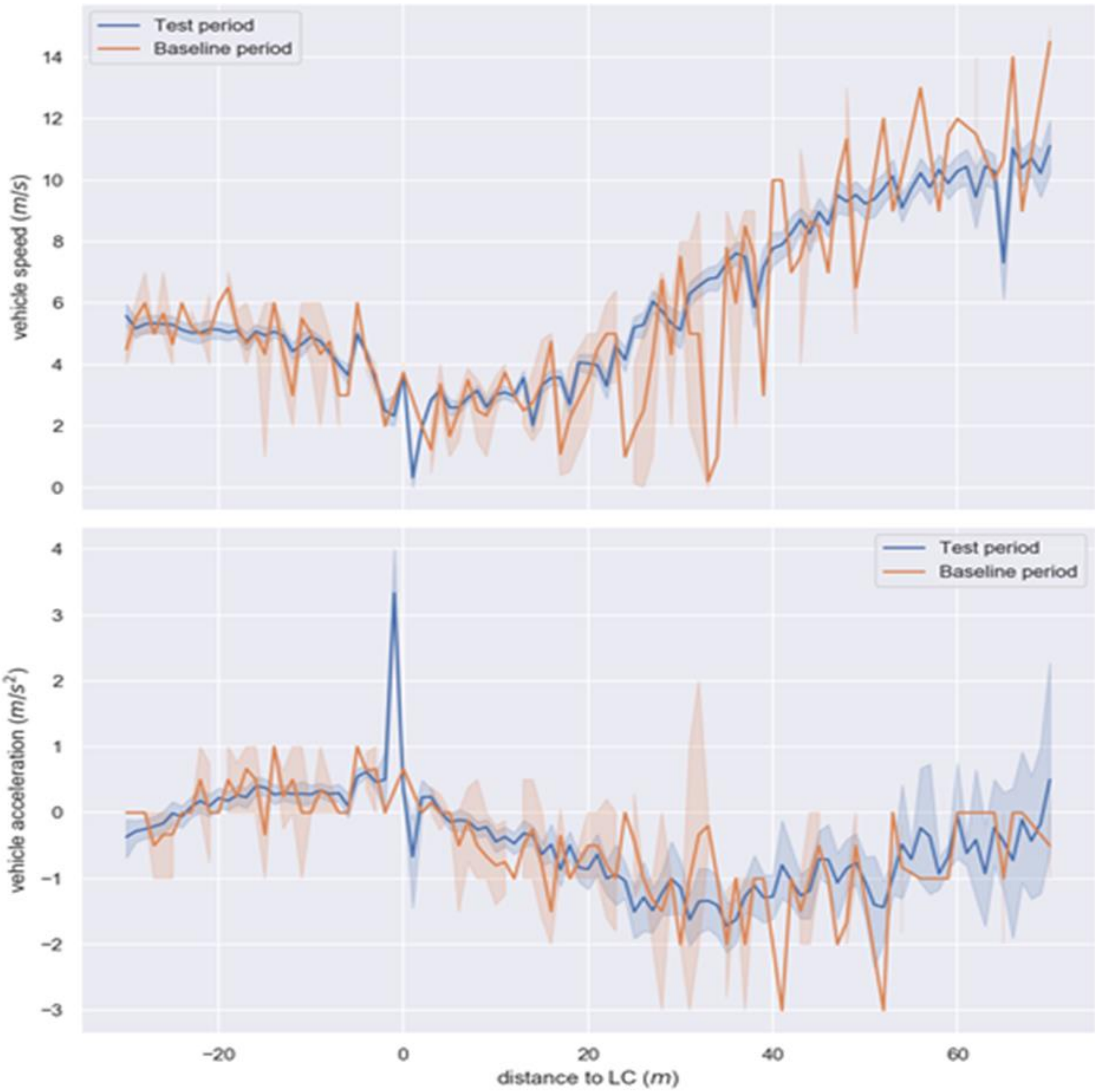

Figure 64. *Plots of aggregated speed and acceleration values with respect to distance from the rail track, around LC3 for vehicles approaching via "Μεγ. Αλεξάνδρου" street. The baseline period line is noisier due to less samples. Negative distance values correspond to points after the vehicle crosses the rail track.*

The agglomerative clustering was implemented utilising the DTW for distance calculation between trajectories, and the number of clusters was tested in the range of 2 to 5 clusters. The visualisations of produced clusters did not result in meaningful clusters. This can be observed in Figure 65, which utilises data from a random sample of 40 trajectories around LC3. The three different line styles indicate the corresponding cluster for each trajectory.

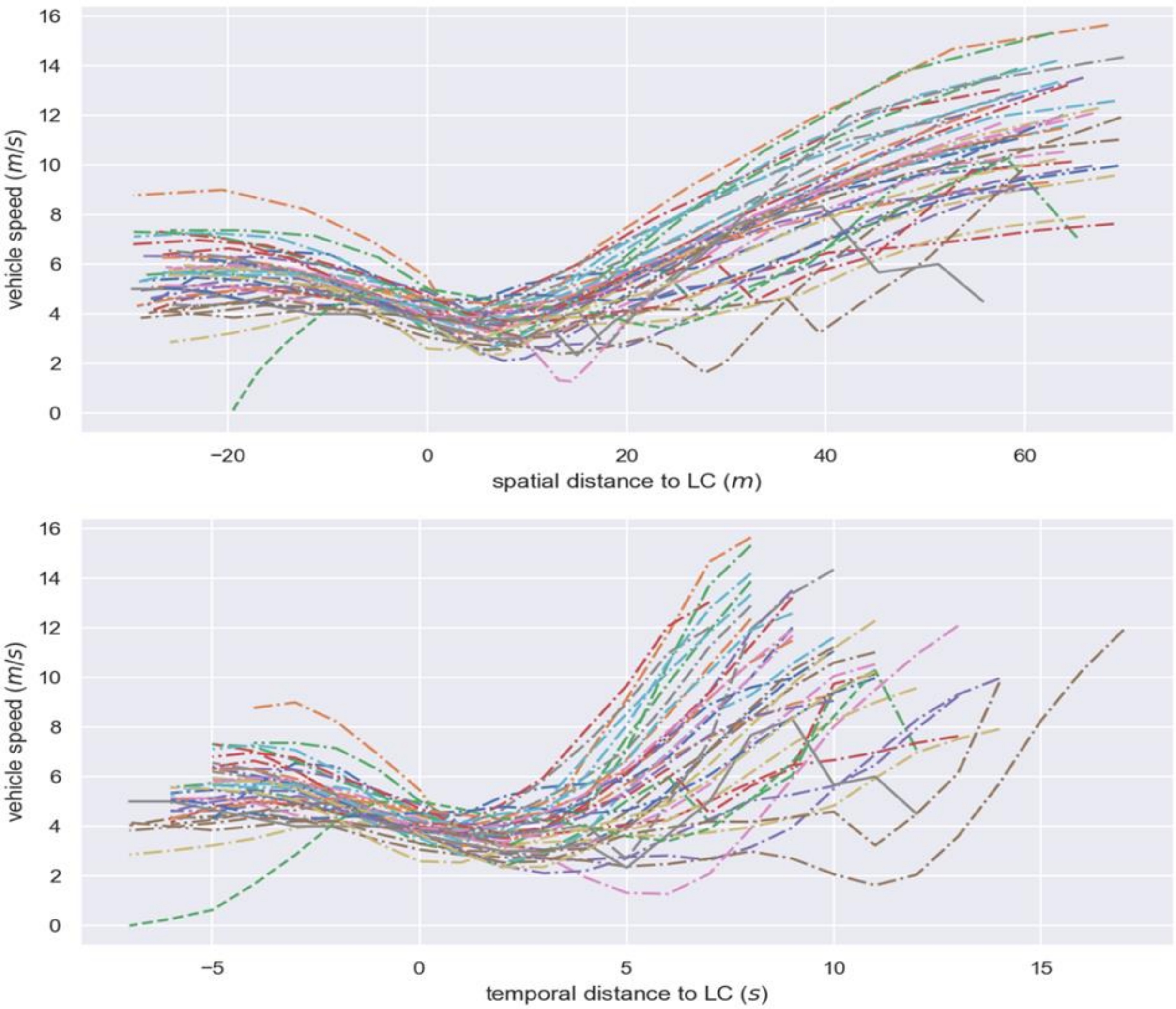

Figure 65. *Vehicle speeds vs spatial and temporal distance to LC3 for a random sample of 40 vehicle trajectories approaching via "Μεγ. Αλεξάνδρου" street. The different line styles (continuous, dashed and dashed-dotted) indicate the cluster each trajectory is assigned to, using the single linkage method.*

In the finest grained level, 252 and 6,478 unique trajectories around LC1 and LC3 respectively were processed. The safety-related KPIs and results are presented in Table 31. In an attempt to quantify the level of driver attention in the open-barrier case, "safety check" events were defined, as instances of vehicle speed dropping below the walking speed threshold of 5 km/h, up to 70 meters before reaching the rail track.

Table 31. Classification of vehicle trajectories crossing the LC.

	LC1 (baseline / after)	LC3 (baseline / after)
# of trajectories with open barriers	6 / 229	112 / 6070
# of trajectories with closed barriers	0 / 17	7 / 289
KPIs for vehicle trajectories with open barriers		
KPI1. Percentage of trajectories with at least 1 "safety check"	33.33% / 7.86%	19.64% / 18.92%
KPI2. Mean # of "safety checks" per trajectory before crossing	0.33 / 0.10	00.20 / 0.23
KPI3. Mean temporal duration of "safety checks" per trajectory (seconds)	1.16 / 0.55	0.86 / 1.17
KPI4. Mean temporal duration of all "safety checks" detected (seconds)	3.5 / 5.77	4.21 / 5.12
KPI5. Mean distance of first "safety check" from LC within 25 meters to LC, ignoring trajectories that did not "safety check" (meters)	22.11 / 14.81	10.81 / 12.75
KPI6. Mean vehicle speed when the distance from the rail is between 5 to 15 meters (m/s)	4.22 / 4.13	3.43 / 3.87
KPI7. Mean vehicle deceleration when the distance from the rail is between 5 to 15 meters (m/s^2)	0.04 / -0.14	-0.29 / -0.32
KPIs for vehicle trajectories with close barriers		
KPI8. Mean time stopped (seconds)	75.82 (non-baseline only)	43.57 / 47.87
KPI9. Mean of max deceleration per trajectory (m/s^2)	-2.04 (non-baseline only)	-1.27 / -2.42

The sample size of trajectories through LC1 for the baseline period is only six trajectories, therefore comparison of the KPIs with the "after" period results is unrepresentative, with large numerical differentiations. For instance, the percentage change of average temporal duration of "safety checks" per trajectory was increased by 65%. The results are more representative and meaningful for comparisons between the "baseline" and "after" periods for vehicle trajectories through LC3, for which the sample size in both periods is sufficiently large. Furthermore, for the case of open barriers, several KPIs indicate safer vehicle trajectories during the "after" period. Most significantly, after launching the safety system, the mean duration of all "safety checks" was increased by 22 % and the average distance of "safety checks" to the rail track also increased by 18%.

The statistical significance of the four improved KPIs 2, 3, 4 and 5 was investigated. Statistical tests were considered in order to assess whether the available data samples for the two periods (before and after the safety system) were drawn from populations with similar distributions. The independent t-test was not applicable because of violation of its assumption that the samples approximate a normal distribution. Instead, the two-tailed Mann-Whitney U test was applied, a nonparametric counterpart of the t-test that does not assume normally distributed samples, with the null hypothesis that the distributions of the data samples are identical. All four tests resulted in p values higher than the 5% threshold, suggesting that samples are drawn from distributions that do not differ significantly. As a result, KPI differentiations and changes cannot be considered statistically significant.

Operational performance evaluation

The backend server data for the period from 1st February to 15th September were analysed to assess the overall operation of the system and the communication between its components. During this six-month period, 249,021 taxi trajectories around LCs were recorded in the FCD. The number of registered unique pop-up warning messages and unique ETA requests to the server are 443,718 and 467,480 respectively. For 124,996 test vehicle trajectories (~65% of total), the pop-up warning was successfully generated and registered, and for 127,306 (~66% of total) a request was successfully posted to the servers and registered. Every time a warning pop-up was generated, the systems have logged a successful request to the server for the ETA, except for three cases.

The estimations of time of train arrival issued by the system were also assessed. For all 106 cases when a taxi was issued with a dynamic message, and therefore an ETA, the corresponding train data pulses where processed to extract the actual arrival time. Figure 66 presents the comparison between estimated and actual crossing times, with respect to train speed and distance to the LC at the moment of prediction.

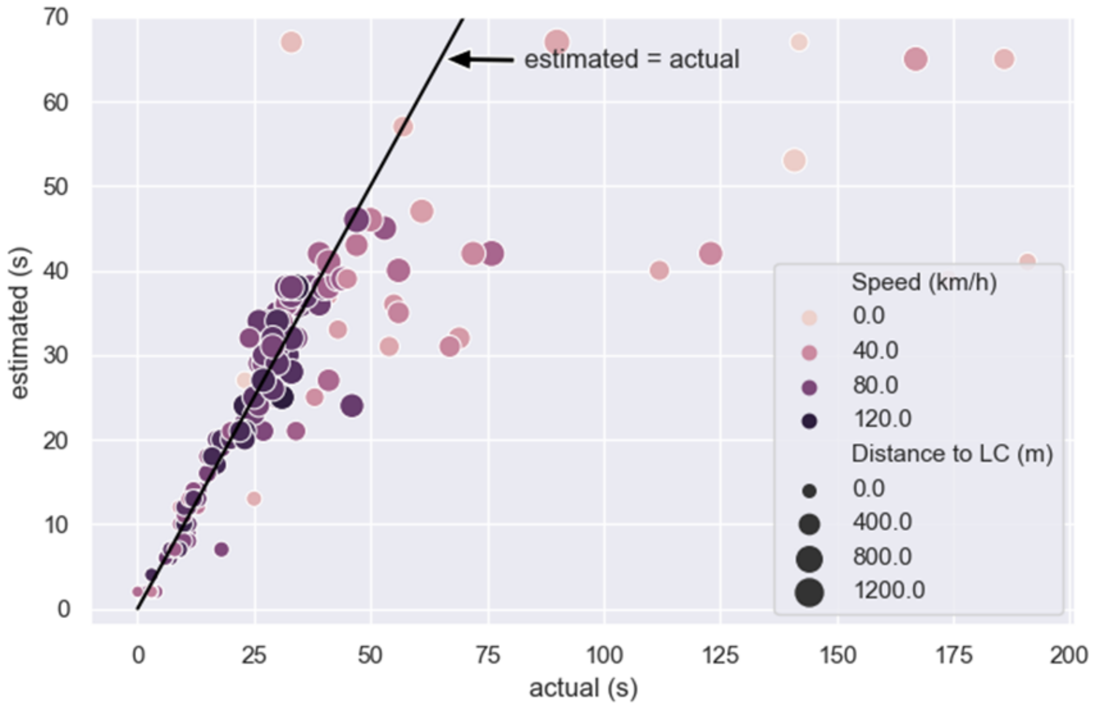

Figure 66. *Estimated versus actual time period until train arrival in seconds.*

As depicted, the neural network predictive algorithm is in most cases highly accurate and more biased towards underestimations than overestimations, so that a prediction error will typically result in a train arriving later than expected, which is a safe scenario. Another remark is the six heavily underestimated cases, with actual arriving time greater than 100 seconds. Those cases where individually examined and the large error was produced due to the combination of extraordinary slow speed at the respective locations. The dataset that was utilised to train the predictive algorithm was recorded by a certain type of trains and did not contain similar cases, thus the model was unable to issue more accurate estimations.

Questionnaire analysis

The survey analysis results are presented in this section. The questionnaires were answered before (1st phase) and after (2nd and 3rd phase) the launch of the tested safety system.

The first questionnaire received 236 responses from drivers, the overwhelming majority of which are male (95.7%). The mean age, years of experience as a professional driver and the estimation of kilometers driven within the previous year are found to be 47 years of age, 15 years of experience and 57K km driven last year. The highlights of the answers are summarised below:

- 86% of drivers believe that LCs are in general moderately to completely dangerous for any driver.
- Almost 45% do not feel safe while driving around LCs near Thessaloniki; 88% state that it is moderately to completely difficult to detect LCs or trains using the current road infrastructure.
- More than 41% report that LC existing infrastructure in Thessaloniki assists them just slightly or not at all.
- More than 81% point out that it is highly significant for them to be aware of both the distance and time of arrival of train to the LC.
- 85% of them believe that it is considerably (17%) or completely (68%) important to use a smart in-vehicle system to increase safety around LCs.

An interesting association was found amongst the answers of questions 5, 10, 11, 13, 14. Those were positive, moderately strong to strong correlations (r ranging from 0.25 to 0.83) with p-values < 0.001. They indicate that the drivers who stated that they consider LCs dangerous, tend to also consider information of the train distance and time of arrival to LC highly important, and they feel that the on-board safety system will be helpful.

Similar association exists among the answers of 6, 7, 8 and 9 with the strongest between 7 and 8 (r=0.633, p-value < 0001). This implies that road users who do not feel safe driving at level crossings also tend to have difficulties in identifying a LC or an incoming train or, generally, a dangerous situation near a LC and they are also dissatisfied with the existing safety measures.

The importance of knowing a train’s distance to LC is strongly correlated to knowing the time of its arrival (r=0.826, p-value < 0001). The answers of questions 10 and 11 are also moderately correlated to the ones of questions 13 and 14.

The second questionnaire only received 56 responses, although exactly the same format and distribution method was used. For this second phase, the critical point was to receive user feedback for the tested system. As a result, the first introductory question was related to experience with the system and the respondents who had not used it were excluded from the following questions. From a total of 32 responses from drivers who had used the system, four were excluded as they did not contain answers for more than ten questions, further reducing the sample size to 28. The highlights of the answers are summarised below:

- 82% of drivers feel at least moderately safer using the system.
- Half of them believe that the system integrates considerably or completely well with the existing LC safety measures in the area and less than 15% stated that it does not help them detect a LC and approaching trains.
- 70% of drivers think that the system enhances the identification of previously unknown LCs
- No driver would ignore the information provided from the system while 92.5% would not even consider taking risks at LCs after being warned by the system.
- More than half of them believe that the system and provided info is considerably or completely reliable.
- More than 40% of drivers stated very interested in using the alert system after the finalisation of the test period.

The third phase questionnaire was answered by 88 drivers, however, 34 of them stated that they do not use the system and another 4 answers contained several empty responses to answers. The final sample size was therefore reduced to 50 responses. The main focus of this survey is on documenting drivers' opinion with regards to the safety system's potential and effect on other users. The highlights of the answers are summarised below:

- The percentage of drivers who feel at least moderately safer using the system was increased from 82% in the second phase, to 92% in the third phase.
- Three out of four believe that the system has a positive effect on the way the drivers approach LCs, and a similar percentage anticipates positive effects on other drivers as well.
- 92% of drivers are considerably or completely positive that the system would assist vulnerable users, like new drivers, approach a LC in a safer way.
- Nine out of ten drivers believe that a similar safety system should be integrated in the navigation system of modern vehicles.

<u>Naturalistic driving study</u>

Data Analysis

Floating car data (FCD) recorded by CERTH were used to identify episodes containing LC traverses in the video data. The FCD file contained data of polygon contacts of the three vehicles with NDS boxes. These data were recorded between Dec 8th 2018 and Feb 4th 2019. The polygon contact timestamps from the FCD were listed and compared to the recording dates and times of the videos from each of the taxis to identify potentially relevant videos.

The videos were then screened for actual LC traverses, using the GPS time displayed in the video. The numerical GPS data channel in the videos could not be used due to readout problems. The video sections containing LC episodes were annotated for a set of target variables (e.g. time of warning onsets, time of LC traverses, active search behaviour, signs of distraction, violations) by a trained rater using a standardised coding scheme and the ELAN software (Version 4.7.3, https://tla.mpi.nl/tools/tla-tools/elan/, Wittenburg et al., 2006). The annotation data were then used to quantify and compare driver behaviour on approach to LCs in the baseline and the test phase.

Results

The total number of LC traverses found in the videos amounted to 26 overall (n = 8 from the baseline phase, n = 18 from test phase). The number was comparatively small because the NDS system was mostly not activated at times when LCs were encountered and vice versa. Further, the number of evaluable videos was diminished by constraints to recording quality (e.g. by changes in camera focus and orientation, poor lighting conditions between 8 p.m. and 8 a.m.). In total, 16 evaluable traverses were identified at LCs that were part of the pilot. These traverses were analysed for active search behaviour on LC approach as a sign of enhanced attention paid to LCs.

Active search behaviour was defined as observable head and/or eye movements (implying that the driver scanned the environment for trains), starting from the point in the video at which the first sign of the LC became visible, until the point at which the tracks were actually crossed. In six cases, the actual warning status could not be observed in the video, leaving 12 cases for analysis. In this small sample, the proportion of active search behaviour was slightly higher after a warning than without a warning (3 of 5 vs. 3 of 7 observations; see Table 32). No instances of critical distraction were observed after a warning.

Table 32. *Active search observed at LCs by warning condition.*

Warning	Active search behavior	No specific search behavior	Total
Yes	3	2	5
No	3	4	7
Total	6	6	12

One rule violation was observed. It occurred during the baseline phase and shows a driver following other vehicles in traversing the LC instead of active warnings and a half-barrier that is already closed.

3.6.4. Discussion

Overall, no significant problems were encountered during the design and development of the safety system and the data collection infrastructure. However, the prolonged period of train data unavailability posed certain difficulties during the pre-launch testing of systems as most of the tests were conducted by simulating train itineraries utilising past data. With fewer than expected number of GNSS monitored trains during the first months of the pilot, the number of dynamic message cases was limited.

A less important issue regarding the FCD recording occurred while taxis were stopped inside two polygons while queuing up for customers. Those cases were detected in the historical dataset and a custom algorithm was developed to exclude them from the system's safety impact analysis.

After discussions with the taxi association during the assessment of the first pilot period, drivers' comments about the safety alert system were predominantly encouraging. Feedback regarding the appropriateness of the audio and visual warnings was positive, as drivers reported that they clearly understood the reason for the generated alert without being annoyed by its severity. However, they also reported that in certain places, alerts were received near LCs although the vehicles were moving in an overpass or surrounding roads next to polygons (false positive events). The majority of false positives were present at the LC located at coordinates 40°39'45.7"N 22°53'49.3"E (Figure 67), where the distance between the LC and the right lane of the overpassing road, “Μοναστηρίου” street, decreases up to approximately 30 meters. Analysis on raw data confirmed those events around the designated areas and revealed that they occurred when the vehicle geo-position sensing was slightly inaccurate, indicating that the vehicle entered the neighbouring polygon. Before the second pilot period, CERTH revised the boundaries of polygons where those false positives were detected, to further increase the distance from nearby road sections in order to avoid false alarms.

Figure 67. *LC at coordinates 40°39'45.7"N 22°53'49.3"E. Screenshot taken from Google Maps Application.*

In an attempt to further refine the system, the second and third questionnaires aimed at revealing potential flows of the app and its functionalities. The drivers were encouraged to propose their ideas on how the safety system could be improved and to comment on their experience with it in an open question, but no relevant comments were recorded.

The pilot testing was implemented in real life conditions and in large scale, with hundreds of vehicles using and testing the system concurrently and continuously. There have been no major issues relevant to the scale of implementation. However, certain limitations regarding the system’s impact assessment are posed by external factors, primarily with regards to backend server logging. The processes of recording and transmitting data to the server, handled by the onboard tablets, is infeasible under certain circumstances, for example in the absence of internet connectivity or inaccurate/unavailable geolocation tracking.

The infrastructure and hardware for this system classify it as low-cost solution. Nowadays, most train operators and taxi associations have already installed GNSS devices on their fleet for monitoring and navigation purposes. Even if the system is to be implemented on privately owned vehicles in the future, the application can be downloaded and installed in the owner’s smartphone or navigation device. The only costs for the end user are the data transmission charges issued by the telecommunications provider whenever the device enters a LC polygon. For the service provider, after the software development, the only expenditure is the server and its maintenance costs.

The comparison of speed and acceleration time series, as recorded before and after activating the warning system, did not indicate a significant effect on the speed of vehicles approaching LCs.

However, the test vehicles were driven by professional taxi drivers with huge experience and knowledge of good practices for safe driving around LCs. The data analysis results support the hypothesis that drivers have adopted a stable behaviour prioritising safe decisions when approaching the potentially dangerous rail tracks.

This is also supported by the outcome of the agglomerative clustering algorithm applied on the trajectory time-series data. The clustering failed to produce meaningful, distinct groups of similar vehicle speed profiles around the LCs, for instance a group of drivers who tend to brake late versus another group who brakes earlier when approaching a LC. Rather, there seems to exist a somewhat uniform distribution of LC approaching driving styles.

Concerning the usage of the NDS system to get a look on drivers‘ actions and reactions at LCs and the suitability of an in-vehicle warning system to enhance safe behaviour, the results observed in the sample are consistent with the idea that warning systems can contribute to enhancing attention at LCs without causing undue distraction. The one instance of a rule violation observed occurred while the warning system was not yet active. However, the sample is very small and does not allow for a generalisable conclusion. Therefore, as a lessons learnt, closer monitoring of system settings and use is necessary to achieve a more representative sample of LC episodes to analyse.

3.7. Real rail environment (VTT)

3.7.1. Additional warning light system at front of the locomotive

The piloted measure is called as *Additional warning light system at front of the locomotive*. The principle of the warning system is shown in Figure 68. 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.

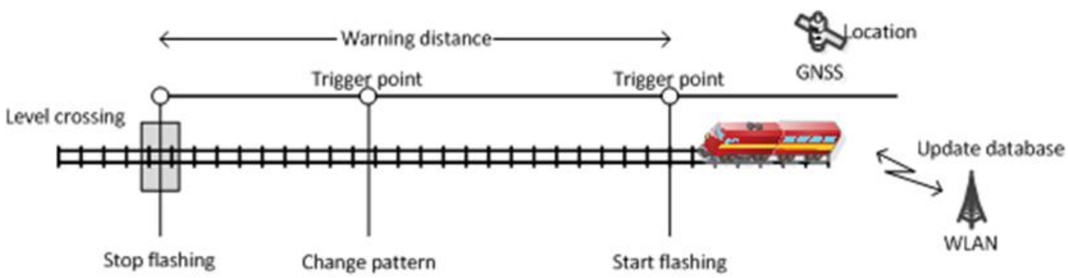

Figure 68. *Warning system principle.*

The operation principle is straightforward. First, the closest LC is searched from the LC database. That specific LC is selected if the direction of travel is towards the LC and distance is shortened. If the train is within the warning distance (distance from the trigger point to LC) the lights are active with the associated pattern and intensity. The additional warning lights are deactivated after the train front has passed the LC.

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 69. It contained three high intensity LED lights and control unit. LED lights were high beam accessories and accepted to be used in road traffic. Each unit had 10,000 lumen light intensity and beam range was up to 800 meters. Lights could be controlled separately. Intensity was not controllable. In Figure 69 lights are attached to the frame, but they could be easily removed and installed to the front of the locomotive at required distances.

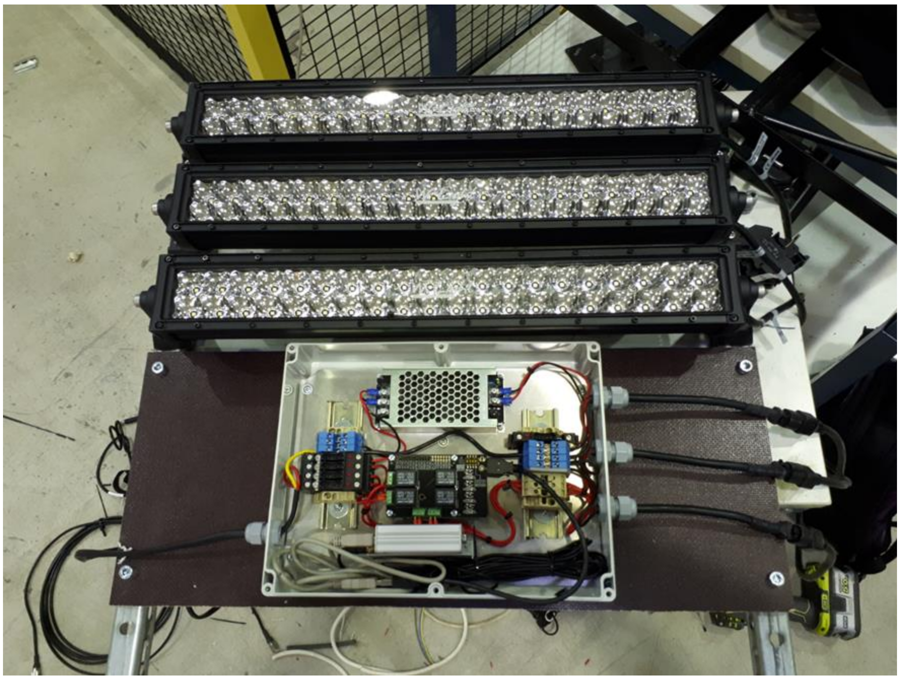

Figure 69. *Prototype hardware.*

3.7.2. Method and data to evaluate the piloted measure

The additional warning light system was tested at real railway environment both from the viewpoint of road user and engine driver.

The tests were conducted on 14th March in Sääksjärvi in Finland. The testing was done in main railway network and one of the three tracks was 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 rented railway vehicle was 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 roadside) and from the angle of the train driver.

The variables included in the tests are presented in Table 33. The speed of the railway vehicles during the tests were 20 km/h. In addition, the possible annoyance of additional warning lights were estimated both from the road user and engine driver perspective.

Table 33. *Variables investigated during the tests.*

Title	Variable
Time of day	– Daylight (12:00–13:30) – Night (at 11 pm–1:30 am)
Light configuration at daytime. Two runs for each scenario.	– Reference with standard lights – 1 x 100 ms flash in every 2 second – 2 x 100 ms flash in every 2 second – 3 x 100 ms flash in every 2 second – 1 + 2 + 3 100 ms flash in every 2 seconds
Light configuration at night time. One run for each scenario.	– Reference with standard lights – 1 x 100 ms flash in every 2 second – 2 x 100 ms flash in every 2 second – 3 x 100 ms flash in every 2 second – 1 + 2 + 3 100 ms flash in every 2 seconds – Dimmed lights 2 x 100 ms flash in every 2 seconds – 5° tilt upwards 2 x 100 ms flash in every 2 seconds – 10° tilt upwards 2 x 100 ms flash in every 2 seconds
Perspective	– Road user – Engine driver

The evaluation was carried out with a web-based questionnaire by rail and road safety experts connected to the SAFER-LC project. For comparison, the questionnaire was filled by non-experts. Three alternative light configurations were compared to the standardly used reference configuration, both in the day time and in the night time conditions. The reference configuration had standard train headlights: three continuous white lights, two on the bottom and one on the top. In the alternative configurations, additional blinking LED lights were installed below each of the headlights. The alternative configurations had different blinking patterns (Table 34).

Table 34. *Four configurations tested.*

Configuration/Number of blinks	Description
0	Reference system without strobe lights
1	Single blink every 1 s
2	Double blink every 2 s
3	Triple blink every 3 s

The questionnaire focused on the expert evaluation of the alternative configurations regarding safety, comfort and suitability for day and night time conditions, as well as on the ergonomical aspects visibility and glare. Benefits and drawbacks were also explicitly asked, along with the configuration the experts preferred. Additionally, we investigated if the blinking lights would make the approaching train appear faster or threatening, and thus influence the judgement of the last safe crossing times.

The questionnaire was based on the road user view videos filmed from the test site. In total, eight videos were used. Four in the day time conditions, demonstrating the reference system and the three alternative configurations, and similarly four in the night time conditions. The duration of videos was 66–68 s for the day time videos, and 111–130 s for the night time videos. The night time videos were longer because we wanted the train to become visible in the beginning of the video, and in the night time this occurred earlier.

First all four day time videos were presented and evaluated, followed by the four night time videos. The reference configuration without blinks (0) was always presented first. It was followed by configuration with two blinks (2), configuration with one blink (1), and finally configuration with three blinks (3).

With the reference configuration, the participants were asked to watch the video and report when they would not anymore start crossing the rails. The minimum safe crossing margin was calculated as the remaining time before the train arrival, determined by one second accuracy as the time when the front of the train reached the right edge of the camera view.

For all the alternative configurations, the participants reported similarly the crossing margin, but they were also asked if they saw any benefits or drawbacks with the alternative configuration compared to the reference configuration, and if they did, describe those. For each alternative configuration they were also asked to rate the alternative configuration on safety, comfort, suitability for day/night time conditions, visibility, and glare, using a 5 step Likert scale, where 1 = worse than the reference system, 3 = equivalent to the reference system, and 5 = better than the reference system. After going through all the four day/night time videos, the participants also reported which one they preferred and why.

Finally, the questionnaire asked participants' background information such as age, gender and self-rated expertise on level crossing and road safety, as well as views in improving level crossing safety in general.

Answering to the questionnaire was voluntary and anonymous. The experts' questionnaire was sent via project email list whereas the non-experts' questionnaire was sent to various email lists of the local university. In total, 18 expert and 16 non-expert responses were received and analysed.

3.7.3. Evaluation results

The distribution of the responses on the five dimensions (safety, comfort, suitability for day/night time conditions, visibility and glare) are shown in Figure 70. Overall, in the day time the alternative configurations were evaluated better than the reference configuration. The preference is clearest on the dimensions safety, suitability, and visibility. In the night time, the responses followed the similar pattern, but they were slightly less favourable for the alternative configuration.

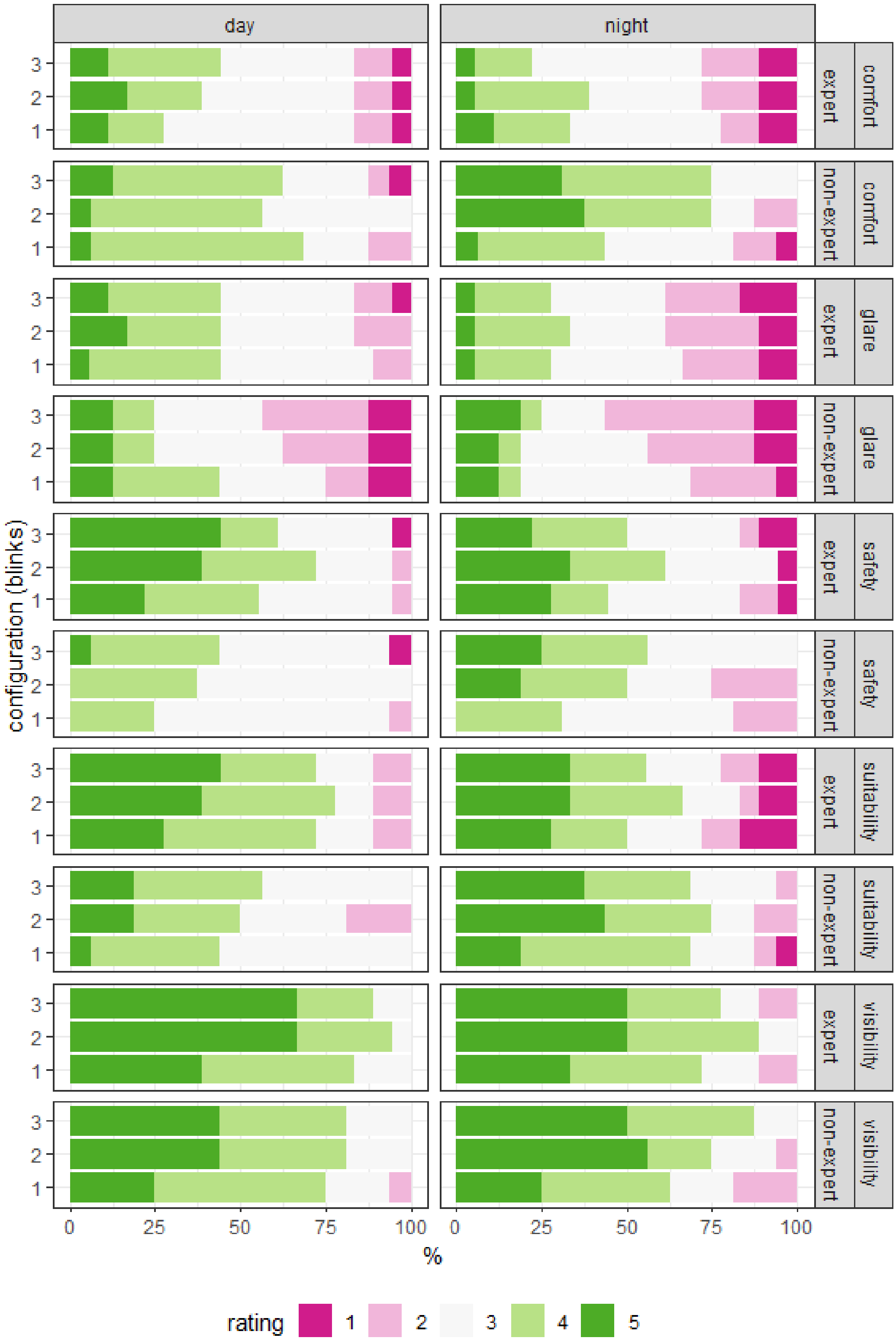

Figure 70. *Ratings of the alternative configurations (colour) compared to the reference: 1 = Worse than the reference system, 3 = Equivalent to the reference system, and 5 = Better than the reference system.*

Benefits and drawbacks

The above evaluation can be further interpreted by investigating the reported benefits and drawbacks of the configurations. The majority of the respondents saw benefits in the alternative configurations, both for the day time and night time conditions. Less than one fifth of the respondents saw drawbacks with the day time videos, and one third for the night time videos (Table 35). Majority of the comments regarding the benefits concerned increased visibility and detectability. Some responses mentioned that it was easier to judge the approach speed or that the train seemed faster with flashes. Drawbacks mentioned were disturbance and potential misinterpretations caused by blinking lights.

Table 35. *Benefits and drawbacks reported for the alternative configuration vs. reference system.*

Group	Timing	Configuration	Benefits (%)	Drawbacks (%)
Experts	Day	1 blink	67	17
		2 blinks	78	17
		3 blinks	72	17
	Night	1 blink	56	33
		2 blinks	72	28
		3 blinks	56	33
Non-experts	Day	1 blink	69	31
		2 blinks	81	44
		3 blinks	69	38
	Night	1 blink	62	38
		2 blinks	88	38
		3 blinks	94	31

Preference

Respondents were also asked to choose which configuration they preferred. In the day time, the majority of expert respondents preferred the alternative configuration 3 with three blinks (Figure 71, left). Among non-experts, the same configuration was the most preferred, but also the configuration with two blinks was popular. In the night time, experts did not prefer any configuration over each other, but non-experts preferred configurations with two or three blinks (Figure 71, right).

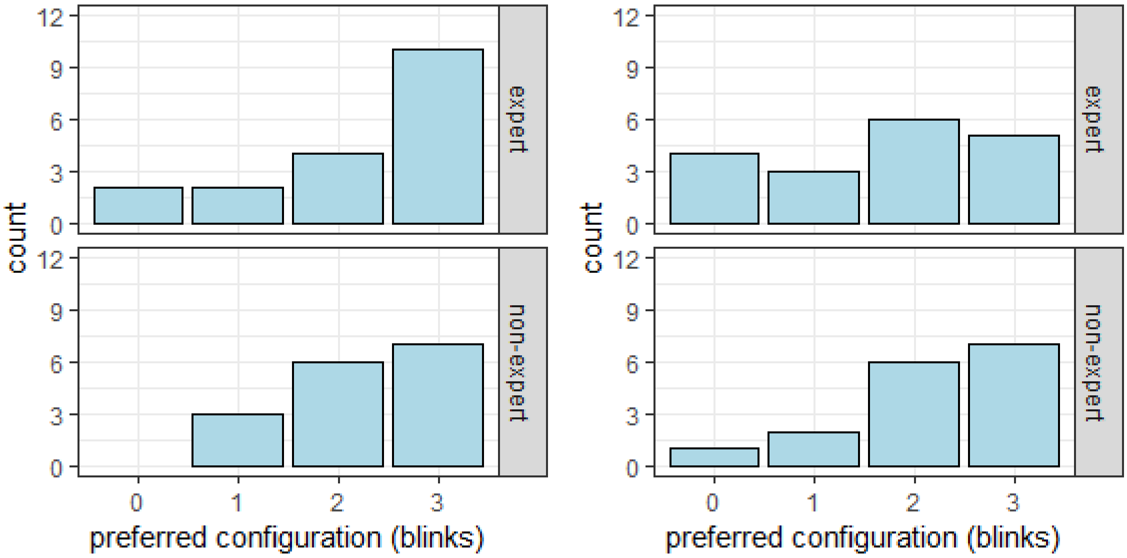

Figure 71. *Preferred configuration in the day time conditions (left) and in the night time conditions (right).*

<u>Crossing margin</u>

Crossing margin distributions are shown in (Figure 72). Crossing margins were shorter in all daytime videos (Mdn = 22 s, M = 28 s, SD = 17 s) compared to the night time videos (Mdn = 84 s, M = 77 s, SD = 30 s). In the night time conditions, the crossing margins were more spread, but also the videos were longer (approximately 60 s vs 120 s). Experts had shorter crossing margins than non-experts (Mdn = 42 s, M = 46 s, SD = 34 s vs. Mdn = 59 s, M = 59 s, SD= 34 s). The main observation is that there were no clear differences between the configurations in the distribution of the time gaps.

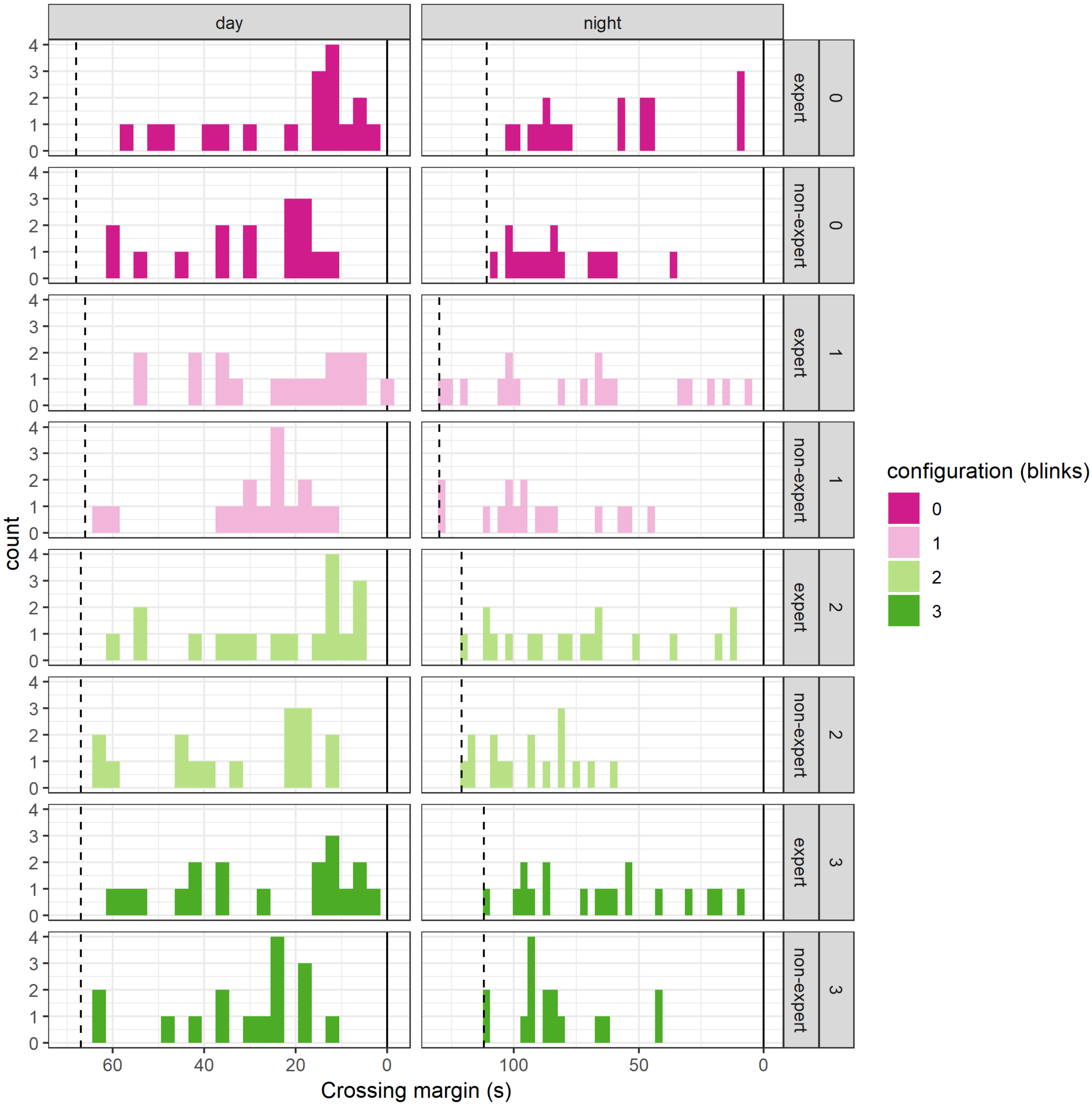

Figure 72. *Histogram of crossing margins with different configurations (rows) and in day/night time conditions (columns). Bin width used was 3 s. The time when train arrive is marked with a solid line, and the maximum possible crossing margin (the duration of the video) with a dashed line.*

3.7.4. Discussion

<u>Conclusions</u>

Both the experts and non-experts evaluated the alternative configurations as better than the reference configuration. Experts saw that the flashing light improved visibility and detectability. Probably for this reason, the experts rated the alternative configuration also safer. Potential drawbacks were related to the flashing lights, which may be disturbing, and cause glare. Concerns on misinterpreting the flashing lights were also raised. The potential adverse effects of flashing lights should be further investigated.

In day time conditions, the experts clearly preferred the configuration 3 with three consecutive blinks followed by 1 s break. In the night time, none of the configurations were clearly preferred. The results suggest that in the night time conditions, the flashing lights caused more glare or were more disturbing. Also, in the night time the train can be already easily detectable without flashing lights. The visual quality of the night time videos was not as good as in the day time, which may have influenced the ratings. Among non-experts, the configuration 3 was most preferred both in the day time and in the night time, but the configuration 2 was also popular.

We were interested to see if the blinking lights would change the appearance of the approaching train (e.g. by making it look faster or more threatening), and thus influence the crossing margins (the time between the last safe crossing time and the arrival of the train). However, the results do not suggest any influence of blinking lights on the crossing margins. In the day time videos, crossing margins were somewhat concentrated around time when the movement of the train started to be clearly visible. In the night time videos, the responses were more evenly spread. It is possible that in the day time conditions the judgments are more based on the estimated arrival time, as the respondents have better visual cues about the speed and distance. Interestingly, non-experts reported larger crossing margins than experts did. This suggests that non-experts were more cautious in their judgements than experts were.

In the experiment, we did not evaluate the videos filmed from the driver's point of view. In the day time videos, the flashes were not clearly visible, and in the night time videos, they were pronouncedly visible, due to the limitations of the video camera. The main concern from the driver's point of view would be the distraction and glare generated by the flashing lights, especially in the night time conditions.

Based on the evaluation, the flashing lights appear to be a promising way to increase the detectability of approaching trains, especially in the day time conditions. In the night time conditions, the flashing lights can be potentially disturbing or misleading. Ways to address these, e.g. by focusing the lights and adapting them to the lighting conditions, should be investigated further. While flashing lights may improve detection of approaching trains, the results do clearly show any influence on the reported crossing margins.

<u>Lessons learned</u>

Figure 73 includes snapshots from the cabin before and during the flash of additional lights. Camera image shows the situation when the flash is brightest. Comparing the image what was seen by eyes, it is much brighter, probably the human eye cannot register such a short flash. The area in front of the vehicle was seen brighter, and the snow reflection increased the effect. Tilting the lights upwards reduced those reflections, which indicates that using narrow beam is better. In such cases, the light contacts the rail further and the reflection effect is mitigated.

Figure 73. *Drivers view. Left using the normal lights, right during the flash. Below lights tilted upwards.*

On the other hand, the visibility of the tilted light from the virtual level crossing was not good. This implies also that disturbance caused to outsiders is rather small. Therefore, the recommendation is to use very narrow beam aimed to the direction of the tracks, and its angle should be adjusted so that the beam hits the ground somewhere between 500–600 metres away.

From the on-site point of view the two-flash pattern appeared to be the best. One flash only seemed to be much dimmer and the three flashes did not seem to improve the visibility significantly when compared to two flashes. However, in the expert evaluation, three flashes was preferred over two flashes in the overall evaluation. Tilting lights upwards reduced the visibility. Test day was cloudy and the train lights were seen rather well. During darkness the train was seen already behind the curve.

Some open questions and subjects to further tests are:

- Flash colour. The white colour was used in the current tests. However, it could be also tested whether the orange colour has better or worse detectability than white. Cairney (2003) e.g. argued that regarding strobe lighting the white flashing lights are relatively ineffective during daylight. Instead of increasing the energy output of the strobe lights, it might be more effective to add a coloured filter to the lights, despite the energy loss entailed. In addition, Cairney (2003) highlighted that with regards to the testing of different colours, it is essential to ensure that there is no potential that these additional train lights could be confused with existing road and rail signalling.
- Pattern. Investigation of the optimal light pattern.
- Weather. Investigation of the influence of fog, rain or snowfall to reflection to driver and visibility to road user.
- Investigation on whether the light pattern should change with speed and/or distance.

3.8. Real rail environment (DLR)

3.8.1. Piloted safety measures

Two measures were piloted at a passive LC strongly frequented by vulnerable road users (VRU):

- A message "← Is a train coming? →" written across the road pavement on LC approach
- A blinking amber light with a train symbol, positioned at the side of the road ahead of the tracks.

Both measures are designed to support safe road user behaviour at passive LCs and can be used to address vulnerable (VRU) as well as motorised road users (MRU).

The major human factors problem observed at passive LCs is that road users often do not scan the tracks to the left and right for a train before crossing the tracks (Grippenkoven & Dietsch, 2015; Grippenkoven et al., 2016). This is probably caused by a combination of factors, including deficient knowledge of the rules and recommended behaviour at passive LCs, insufficient activation of such knowledge, low expectancy of a train occurring, and subjective effort of proactive scanning to the left and right (Ellinghaus et al., 2015).

Message "← Is a train coming? →"

The pavement message (see Figure 74) is expected to work by enhancing the probability that oncoming trains get detected by providing a reminder of the necessity to scan the tracks for a train and thus facilitating this target behaviour. The message is phrased as a question, not an instruction (e.g. "Look for a train!"), to enhance acceptance and evoke road users' intrinsic interest in knowing whether a train is coming. The measure, as it was implemented, requires vision as well as basic reading and language skills from the road user to be effective. The message needs to be consciously processed and aims to elicit a voluntary visual search for a train.

Figure 74. *Implementation of the pavement message on approach to the LC. The German question "Kommt ein Zug?" translates to "Is a train coming?".*

For the pilot, the message was applied to the road surface using removable paint (chalk spray) at around 35 m ahead of the LC.

Blinking amber light with train symbol

The blinking train symbol just ahead of the LC is expected to enhance the probability that oncoming trains are detected by increasing road users' awareness that a train might be approaching and thus increase the motivation to visually scan the tracks to the left and right.

In the pilot, the amber light was implemented on the eastern side of the LC (Figure 75). The blinking was activated whenever a road user was detected approaching the LC from this side (cf. methods).

a

b

Figure 75. *Implementation of the amber light on approach to the LC.*

3.8.2. Method and data to evaluate the piloted measure

<u>Test site</u>

The pilot study took place at a passive LC situated in the north of Braunschweig (see Figure 76) mainly frequented by cyclists and pedestrians. The road is closed to four-wheelers, but can also be used by single-track motorised vehicles such as motorbikes, as well as other VRUs like horse riders, wheel-chair users, skaters etc. Leading through a surrounding of meadows and forest, it is used by numerous cyclists on their way to and from work and is also a popular route for leisure trips.

a **b**

Figure 76. *The test site: passive LC at Ottenroder Straße, Braunschweig (a - aerial view, b - western approach view).*

<u>Equipment</u>

To examine the effects on road user behaviour, the DLR mobile traffic data acquisition system was installed at the LC. The system is part of the DLR test field AIM (*Application Platform for Intelligent Mobility;* Knake-Langhorst et al., 2016). The implementation used in the pilot consisted of a semi-mobile pole on a concrete foundation, a sensor head, and a weather-proof cabinet, containing processing computers as well as devices to allow remote access by an LTE-connection and V2X-ability (see Figure 77). The sensors used were a set of stereo-cameras, supported by an active infrared lighting system for artificial scene illumination to enable sensing during day and night time. The system fuses the sensor data and automatically processes them 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 were tracked with a rate of 25Hz and automatically stored in a database. Moreover, the low-resolution scene videos that are the input to the computation of the trajectories were recorded in accordance with data protection regulations to allow the study of road user behaviour beyond kinematics.

a

b

Figure 77. *The mobile traffic data acquisition system as used in the pilot: a – pole with sensor head and control cabinet, b – positioning of the system relative to the LC (viewed from rear).*

The traffic data acquisition system was also used to control the elicitation of the blinking in the amber light measure dependent on the approach of VRUs to the LC. For this, a geofencing algorithm was applied to the trajectory data in real time (see Figure 78). The target road segment started at 40 m ahead of the LC and ended at 6 m ahead of it. When a road user was detected entering it from the eastern side (right side in the figure), the blinking was triggered, continuing until the road user left the target area. If other road users entered while the amber light was still active, it remained active until the last one was out of the area. The blinking was only elicited by road users with west-bound trajectories; road users traveling in the opposite direction did not influence the amber light.

Figure 78. *Geofencing for triggering the blinking of the amber light (see text for procedure).*

<u>Design and procedure</u>

The pilot data were collected from mid-August to the end of September 2019. The pilot started with the assessment of baseline data at the LC with no additional measure applied (2 weeks), followed by a test period with the pavement message *Is a train coming?* (2 weeks). After a recovery phase without a test measure (1 week), the *blinking amber light* was implemented (2 weeks).

3.8.3. Evaluation results

<u>Trajectory data</u>

Overall, the trajectory data of 18,529 VRUs on a west-bound trajectory were recorded during the baseline phase and the two test phases. The majority of these VRUs were bicyclists (n = 16,049). The number of pedestrians observed was 2,480. Table 36 shows the frequencies of the types of VRUs split by the three pilot phases.

Table 36. *Frequencies of VRU types observed during the test phases.*

Condition	VRU type	
	Bicyclists	**Pedestrians**
Baseline	**4,598**	**618**
Message	**6,362**	**861**
Amber light	**5,089**	**1,001**

For slow-moving VRUs such as pedestrians, velocity choices were not expected to play a major role for their possibilities to come to a stop ahead of the LC in due time if necessary. Therefore, velocity ahead of the LC was only analysed as a safety indicator for the VRU group of bicyclists. Using daytime data (between 7:00 am to 7:00 pm), the mean velocity on the last 25 m ahead of the LC was computed for each bicyclist. Figure 79 shows the mean of this approach velocity by test condition. Bicyclists went 17.5 km/h on average in the baseline condition (*SD* = 5.58). The mean velocity observed in the condition with the *Message* ← *Is a train coming?* → *(M = 17.6, SD* = 5.72*)* does not statistically differ from this value, $t(10958) = -0.912$, $p = 0.361$. However, in the *Blinking amber light* condition, bicyclists went significantly slower than in the baseline condition, with a mean velocity of 16.4 km/h ($SD = 5.54$), $t(9685) = 9.912$, $p = 0.000$, all p values Bonferroni-corrected). The mean difference of 1.1 km/h represents an effect of small size (*Cohen's d* = 0.10).

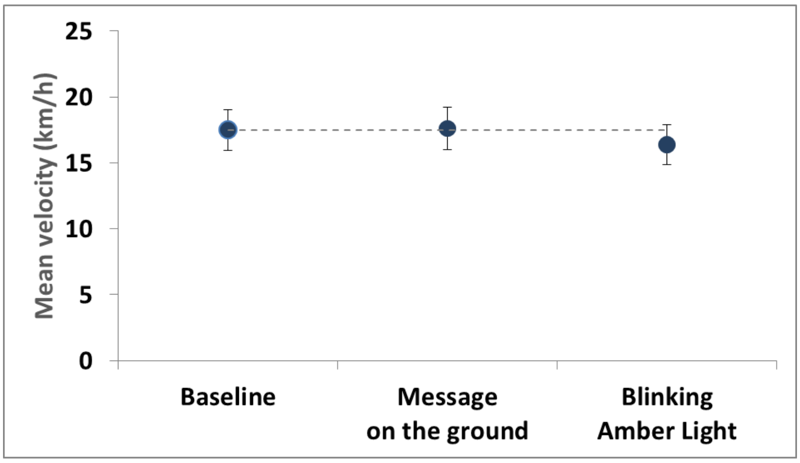

Figure 79. *Mean velocity of bicyclists on the last 25 m ahead of the LC by test condition.*

Video Annotation Data

To assess VRU behavior on approach to the LC, a sample of the low-resolution videos was annotated using the ELAN software (Version 4.7.3, https://tla.mpi.nl/tools/tla-tools/elan/, Wittenburg et al., 2006). Defined categories of target behaviour included *lateral head movements to the left* and *right* as an indicator of gaze direction, and *visual distraction* (e.g. VRU looks down, looks to other people). VRU features coded included gender, age group, and VRU type. For each of the three test conditions, the behaviour of 80 VRUs with west-bound trajectories was coded. Within each condition, an equal sample was taken from the first and last weekday of the respective phase, and within each of the sampled days, an equal sample was taken from each of the peak times starting at 7:30 a.m. and 5:00 p.m. The first 20 VRUs appearing in each of the defined timeslots were coded. The defined *LC approach* zone started at around 20 m ahead of the tracks and ended at around 1 m ahead of the tracks. The low-resolution videos did not allow observation of VRU behaviour ahead of this zone. Moreover, due to vegetation, VRUs were probably unable to see the track periphery much before entering this area.

The resulting sample consisted of 240 VRUs (n = 133 male, n = 106 female, n = 1 not assigned). Of these, 157 were identified as adults (18–65 years), 37 as youngters (14–17 years), 34 as children (0–13 years), and 12 as seniors (> 65 years). The most frequent road user type observed was bicyclist (n = 214), the remaining VRUs were pedestrians (n = 20), motorcyclists (n = 2), horse riders (n = 1), and other VRUs (n = 3).

To analyse the effects of the applied measures on active visual search for a train, we assessed how many of the observed VRUs turned their head in a given direction (*left*, *right*, *both ways*) at least once on LC approach, or turned their head *neither way*. Head turns that could be assigned to a distraction (e.g. VRU looked to other VRU) were not counted. The results are given in Table 37.

Table 37. *Proportion of VRUs who turned their head in a given direction at least once on LC approach (excluding head turns due to distraction).*

Condition	*n*	*% of VRU turning head on LC approach*			
		Left	**Right**	**Both ways**	**Neither way**
Baseline	*80*	**87.5**	**90.0**	**82.5**	**3.8**
Message "Is a train coming?"	*80*	**86.3**	**92.5**	**83.8**	**5.0**
Blinking amber light	*80*	**95.0**	**93.8**	**90.0**	**1.3**

In the baseline condition, the most desirable behaviour from a safety perspective, turning one's head both to the left and right, was performed by 83 % of VRUs on approach. Around 90 % of VRUs turned their head to at least one side, while 4 % did not turn their head at all. In the condition with the *Message ← Is a train coming? →,* the observed proportions resemble the ones in the baseline. For the *Blinking amber light*, increases of around 8 % are observed for head turns to the left and both ways, and an increase of around 4% is observed for heads turns to the right. The proportion of VRU showing no head turn at all drops to 1 %.

3.8.4. Discussion

<u>Lessons learned</u>

Two low-cost safety measures for passive LCs were tested at a LC exclusively frequented by VRUs: a message ← Is a train coming? → written across the pavement on approach to the LC, and a blinking amber light showing a train symbol that was activated whenever a road user approached the LC. At passive LCs, the most relevant behaviour to be facilitated by a safety measure is for road users to look out to the left and right before crossing the tracks. Based on videos from a mobile traffic data acquisition system, VRUs' head movements on approach to the LC were used as a measure of gaze behaviour to assess the effects of the two measures. Moreover, velocity data of fast-moving VRUs (bicyclists) were analysed.

The results show a clear effect of the blinking amber light, increasing the rate of active visual search behaviour. No such effect was observed for the message written on the ground. Also, the mean velocity of bicyclists ahead of the LC was found to be slightly reduced when the amber light was applied, while it remained unchanged with the message on the ground.

In the interpretation of these results, it is necessary to consider that the vast majority of road users who contributed to them were bicyclists. Especially from a bicyclist's perspective (elevated viewpoint, moving relatively fast), the message on the ground was probably less salient than the amber light. Therefore, it could be that for pedestrians, who have more time to notice and process the message on the ground, the results look different. So far, we could not assess this due to the low number of pedestrians observed in the current sample. The video annotation will however be continued to answer this question in future research.

It is interesting to see that the overall proportion of VRUs who checked the rails to the left and right obtained in the current study was relatively high compared to the results of other studies (e.g. Grippenkoven, & Dietsch, 2015; Grippenkoven et al., 2016). There are several potential reasons for this difference. For one thing, the road users analysed in the cited studies were car drivers, not

VRUs. As the designation implies, vulnerable road users might be more sensitive to the hazard of a collision and therefore more motivated to look out for a train. Another explanation could be seen in connection with the velocity at which road users move, as mentioned already, implying that a faster approach reduces the (subjective) time available to look any other direction than straight ahead. Finally, the assessment method used was different: The cited studies used eye-tracking as opposed to the evaluation of head movements applied in the current study. As the low resolution of the videos makes the distinction of the target behaviour difficult, the video annotator used a liberal criterion to code for head movements. Therefore, the absolute values obtained might overestimate the results that would be obtained with other measurement methods. However, the relative differences observed between the different conditions would likely remain the same.

The current study relied on indicators derived from observation only. While behavioural observations have the advantage of a high face validity with regard to practical effects on traffic safety, they tell us relatively little about the inner views and understanding on the part of the road users. Therefore, it would be desirable for future studies to also include subjective assessments, e.g. to assess whether the measures were noticed and correctly understood by the road users, whether the measures motivated road users to behave safely and how the measures could be improved from a user perspective.

Applicability of results to different circumstances and recommendations

As mentioned before, the message on the ground might theoretically be more effective for slower-moving road users such as pedestrians. If the velocity at which the writing is passed is indeed a critical factor, the measure in the tested form would not be useful for MRUs either. However, if the problem was that our pilot pavement writing was not salient enough to draw the attention of fast-moving road users, this may be compensated for by enhancing its saliency, e.g. by making it bigger, brighter, and / or more colourful.

Any road marking can only be applied on a paved road with an even surface. Thus, the message written on the road does not hold for road environments such as gravel roads, cobblestone, tracks etc. For these and other situations, a sign with the same message ← *Is a train coming?* → is a viable alternative (cf. subchapter 3.1).

The blinking amber light showing a train symbol proved effective in the current study. To work, it requires electricity, which is often not readily available at passive LCs. If no power connection is available, one possibility to design a self-supporting system could be to use batteries and solar cells for power supply (Liikennevirasto, 2015). Furthermore, an actuation of the blinking by the approaching road users themselves is certainly a useful feature, as the experience of eliciting an effect in the environment probably enhances the attention paid by the road user. In the study, the actuation was controlled via the mobile traffic data acquisition system, using wireless communication. This technical solution lent itself to the implementation as the system was to be applied for data acquisition anyway. The same effect could be achieved with easier technical solutions as well, e.g. by using a sensor in or near the road (Grippenkoven et al., 2016; Noyce & Fambro, 1998). Ultimately, a blinking light with a train symbol could also work steadily, independent of road users approaching.

Acknowledgements

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4. SUMMARY OF MAIN FINDINGS

The main safety related findings of each piloted measure are summarised in Table 38 and Table 39. Table 38 covers measures mainly concerning indirect safety effects, or measures that enable safe crossing of LCs, whereas Table 39 presents the main safety related findings of measures with direct safety effects.

Table 38. *Main safety related findings by piloted measure (mainly indirect safety effects).*

Measure	Findings
Smart Detection System	▪ System was able to detect 84% targeted cases (traffic disruptions on LC). ▪ System was able to correctly classify 78.6% of the objects detected from a total of 341 objects evaluated (pedestrian, car, train and two wheel vehicles).
Early train and hazard information warning by means of collective perception messaging (CPM) and drivers' warning	▪ Intersection assist safety applications (collision warning safety applications) worked safely and reliably according to the standards and technical specification of the technology. No misbehaviour of the tested methods were detected. ▪ Extended range train detection showed that by systematic use of the demonstrated method, the approaching train is safely detectable, warning road users from several kms away from the intersection. ▪ Perception range extension by means of multi-hop Decentralized Environmental Notification Message (DENM) forwarding can provide another train detection method in LCs where no additional infrastructure is available for detection. The detection method relies on standard V2X methods. The detection accuracy depends on the number of available active V2X stations in LC vicinity.
Smart Communication System 1 (V2X communication)	▪ The DENMs of all scenarios were well received. ▪ Communication range: In the case of line-of-sight the maximum range is about 250 m. In case of 'Non line-of-sight' (NLOS), the maximum range in Aachen site (presence of trees, buildings etc.), was about 60 to 80 m. With the multi-hop solution (two vehicles were used), the maximum range was between 160 to 180 meters.
Smart Communication System 2 (Communication to control room)	▪ Successful transfer of video file between the Smart Detection System (SDS) and roadside unit (RSU) using a VPN connection and a test RSU. ▪ When the camera detected an event, the RSU uploaded it to the platform, and by clicking on the alert, the video files were aggregated, starting from the event detection until the end of the event.
Monitoring and remote maintenance	▪ The tested methods showed their effectiveness in detecting and quantifying a geometric evolution of LC. However, they

	need to be improved and industrialised to be easily used by infrastructure managers.
V2X messaging system between automated vehicles and passive level crossings	▪ Enables the safe crossing of passive LCs by automated vehicles. ▪ Accuracy of stopping at the correct point: The average stopping distance of the car was 4.22 meters from the virtual stop line (0.42 meters from the car front). ▪ Average time taken for the vehicle to resume movement after the traffic light's change of state was 908 milliseconds.

Table 39. *Main safety related findings by piloted measure (direct safety effects).*

Measure	Findings
Passive LC signs promoting correct behaviour and danger of LCs	
Sign 'Look for train'	▪ The sign 'Look for train' induced large increases in visual search for a train to the left side of the tracks, while search behaviour to the right side was hardly increased. ▪ No effect on approach speed was observed. ▪ The measure gained high ratings on perceived usefulness and ease-of-use dimensions.
Road marking "← Is a train coming? →"	▪ No change was observed in head turning behaviour on LC approach as an indicator of active visual search compared to the baseline in a VRU sample consisting mostly of bicyclists. ▪ No change was observed in mean velocity on LC approach in a sample of bicyclists.
Coloured road markings	Results on this measure were very scattered: ▪ For some, having this marking on the ground was a repetition of the 'LC ahead' sign (A7 panel) and was perceived to have the same meaning. ▪ For others, the visual quality of the simulator disturbed them, some thought they saw a speed bump, some focused to read the text and were subsequently surprised to arrive so quickly at the LC. ▪ Some interpreted the sign as a STOP and some perceived the painted arrow as an instruction to accelerate.
Speed reduction measures	
Speed bumps and flashing posts	▪ More than half of test subjects reacted to the speed bumps, leading to a deceleration of LC approach speeds. ▪ The subjects understood that the speed bumps announce a danger, but few associated this with the LC. ▪ It is noteworthy that very few subjects saw the side light beacons as they focused on the speed bumps. ▪ Some subjects expressed their dislike of speed bumps because they considered them uncomfortable or dangerous for motorcycles.
Funnel effect pylons	▪ 60% did not see the safety measure .

	▪ 30% saw the safety measure but did not understand it. ▪ Only 10% of subjects understood that there is a danger zone with a funnel effect and reacted on the sight on the pylons leading to speed reduction on the approach to the LC.
Noise-producing pavement	▪ The noise-producing pavement did not increase visual search for a train, and had no effect on speed. ▪ This measure gained moderate ratings concerning its perceived usefulness and low to moderate ratings concerning its ease of use. ▪ Many of the participants gave the additional qualitative feedback that they did not relate the rumbling to the LC.
Active warnings linked with approaching LC	
Proximity message via in-car device	▪ In total, 70% of subjects reacted when receiving a notification sound (beep) providing information of LC status (LC closed, road works at LC or LC in xx meters), allowing them to anticipate their speed on approach to the LC and to better prepare for the stop. ▪ The majority of subjects understood that message was sent to anticipate situations demanding attention on approach to the LC. ▪ In situations where the message was not received, the subjects resumed their typical behavior and were not worried about the lack of message. ▪ Based on the interviews some subjects preferred to concentrate on their driving because receiving messages on a screen distracts them and forces them to take their eyes off the road, which they considered dangerous.
Blinking amber light with train symbol	▪ Increase by 4−8% observed in head turning behaviour on LC approach (left, right, both ways) as an indicator of active visual search compared to the baseline in a VRU sample consisting mostly of bicyclists. ▪ Slight decrease (-1.1 km/h) observed in mean velocity on LC approach in a sample of bicyclists.
Blinking lights drawing driver attention (Perilight)	▪ The PeriLight induced large increases in visual search for a train both to the left and the right side of the tracks as well as a speed reduction on approach to the LC. ▪ Significant decrease in speed on LC approach, starting at ~100 m before LC with maximum at ~50 m before LC. ▪ The measure gained high ratings on perceived usefulness and moderate to high ratings on the ease-of-use dimensions.
Traffic lights	Flashing orange light ▪ All the participants slowed down at the sight of the flashing orange light, even those who misinterpreted it to indicate a road intersection. ▪ The participants often reported being confused when meeting a flashing orange traffic light. Confusing elements included the orange color, the flashing itself, and the light's position as the

	lowest light. ▪ An orange flashing light can be a source of distraction, leading to sudden or hard braking, or uncertainty over the risk of an approaching train. Moreover, it is possible that the participants habituate to the warning, slowing down only during the first times. Green light ▪ The green light visibly reassures the participants. It encouraged them to cross the LC without precautions and at higher speeds. ▪ In some cases the green light could cancel the caution induced by the 'LC ahead' sign (A7 panel) (lack of indication on the triggering of the LC). When participants see the green light, they trust that there will be no train and speed up. The four subjects who were aware of the contradiction between green light and the approaching LC pointed out the limits of this solution.
Active warnings linked with approaching train	
In-vehicle train and LC proximity warning	▪ LCs usage: ~600 vehicles and more than 200k registered trajectories in ~6 months. ▪ No significant differentiations in aggregated speed and acceleration profiles identified in the pre-post system comparison. ▪ There are no indications of distinct and characteristic driving behaviors amongst the taxi drivers. ▪ Disaggregated examination of trajectories reveal improvements in five safety related KPIs for the case when the barriers are open. "Safety checks" with the warning system enabled appear to be more frequent, longer and at safer spatial distance to the rail line. ▪ The Artificial Neural Network predictive algorithm is capable of highly accurate predictions on the estimated time of train arrival to LC. ▪ Encouraging feedback from the questionnaires answered by taxi drivers. Before deploying the piloted system, the majority stated that LC safety infrastructure in Thessaloniki is inadequate. After its deployment, most drivers reported that they felt safer and that they trust the provided information; many of them would be interested in using the system in the future.
Rings	▪ Majority (90%) of the subjects interpreted this measure as a village entrance decoration unrelated to the LC. ▪ Only 10% of the subjects understood that the rings indicated the approaching train and closure of the LC. ▪ Some subjects were so focused on this safety measure that they missed some information such as the 'LC ahead' sign (A7 panel) or the approaching LC and were surprised at the sight of the LC being closed.

	▪ The subjects were often distracted by the rings and did not make the link with the LC.
Measures improving detectability of train	
Additional warning light system at front of the locomotive	▪ Auxiliary strobe lights were estimated to improve visibility and detectability of train as well as safety at LCs. ▪ In daytime conditions, the experts clearly preferred the warnings lights with three consecutive blinks followed by 3 s break. In the night time condition, none of the configurations were clearly preferred. ▪ Auxiliary strobe lights appear to be a promising way to increase the detectability of approaching trains, especially under daytime conditions.
Improved train visibility using lights	▪ The blinking train was detected earlier and more reliably than the normal train, induced earlier speed reduction. ▪ This measure gained high subjective ratings on the usefulness and ease-of-use dimensions assessed.

5. ESTIMATION OF SAFETY POTENTIAL

Due to the small-scale nature of the conducted pilot tests, it was not possible to calculate quantitative estimates on safety effects of the measures in terms of annual reductions in the number of LC fatalities and/or accidents based on the results of the pilots. However, since numerical estimates of safety effects are needed for the cost-benefit calculations (WP5 of the SAFER-LC project) the authors made an attempt to draw these estimates based on: i) existing statistics on LC safety (subchapter 5.1), and ii) existing studies on effects of LC safety measures (subchapter 5.2).

Table 40 presents the overview of safety measures piloted in the SAFER-LC project and their short descriptions. The focus has now shifted from the pilot sites to the investigation of individual safety measures and their effects. Therefore, in Table 40 the similar measures and their descriptions have been combined.

Table 40. *Overview of safety measures piloted in the SAFER-LC project and their short descriptions.*

Type of measure	Name of measure	Short description
Measures with mostly indirect safety effects	Smart detection and communication system	System (interfaced with a roadside unit) which sends information to cars, control room and trains about potentially dangerous situations detected at active LCs by cameras and/or V2X communication.
	V2X messaging system between automated vehicles (AVs) and passive LCs	V2X messaging system enabling automated vehicles (AVs) to cross the passive LCs safety.
	Monitoring and remote maintenance	System monitoring the condition of LCs and detecting potential problems with rail infrastructure (e.g. any deterioration) by using sensors on the track and road (seismic sensors, photogrammetric system and thermal infrared method).
Passive LC signs promoting correct behaviour and danger of LCs Objective: improve detection of LC and assist in visual search for potentially approaching train	Sign 'Look for train'	Sign displaying a message and pictogram advising road users to look for a potentially approaching train.
	Road marking "← Is a train coming? →"	Message on pavement reminding road user to scan the tracks for a potentially approaching train.
	Coloured road markings	Painting of road leading to a LC with different colours combined with pavement marking with text: "train".
Speed reduction measures Objective: reduce LC approach speeds and	Speed bumps and flashing posts	Installation of an array of speed bumps (150, 100 and 50 m) before the LC. To increase effectiveness, the bumps are coupled with red flashing posts (equipped with red LED lights).

improve detection of LC.	Funnel effect pylons	Creating a funnel effect on approach to LC on straight roads. This effect is achievable by installing 10–15 pylons of different sizes covered with reflective stickers on both sides of the road from a distance of 2 meters of the LC to 10 meters. Pylons are placed at an angle which generates the funnel effect.
	Noise-producing pavement	Use of special road pavement, which passively produces noise and vibration as cars drive over it.
Active warnings linked with approaching LC Objective: draw driver attention and increase the probability that road users detect the approaching LC and scan for potentially approaching trains.	Proximity message via in-car device	System provides information on LC status (LC closed, LC at 300 m etc.) to car drivers via in-vehicle device
	Blinking amber light with train symbol	Blinking train symbol located just ahead of the LC, which activates whenever a road user is approaching a LC.
	Blinking lights drawing driver attention (Perilight)	Blinking lights positioned in the peripheral vicinity of a LC (left and right), which activate whenever a road user is approaching a LC and support the visual scanning of tracks for potentially approaching trains.
	Traffic lights	Use of traffic lights at LCs (instead of conventional LC lights) to support road users to respect the stop before the LC.
Active warnings linked with approaching train Objective: improve detection of LC and provide up-to-date information on potentially approaching trains	In-vehicle train and LC proximity warning	System informing car drivers about the presence of a LC through a dedicated pop-up window and a short audio alert via in-vehicle device on LC approach. The warning also includes the estimated time of arrival whenever and incoming train is expected to reach the LC within one minute.
	Rings	Installation of two rings above the road before the LC (one 10 meters in before the LC and another one 150–200 meters before the LC). The rings are equipped with a set of LEDs and an orange light, which flash when train is approaching.
Measures improving detectability of train Objective: improve the detection of a train	Additional warning light system at front of the locomotive	Installation of additional blinking lights on the locomotive to complement the regular triangular lights. The blinking lights activate when the train is arriving to the LC.
	Improved train visibility using lights	Installation of additional blinking lights on the locomotive to complement the regular

		triangular lights. The blinking lights activate when the train is arriving to the LC.

5.1. Definition of targeted LC accidents

The identification of available information on LC accidents started by the review of the available European-wide LC accident statistics and the already collected and documented information on in-depth analysis of LC accidents in selected countries which was conducted as part of deliverable D1.2 (Silla et al., 2017). Based on these reviews, the three most relevant variables related to LC accidents for the identification of the safety effects were selected:

- Type of LC
- Type of victim, and
- Type of behaviour.

The shares of LC accidents by type of LC used in our estimations of safety potential were taken from the ERAIL database (2019) sustained by the European Union Agency for Railways. This data includes information for all EU-28 countries. In our assessment, we used the accident data from 2016 that was the most recent and most complete data reported to the ERAIL database. The breakdown of LC types according to the level of protection was applied from the categorisation used by the European Union Agency for Railways (see e.g. European Union Agency for Railways, 2017; ERAIL database, 2019):

- Active LC with automatic user-side warning
- Active LC with automatic user-side protection (and warning)
- Active LC with automatic user-side protection and warning, and rail-side protection[5]
- Active LC with manual user-side protection and/or warning
- Passive LC

The share of LC accidents by type of LC in 2016 in EU-28 is reported in Table 41.

[5] "Rail-side protected: A level crossing where a signal or other train protection system permits a train to proceed once the level crossing is fully user-side protected and is free from incursion" (EU DIRECTIVE 2016/798).

Table 41. *Share of LC accidents by type of LC in 2016 in EU-28[1] (n=369) (ERAIL database 2019).*

Type of LC		Share
Active LC	with automatic user side warning	30.62%
	with automatic user-side protection (and warning)	22.22%
	with automatic user-side protection and warning, and rail-side protection	3.25%
	with manual user-side protection and/or warning	4.07%
Passive LC		39.84%
Total		**100%**

[1] Data from 2016 excluding CY, DK, FR and IT due to the incompleteness of the reported data.

The ERAIL database also includes data on the total number of annually killed and seriously injured persons in LC accidents by country. If considering the same countries as for the dataset presented in Table 41 above, 213 persons were killed and 202 were seriously injured in LC accidents in 2016. The total number of LC accidents in 2016 was 369, and hence, based on the above numbers, we can assume that most of the LC accidents reported to the ERAIL database include serious injuries and/or fatalities. However, the number of killed and seriously injured persons is not presented by LC type and thus cannot be used in our assessment.

The information on the share of LC accidents by type of victim was collected from one of the earlier deliverables (D1.2) produced in the SAFER-LC project (Silla et al., 2017). The shares of LC accidents by type of victim presented in Table 42 covers in-depth LC accident data from Greece (2012–2017), Finland (2006–2015), France (2012–2016), Italy (2011–2016), Norway (2012–2016), and Turkey (2012–2016).

Table 42. *Share of LC accident severities by type of victim (Silla et al., 2017).*

Type of victim	Fatalities (%)	Injuries (%)
Car drivers & passengers	53.38%	75.92%
Mopedists & motorcyclists	6.77%	4.63%
Pedestrians & cyclists	37.22%	16.21%
Other	2.63%	3.24%
Total	**100% (n=266)**	**100% (n=216)**

The information on type of victim was not available by LC type and thus the similar shares were assumed to both active and passive LCs. Furthermore, in our assessment, only the division of fatalities by victim type was used. This approach was chosen as most of the LC accidents contained within the ERAIL database include serious injuries and/or fatalities. In Silla et al. (2017) the variable ‘Injuries’ included both serious and light injuries and thus the shares for the ‘Fatalities’ were considered more relevant for the safety potential estimation conducted as part of this study.

Share of fatal LC accidents by type of behaviour resulting in the realisation of LC accidents and by type of LC are presented in Table 43. The categories for the behaviour were identified from two sources: 1) An article written by Laapotti (2016), and 2) Deliverable D1.2 of this project (Silla et al., 2017). Finally, the categories for the type of behaviour were adapted from Laapotti (2016). While Laapotti (2016) separated the 'Situation awareness error' into two separate categories: 'Observation error' and 'Anticipation or evaluation error', the two are combined in this study, since without detailed accident description the classification of behaviours to detailed categories was found challenging.

Table 43. *Share of fatal LC accidents by type of behaviour resulting in the realisation of LC accidents and by type of LC (Silla et al., 2017; Laapotti, 2016).*

Type of behaviour	**Active LC (%)** (Silla et al. 2017)	**Passive LC (%)** (Laapotti 2016)
Situation awareness error	53.5%	93.5%
Vehicle handling error	9.3%	2.8%
Other human risk factors	34.9%	2.8%
Vehicle risk factors	1.5%	0.9%
Other	0.8%	0.0%
Total	**100% (n=129)**	**100% (n=107)**

Laapotti analysed fatal motor vehicle accidents at level crossings in Finland during the years 1991–2011 (n=142). She compared accidents at passive and active railway level crossings, and both immediate and background risk factors were considered. The accidents analysed by Laapotti were originally investigated in detail by road accidents investigation teams. In total, 79% of investigated LC accidents in Finland occurred in passive LC and thus the findings from Laapotti were used for passive LCs. The information on different types of behaviours related to accidents at active LCs were applied from the French data reported in Silla et al. (2017). The French data covers the years 2012–2016, and in France 87% of fatal LC accidents and 81% of LC accidents with injuries only occur at active LCs. To be consistent, the shares presented in Table 43 concern fatal LC accidents both in active and passive LCs.

Targeted LC accidents by piloted safety measure according to the above categorisations are presented in Table 44.

Table 44. *Definition of targeted LC accidents by safety measure.*

Measure	Type of LC					Type of victim				Type of behaviour				
	Active LC													
	With automatic user-side warning	With automatic user-side protection (and warning)	With automatic user-side protection and warning and rail-side protection	With manual user-side protection and/or warning	Passive LC	Car drivers and passengers	Moped riders and motorcyclists	Pedestrians and cyclists	Other	Situation awareness error	Vehicle handling error	Other human risk factors	Vehicle risk factors	Other
Smart detection and communication system	X	X	X			X	X	X	(x)	X	X	(x)	X	
V2X messaging system between AVs and passive LCs					X	X				X	X	(x)	(x)	
Monitoring and remote maintenance	*No information available*													
Sign 'Look for train'					X	X	X	X	X	X		(x)		
Road marking					X	(x)	X	X	X	X		(x)		
Coloured road markings		X	X			X	(x)	(x)		X				
Speed bump and flashing posts		X	X			X	(x)			X				
Funnel effect pylons		X	X			X	(x)			X				
Noise-producing pavement	(x)				X	X	(x)			X		(x)		
Proximity message via in-car device		X	X			X	(x)			X				
Blinking amber light with train symbol					X	X	X	X	X	X		(x)		
Blinking lights drawing driver attention (*Perilight*)					X	X	X	X	X	X		(x)		
Traffic lights		X	X			X	(x)	(x)		X				
In-vehicle train and LC proximity warning	(x)	(x)	(x)	X	X	X	(x)			X		(x)		
Rings		X	X			X	(x)			X				
Additional warning light system at front of the locomotive					X	X	(x)	(x)		X				
Improved train visibility using lights	(x)	(x)	(x)	(x)	X	X	X	X	X	X		(x)		

The safety potential of each measure is presented in Table 45. This table includes an estimation on the share of potentially prevented LC accidents by measure. This estimate is calculated based on the markings included in the previous table (Table 44). The low value indicated the markings with

‘X’. The high value covers also the markings with ‘(x)’. If no markings with brackets exist, the low and high value are the same.

Table 45. *Share of potentially prevented LC accidents by measure (including a range from low to high).*

Measure	Type of LC		Type of victim		Type of behaviour		Total	
	Low (%)	High (%)	Low (%)	High (%)	Low (%)	High (%)	Low (%)	High (%)
Smart detection and communication system	56.1%	56.1%	97.4%	100.0%	64.3%	99.2%	**35.1%**	**55.6%**
V2X messaging system between AVs and passive LCs	39.8%	39.8%	53.4%	53.4%	96.3%	100.0%	**20.5%**	**21.3%**
Monitoring and remote maintenance	*No information available*							
Sign ‘Look for train’	39.8%	39.8%	100.0%	100.0%	93.5%	96.3%	**37.3%**	**38.4%**
Road marking	39.8%	39.8%	46.6%	100.0%	93.5%	96.3%	**17.4%**	**38.4%**
Coloured road markings	25.5%	25.5%	53.4%	97.4%	53.5%	53.5%	**7.3%**	**13.3%**
Speed bump and flashing posts	25.5%	25.5%	53.4%	60.2%	53.5%	53.5%	**7.3%**	**8.2%**
Funnel effect pylons	25.5%	25.5%	53.4%	60.2%	53.5%	53.5%	**7.3%**	**8.2%**
Noise-producing pavement	39.8%	70.5%	53.4%	60.2%	93.5%	96.3%	**19.9%**	**40.8%**
Proximity message via in-car device	25.5%	25.5%	53.4%	60.2%	53.5%	53.5%	**7.3%**	**8.2%**
Blinking amber light with train symbol	39.8%	39.8%	100.0%	100.0%	93.5%	96.3%	**37.3%**	**38.4%**
Blinking lights drawing driver attention (*Perilight*)	39.8%	39.8%	100.0%	100.0%	93.5%	96.3%	**37.3%**	**38.4%**
Traffic lights	25.5%	25.5%	53.4%	97.4%	53.5%	53.5%	**7.3%**	**13.3%**
In-vehicle train and LC proximity warning	43.9%	100.0%	53.4%	60.2%	93.5%	96.3%	**21.9%**	**57.9%**
Rings	25.5%	25.5%	53.4%	60.2%	53.5%	53.5%	**7.3%**	**8.2%**
Additional warning light system at front of the locomotive	39.8%	39.8%	53.4%	97.4%	93.5%	93.5%	**19.9%**	**36.3%**
Improved train visibility using lights	39.8%	100.0%	100.0%	100.0%	93.5%	96.3%	**37.3%**	**96.3%**

5.2. Effectiveness estimates

The estimates on the effectiveness of LC safety measures were investigated to some extent as part of the literature review conducted in Task 2.1 and reported in deliverable D2.1 (SAFER-LC

Consortium, 2018c). This literature review covered 125 documents, which were collected from online scientific databases and web tools (e.g. RSSB Spark web tool), ResearchGate database, websites of related research projects and cited references listed in the bibliography of other publications. No limits were set to the geographic coverage or type of literature to be included. The *Review Form* used in Task 2.1 included a specific field to document information on safety measures investigated or discussed as part of the reviewed documents. However, only some of the safety measures piloted in the SAFER-LC project were covered in this literature review and hence additional information sources were needed.

The main source for the effectiveness estimates used in this study was the study of Silla et al. (2015) on *Survey and assessment of measures aiming to improve the safety of LCs*. This study investigated the measures from a Finnish perspective. In total, the assessment included 15 criteria, of which the safety effects of the measure was most relevant for the assessment conducted as part of the SAFER-LC project. Information on safety effects of each measure were primarily collected from Finnish level crossing related studies, and from the presentations of the biannual international level crossing symposiums (held since 2004). These sources were complemented with literature review and the studies indicated in the reference list of the above documents. The assessment included 37 safety measures. The list of measures selected for the assessment was rather comprehensive and included most measures that are known to be used in some countries or are estimated to be promising for the prevention of level crossing accidents.

The estimates on safety effects in Silla et al. (2017) were mainly based on i) the findings from previous assessment studies, and ii) the estimates of safety effects used in the Finnish safety evaluation tool Tarva LC (for estimation of safety effects of level crossing improvements using impact coefficients) (Peltola et al., 2012; Peltola, 2012). Peltola et al. (2012) worked out the estimates of safety effects based on an extensive review of international literature. The final estimates in Peltola et al. (2012) were produced by a group of Finnish level crossing experts based on the first estimates of the effects collected from the literature.

Numerical estimates in Silla et al. (2015) were only provided if quantitative estimates were available in previous assessment studies or in Peltola et al. (2012). The estimates were provided by using the following ranges:

- < 5%
- 5–20%
- 20−50%
- > 50%
- No information (no estimates available)

The estimated safety effects by piloted safety measure are listed in Table 46.

Table 46. *Estimated safety effects by piloted safety measure.*

Measure	Estimated effectiveness	Reduction
Smart detection and communication system	▪ No direct safety effects. ▪ Effectiveness depends on the action taken by the personnel in the control room, unless the information is automatically provided to engine drivers and/or car drivers.	–
V2X messaging system between AVs and passive LCs	▪ No direct safety effects. ▪ Enables the safety crossing of LCs by AVs.	–
Monitoring and remote maintenance	▪ No direct safety effects. ▪ Effectiveness depends on actions made based on detected problems. The main benefits are expected to be related to costs that can be avoided if infrastructure maintenance becomes more targeted.	–
Sign 'Look for train'	▪ Estimate for 'Traffic signs warning/informing road users of approaching LC' could be applied to this measure (Silla et al., 2015). ▪ In the pilot test, the fraction of road users who did not look for a train at a passive crossing was reduced by 1−15%, depending on the test condition (left / right). ▪ The effectiveness estimate was chosen as <5% due to the following reasoning: i) The above reduction (1–15%) is limited to LC accidents due to observation error. ii) It is not possible to assume that all road users who look at the approaching train will also act appropriately to avoid an accident by action. iii) The pilot study did not cover behavioural adaptation (i.e. long-term effects) which is rather likely with road user activated safety measures.	<5%
Road marking "🡐 Is a train coming? 🡒"	▪ Estimate for 'Road markings to highlight LC' could be applied to this measure (Silla et al., 2015). ▪ In the pilot test, the fraction of road users who did not look for a train at a passive crossing was not reduced with this measure.	<5%
Coloured road markings	▪ Estimate for 'Road markings to highlight LC' could be applied to this measure (Silla et al., 2015).	<5%
Speed bumps and flashing posts	▪ Estimate for 'Speed bumps' could be applied to this measure (Silla et al., 2015).	5–20%

Funnel effect pylons	▪ No numerical estimate available. ▪ Effect was conservatively estimated to be 1/10 of the effect with more 'intrusive' speed reduction measures (speed bumps and noise-producing pavement).	0.5–2% (instead of 5–20%)
Noise-producing pavement	▪ Estimate for ‘Speed bumps’ (Silla et al., 2015) could be used as a starting point. ▪ Effect was estimated to be half of the effect of speed bumps since noise-producing pavement does not 'force' the driver to slow down the same way as the speed bumps do. ▪ The results of the pilot reveal that subjects in the simulator study did not reliably relate this measure to the LC.	2.5–10% (instead of 5–20%)
Proximity message via in-car device	▪ No numerical estimate available. ▪ Effectiveness was estimated to be significantly smaller than in in-vehicle warning system since this system provides information on active LCs that are equipped with warning devices. ▪ Some subjects in the simulator study indicated that they preferred to concentrate on their driving instead of the messages. This was because reading messages on a screen was considered distracting and dangerous, as it forced subjects to look elsewhere from the road.	<5%
Blinking amber light with train symbol	▪ Estimate for ‘Active warning signs’ (Silla et al., 2015) could be used as a starting point. ▪ Estimate on active warning light includes both vehicle activated and train activated lights. Since this is vehicle activated sign the effectiveness was estimated to be closer to the low range of the estimate. ▪ In the pilot test, the fraction of road users who did not look for a train at a passive crossing was reduced by 4 to 8%, depending on the test condition (left / right).	5–10% (instead of 5–20%)
Blinking lights drawing driver attention (*Perilight*)	▪ Estimate for ‘Active warning signs’ (Silla et al., 2015) could be used as a starting point. ▪ In the pilot test, the fraction of road users who did not look for a train at a passive crossing was reduced by 19% (both left and right). ▪ This same measure was also piloted by Grippenkoven et al. (2016). They found out that the reduction of fraction of drivers who did not look was: 47% on the left, 23% on the right side in daytime; 59% on the left, 53% on the right side at night.	5–20%

	▪ The effectiveness estimate was chosen as 5–20% due to following reasoning: i) The above reduction (23–59%) is limited to LC accidents due to observation error. ii) It is not possible to assume that all road users who look at the approaching train will also act appropriately to avoid an accident by action. iii) The focus should be on the reduction in daytime since based on deliverable D1.2 (Silla et al., 2017) most LC accidents occur during daytime. iv) The pilot study did not cover behavioural adaptation (i.e. long-term effects) which is rather likely with road user activated safety measures.	
Traffic lights	▪ No information available. ▪ Rather small safety effects are expected since this measure was installed to active LCs with barriers.	<5%
In-vehicle train and LC proximity warning	▪ No numerical estimate available. ▪ Estimate for 'Active warning signs' could be applied to this measure (Silla et al., 2015) could be used as a starting point. ▪ Estimate on active warning light includes both vehicle activated and train activated lights. Since in addition to vehicle activation this includes information on train arrival the effectiveness was estimated almost similar to train activated lights (which provide warning only when a train is approaching).	10–15% (instead of 5–20%)
Rings	▪ No numerical estimate available. ▪ Estimate for 'Train activated warning light at LC' (Silla et al., 2015) could be used as a starting point. ▪ Effectiveness was estimated to be smaller since the design of the warning does not directly link the warning to an approaching train. Majority (90%) of the subjects in the simulator study interpreted this measure as a village entrance decoration unrelated to the LC.	2.5–10% (instead of 5–20%)
Additional warning light system at front of the locomotive	▪ Mok & Savage (2005) analysed US LC accident data (1975–2001) using negative binomial regression analysis. The results show that use of ditch lights (additional lights on locomotives) reduced LC accidents by 29% and fatalities by 44%. Despite LC safety gradually increasing over the time period, the data show a substantial 30% decrease in accidents from 1994–1998, following an FRA mandate to install ditch lights on all trains. These reduction estimates were not directly applied to our study	15–30% (instead of 29–44%)

	since the modelling exploited currently almost 25 years old accident data. The European railway safety has improved from those days and thus the obtained effectiveness estimates cannot be applied as such to the current situation. In addition, the authors mentioned that the calculated reduction could also be influenced by general improvements in road safety and improvements in LC environments that could not be considered by the model. ▪ In the pilot test, the fraction of road users who did not look for a train at a passive crossing was reduced 11−20%, depending on the test condition (left / right). ▪ The findings of Grippenkoven et al. (2016) can also be considered relevant for the additional blinking lights at train front even though they were not directly applied to the effectiveness estimate (see reasoning used for Perilight). However, the difference here is that this measure is linked to the approaching train and hence no significant behavioural adaptation is expected. ▪ Based on deliverable D1.2 (Silla et al., 2017) it is expected that the effectiveness of this measure is higher at passive LCs compared to the active ones due to a high share (34.9%) of LC accidents at active LCs that are due to other human risk factors (i.e. deliberate risk taking) which (most probably) cannot be prevented with this measure. The corresponding share at passive LCs is 2.8%.	
Improved train visibility using lights	▪ See above (Additional warning light system at front of the locomotive).	15–30% (instead of 29–44%)

The above effectiveness estimates were applied to the share of relevant LC accidents. Such estimates were performed separately for all safety measures. The challenge was that some of the measures were applied to different types of LCs than they were expected to be most effective in deliverable D2.3 (Dressler et al. 2018). Therefore, the calculation of the potential safety effects were conducted to targeted LC types identified in WP4 and in Dressler et al. (2018). The targeted LC types by safety measure are presented in Table 47 and the estimates of safety effects by measure are presented in Table 48.

Table 47. Targeted LC types by safety measure.

Measure	**WP4**	**Dressler et al. 2018**
Smart detection and communication system	Active LCs with automatic user-side warning and/or protection	Active LCs with automatic user-side protection
V2X messaging system between AVs and passive LCs	Passive LCs	Not included
Monitoring and remote maintenance	All LC types	Not included
Sign 'Look for train'	Passive LCs	Passive LCs
Written letters on ground	Passive LCs	Not directly included
Coloured road markings	Active LCs with user-side protection (and warning)	All types of LCs
Speed bumps and flashing posts	Active LCs with user-side protection (and warning)	Passive LCs
Funnel effect pylons	Active LCs with user-side protection (and warning)	Passive LCs
Noise-producing pavement	Passive LCs, (Active LCs with automatic user-side warning)	Passive LCs
Proximity message via in-car device	Active LCs with user-side protection (and warning)	Passive LCs (and all other LC types)
Blinking amber light with train symbol	Passive LCs	Passive LCs
Blinking lights drawing driver attention (*PeriLight*)	Passive LCs	Passive LCs
Traffic lights	Active LCs with user side protection (and warning)	Active LCs with user-side protection (and warning)
In-vehicle train and LC proximity warning	Passive LCs, Active LCs with manual user-side warning and/or protection, (all other LC types)	Passive LCs (and all other LC types)
Rings	Active LCs with user-side protection (and warning)	Passive LCs
Additional warning light system at front of the locomotive	Passive LCs	All types of LCs
Improved train visibility using lights	Passive LCs (all other LC types)	All types of LCs

Table 48. *Estimates of safety effects by measure assuming 100% coverage (LCs, train and/or road users) in the implementation of each measure.*

Measure	**Estimated effectiveness**			
	WP4		**Dressler et al. 2018**	
	Low	**High**	**Low**	**How**
Smart detection and communication system	*No direct safety effects expected*			
V2X messaging system between AVs and passive LCs	*No direct safety effects expected*			
Monitoring and remote maintenance	*No direct safety effects expected*			
Sign 'Look for train'	0.0%	2.0%	0.0%	2.0%
Road marking	0.0%	2.0%	Not included	
Coloured road markings	0.0%	1.3%	0.0%	5.0%
Speed bumps and flashing posts	1.3%	5.1%	2.0%	8.0%
Funnel effect pylons	0.1%	0.5%	0.2%	0.8%
Noise-producing pavement	1.0%	7.1%	1.0%	4.0%
Proximity message via in-car device	0.0%	1.3%	Not included	
Blinking amber light with train symbol	2.0%	4.0%	2.0%	4.0%
Blinking lights drawing driver attention (*Perilight*)	2.0%	8.0%	2.0%	8.0%
Traffic lights	0.0%	1.3%	0.0%	1.3%
In-vehicle train and LC proximity warning	4.4%	15.0%	4.0%	15.0%
Rings	0.6%	2.6%	1.0%	4.0%
Additional warning light system at front of the locomotive	6.0%	12.0%	15.0%	30.0%
Improved train visibility using lights	6.0%	30.0%	15.0%	30.0%

The above safety estimates assume 100% coverage regarding the implementation of the measure. Specifically, this means that all relevant LCs, trains and/or road users would be equipped with the system. In addition, the above estimates assume that the functionality and reliability of the system is 100% safe all the time and all the road users obey the provided information and/or warnings. In practice, these assumptions are unrealistic. This holds especially for the first assumption on penetration rate of each safety measure. It is not economically feasible and not necessarily even practical to equip all the LCs, trains and/or road users with the piloted safety measures.

The connection between safety benefits and the penetration rate is not expected to be linear. For example, in case the implementation of piloted safety measure(s) start from the most accident prone LCs (with high road traffic volumes), high safety benefits can be expected even with low implementation rates. Therefore, in future exploitation phases, it would be useful to identify the LCs with the higher marginal results for an efficient implementation. This has to satisfy the positive marginal utility aspect which means the safety measures should be applied in LCs that will introduce clear benefits to the users by avoiding fatalities, (severe and light) injuries, environmental damage, infrastructure damages (rail, road – vehicles included), and (primary and secondary) traffic delays. The benefits of the piloted safety measures will be estimated and presented in deliverable D5.3 (Business models to deploy the SAFER-LC solutions).

Furthermore, it is important to note that the estimates for safety effects vary significantly depending on the estimation in regards to targeted LC types. The measures with high effectiveness estimates in Table 48 are typically those that are estimated to be relevant for all types of LCs (see Table 47).

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The piloting of safety measures in WP4 was conducted in various level crossing environments and in different countries as described in deliverable D4.3 (Carrese et al., 2019). In some cases, the selected measures were not suitable for piloting in a real world experimental context and/or the implementation in real railway environment was not feasible, for example, due to financial resources, timing of our piloting period and/or lack of suitable pilot site(s). Therefore, pilot test sites in the SAFER-LC projects varied from simulation studies to controlled conditions and real railway environments. Some of the measures ('In-vehicle warnings to driver', and 'Additional lights to train front') were tested in two different environments to collect complementary information on their safety effects via two types of installation.

As indicated in chapter 2.2 of this deliverable, it was recommended to the pilot test leaders to carry out an evaluation: (1) in a real experimental context (i.e. units are assigned randomly to a treated and untreated group to control the potentially confounding factors) and (2) by collecting evaluation data both in 'before' and 'after' conditions. Pilot test leaders were encouraged to collect control data whenever possible, especially, in before-after (baseline and after implementation) studies to allow the separation of the effects of the measure from other simultaneously affecting factors. In practice, the data collection for many of the pilots were short term. This was partly due to the nature of the piloting (simulator studies) and partly due to financial and time constraints. Many of the pilots included 'before' and 'after' data collection but the collection of control data was more limited. Since the time for the piloting was rather short in many of the pilots, the results did not allow any estimation on the long term effects of measures.

Due to the nature of the conducted pilots (small-scale pilot tests), it was hardly possible to calculate any quantitative estimates for safety effects of the measures in terms of annual reductions in the number of LC fatalities and/or accidents based on the results of the pilots. However, since numerical estimates of safety effects are needed for cost-benefit calculations (WP5 of the SAFER-LC project), the authors made an attempt to draw these estimates based on the applicability of safety measures to different LC types, road users and behaviours leading to LC accidents (subchapter 5.1) based on pre-existing information on the effects of LC safety measures (subchapter 5.2). The authors acknowledge that many uncertainties are related to these estimates. However, the assumptions used in the calculations are clearly documented and hence the estimates can be easily updated if more detailed statistics or more information on safety effects become available. Therefore, a detailed documentation of LC accident data (information on additional variables and details) is highly recommended to enable drawing of these estimates.

It should be noted that some of the piloted safety measures are somewhat different from the ones reported in the SAFER-LC deliverable D2.3 (Dressler et al., 2018). In Dressler et al. (2018) the safety measures were divided into three different groups: 1) Measures for passive level crossings, 2) Measures for level crossings with barriers, and 3) Measures for all kinds of level crossings. In our safety potential estimation the LC type groups were slightly different due to the classifications used in the railway accident database sustained by the European Union Agency for Railways (see e.g. European Union Agency for Railways 2017 and ERAIL database 2019). In this classification the main categories for the LC types include:

- Active LC with automatic user-side warning

- Active LC with automatic user-side protection (and warning)
- Active LC with automatic user-side protection and warning, and rail-side protection
- Active LC with manual user-side protection and/or warning, and
- Passive LC.

In addition, there are some slight differences in the LC type applicability of safety measures reported in Dressler et al. (2018) and the ones piloted as part of WP4. For example, all the safety measures piloted in SNCF simulator were applied to active LCs with barriers. In Dressler et al. (2018) some of these measures ('Funnel effect pylons', 'Rings' and 'Speed bump combined with flashing posts') were estimated to be most effective in passive LCs. However, the selection of relevant LC types for the simulator study is understandable since in France most LCs are active with barriers and most LC accidents also occur at active LCs with barriers. Based on this decision, it is important to note that the estimated effectiveness of these safety measures would be higher if implemented to passive LCs instead of active LCs with barriers (see Table 48).

Based on the safety potential calculations presented in chapter 5 the piloted measures that were estimated to have the highest safety benefits are:

- Additional lights at the train front, covering measures 'Additional warning light system at front of the locomotive (6.0–12.0%)' and 'Improved train visibility using lights (6.0–30.0%)'. This measure was estimated to have rather high effectiveness (prevention of 15–30% of relevant LC accidents) and target rather large share of LC accidents (19.9−96.3% depending on the approach).
- In-vehicle train and LC proximity warning (4.4–15.0%). It is important to be noted that the effectiveness of this measure depends on the usage of the in-vehicle devices. In practice, the car driver needs to install the application on a smart mobile device, and location tracking should be enabled on this device while driving. Furthermore, the driver needs to allow the application to run seamlessly on the background and also notice the visual or auditory warning in order to perform the required action on time (e.g. stop before the LC). However, these latter requirements are valid for all LC safety measures.
- Speed bumps and flashing posts (2.0–8.0%). This accident reduction estimate concerns the situation where the measure is implemented to passive LCs (where the highest safety effects were expected in Dressler et al. 2018).
- Blinking lights drawing driver attention (*Perilight*) (2.0–8.0%). This measure is targeted to passive LCs.

Some concerns on applicability of piloted safety measures in different railway environments are listed below:

- Written letters on ground and coloured road marking: Any road marking can only be applied on a paved road with an even surface. Thus, the message written on the road does not hold for road environments such as gravel roads, cobblestone, tracks etc. Furthermore, these measures are not perfectly suitable to countries with snow and long winter with darkness.
- Noise-producing pavement and speed bumps: These measures are not well suited to gravel roads. In addition, these measures are not effective in case of snow.
- Blinking amber light with train symbol and blinking lights drawing driver attention (*Perilight*): It is important to note that these measures are targeted to passive LCs and require power.

However, in practice many of passive LCs no mains power is available and thus other alternative power sources need to be investigated. The effectiveness of these measures was estimated somewhat lower than active LCs with sound and/or light warning since the warning in these measures is linked to LC approach and not to actual arrival of train.

- In-vehicle train and LC proximity warning: This system may not operate satisfactory for LCs surrounded by roads on which Global Navigation Satellite System (GNSS) reception is poor.

The safety effect results of the piloted measures are promising. Therefore, it is recommended that some of most promising measures will be tested in larger scale real world experiments with well-planned research designs to obtain more information on their effects (also on long term) on road user behaviour and thus on road safety. This would also support the more exact numerical estimation of safety effects of the piloted measures.

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ANNEX A: FIRST PHASE QUESTIONNAIRE (BEFORE LAUNCHING THE APPLICATION) TO TAXI DRIVERS TESTING THE "IN-VEHICLE TRAIN AND LC PROXIMITY WARNING" MEASURE.

1. What is your age?

   ………………………

2. What is your gender?
   ☐ Male ☐ Female

3. How many years of experience do you have as a professional taxi driver?

   ……………………....

4. How many km have you driven within the last year?

   …………………………

5. How potentially dangerous are Level Crossings for a driver?
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

6. How safe do you currently feel using the LCs in the Thessaloniki area?
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

7. How easy is it to detect the presence of a LC or an approaching train based on the existing LC safety measures (e.g. signs)?
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

8. How easy is it to identify LCs that you were not previously aware of or a possible danger at a LC based on the existing LC safety measures (e.g. signs)?
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9. To what extent do the current safety measures at LCs in Thessaloniki help you to know how to cross safely?
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

10. How important is it for you to know how far away the train is from the LC?
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

11. How important is it for you to know when the train will arrive at the LC?
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

12. To what extent do you take risks at LCs (e.g. crossing after being alerted of an approaching train)?
    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

13. How experienced are you driving with smart driver-assistance devices (e.g. GNSS, collision warning systems, over speeding warnings, etc.)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

14. How important is the use of an in-vehicle alert system to increase safety at LCs?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Comment Box
(Here you can provide any additional feedback or clarifications you may have on the answers).
………

ANNEX B: SECOND PHASE QUESTIONNAIRE (AFTER LAUNCHING THE APPLICATION) TO TAXI DRIVERS TESTING THE “IN-VEHICLE TRAIN AND LC PROXIMITY WARNING” MEASURE.

1. What is your age?

   ………………………

2. What is your gender?
   € Male € Female

3. How many years of experience do you have as a professional taxi driver?

   ……………………....

4. How many km have you driven within the last year?

   …………………………

5. To what extent do you feel safer using the in-car alert system? (feeling of safety/reliability, acceptance)
   € 1 € 2 € 3 € 4 € 5

6. How well does the in-car alert system complement the existing LC safety measures (e.g. signs) in the Thessaloniki area? (acceptance)

   € 1 € 2 € 3 € 4 € 5

7. How easy is it to detect a LC and approaching trains using the in-car alert system? (detectability)
   € 1 € 2 € 3 € 4 € 5

8. How easy is it to identify LCs that you were not previously aware of or a possible danger at a LC using the in-car alert system? (identification)
   € 1 € 2 € 3 € 4 € 5

9. To what extent does the in-car alert system help you to know how to cross LCs safely in Thessaloniki? (rule knowledge)
   € 1 € 2 € 3 € 4 € 5

10. How likely it is that you would ignore the information provided by the in-car alert system (e.g. crossing after being alerted to an approaching train)?(decision making)
    € 1 € 2 € 3 € 4 € 5

11. To what extent do you take risks at LCs (e.g. crossing after being alerted to an approaching train)?(behavioural execution)
€ 1 € 2 € 3 € 4 € 5

12. How reliable do you think the information provided by the in-car alert system is? (reliability)
€ 1 € 2 € 3 € 4 € 5

13. To what extent do the following characteristics encourage you to use the LC detection application? (usability)

	1	2	3	4	5
User friendly interface	☐	☐	☐	☐	☐
Ease of use	☐	☐	☐	☐	☐
LC identification accuracy	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Visual message appropriateness	☐	☐	☐	☐	☐
Visual message length	☐	☐	☐	☐	☐
Auditory message appropriateness	☐	☐	☐	☐	☐
Auditory message length	☐	☐	☐	☐	☐
Auditory message volume	☐	☐	☐	☐	☐
Other …………………………....					

14. How interested would you be in using the in-vehicle alert system after the end of the test period? (acceptance)
€ 1 € 2 € 3 € 4 € 5

Comment Box

(Here you can provide any additional feedback or clarifications you may have on the answers).

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