SAFER-LC PROJECT

SAFER LEVEL CROSSING BY INTEGRATING AND OPTIMISING ROAD-RAIL INFRASTRUCTURE MANAGEMENT AND DESIGN

LESSONS LEARNT

April 2020

SAFER-LC

This project has received funding from the European Union's Horizon 2020 research and innovation programme uner grant agreement No 723205

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Abbreviations

Short name	Name
AV	Automated Vehicle
BCR	Benefit Cost Ratio
CAM	Cooperative Awareness Message
CBA	Cost-Benefit Analysis
CP	Collective Perception
CPS	Collective Perception Service
DENM	Decentralized Environmental Notification Message
EC	European Commission
ERA	European Union Agency for Railways
ETSI	European Telecommunications Standards Institute
EU	European Union
HF	Human Factor
IP	Internet Protocol
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LC	Level crossing
LED	Light Emitting Diode
LTE	Long Term Evolution (standard for wireless broadband)
MRU	Motorised Road User
NPV	Net Present Value
RSU	Roadside Unit
SDS	Smart Detection System
V2X	Vehicle to everything
VRU	Vulnerable Road User
WP	Working package (of project SAFER-LC)

1. BRIEF OUTLINE AND AIMS OF THE GUIDANCE

In line with the global efforts to improve safety at level crossings (LCs), this guidance document sums up important practical information and recommendations collected and produced during the SAFER-LC project (SAFER Level Crossing by integrating and optimising road-rail infrastructure management and design) which lasted 3 years from 1 May 2017 to 30 April 2020.

There are two parts to the guidance: the first part of the document provides an overview on level crossing accidents and what we can learn from them. It also illustrates several tools that were developed in project SAFER-LC to assess the level of risk and the effectiveness of safety measures: the level crossing risk evaluation method, the Human Factors methodological framework, the safety evaluation framework of safety measures, and the financial evaluation framework of safety measures.

The second part of the document focuses on the actual evaluation of safety measures in project SAFER-LC and recommendations about their implementation. It gives an overview of the pilot test sites and provides examples of safety measures which were tested. These safety measures are presented with implementation tips, potential criticalities, examples, empirical evidence, etc. However, this document includes only a limited collection of the available measures for road and railway stakeholders.

The complete guidance on safety measures for level crossings and more examples are available in the online SAFER-LC toolbox: http://toolbox.safer-lc.eu/

This document is intended for guidance only. Its contents shall be neither considered as definitive nor as requirements. The measures provided as examples are likely to evolve over time and are to be used by road and railway stakeholders as seen fit and on their own responsibility.

This work has been carried out as part of the SAFER-LC project (https://safer-lc.eu/). This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723205.

2. INTRODUCTION

2.1. OVERVIEW ON LC SAFETY IN EUROPE

In 2017, there were 108,385 level crossings (active and passive) in the 28 EU Member States (European Union Agency for Railways, 2020). According to the situation in 2014, there were on average five level crossings per 10 line-km in the EU. There are on average 50 LCs per 100 line-km in the EU. The lowest densities of level crossings could be found from in Bulgaria and Spain, where there were less than 25 level crossings per 100 line-kilometres. (European Union Agency for Railways, 2016).

In 2017, in a total of 1,848 significant railway accidents occurred in the EU Member States, resulting in 974 fatalities and 754 seriously injured persons. In the same year, there were 466 level crossing accidents resulting in 298 fatalities and 218 seriously injured persons. (European Union Agency for Railways, 2020). Specifically, the number of fatalities in level crossing accidents represented 31% of railway fatalities (suicides excluded).

The risk at level crossings in the EU countries is shown in Figure 1 that presents the level crossing fatalities per million train kilometres. In addition to the country level analysis, the risk at level crossings was also analysed at EU-28 level. Based on EU-28 numbers, both the risk of fatalities and serious injuries has decreased over the years. The risk of fatality decreased from 0.106 (2006–2008) to 0.044 (2015–2017) whereas the risk of serious injury was reduced from 0.114 (2006–2008) to 0.057 in (2015–2017) (European Union Agency for Railways, 2020).

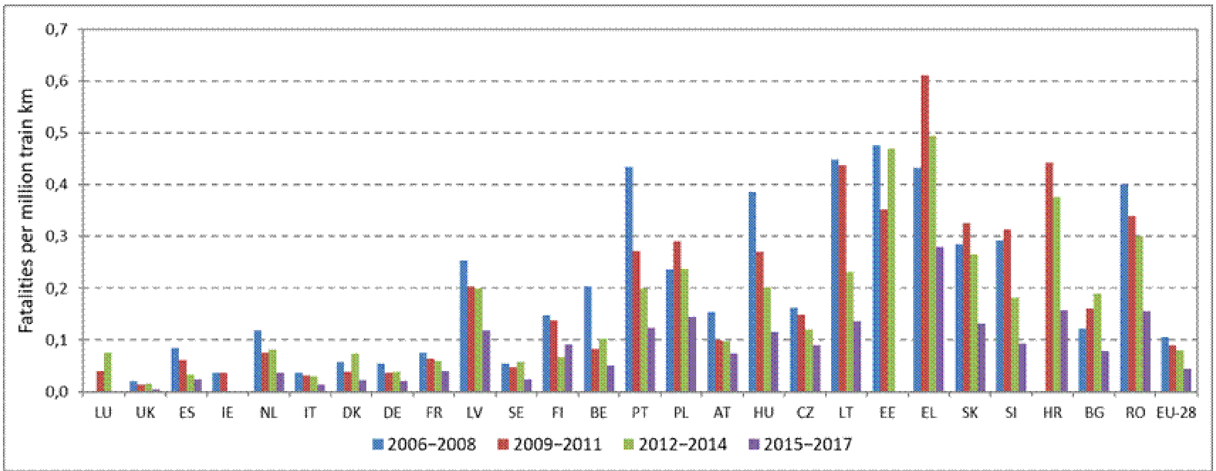


Figure 1. Level crossing fatalities per million train kilometres in the EU by country and by EU-28 (European Union Agency for Railways, 2020).

Fatalities and serious injuries in level crossing accidents form an important proportion of the total number of victims in accidents occurring on railways (close to 30%), whereas from the road perspective the share of level crossing accidents from all road accidents is only 1% (European Union Agency for Railways, 2018).

2.2. OVERVIEW ON LC ACCIDENTS

Some main characteristics of LC accidents are described here based on the available Europe-wide LC accident statistics (ERAIL database sustained by the European Union Agency of Railways) and the already collected and documented information on in-depth analysis of LC accidents in selected countries which is reported as part of deliverable D1.2 of the SAFER-LC project (Silla et al., 2017). From the safety assessment perspective, the three most relevant variables related to LC accidents are: i) type of LC, ii) type of victim, and iii) type of behaviour.

The statistics show that most LC accidents occur at passive LCs (39.8%) and at active LCs which are equipped with automatic user side warning (30.6%) (Table 1). The breakdown of LC types according to the level of protection in Table 1 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).

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

<table>
<tr><th colspan="2">Type of LC</th><th>Share</th></tr>
<tr><td rowspan="4">Active LC</td><td>with automatic user side warning</td><td>30.6%</td></tr>
<tr><td>with automatic user-side protection (and warning)</td><td>22.2%</td></tr>
<tr><td>with automatic user-side protection and warning, and rail-side protection</td><td>3.3%</td></tr>
<tr><td>with manual user-side protection and/or warning</td><td>4.1%</td></tr>
<tr><td colspan="2">Passive LC</td><td>39,9%</td></tr>
<tr><td colspan="2">Total</td><td>100%</td></tr>
</table>

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

According to the analysis conducted as part of WP1 (Silla et al., 2017), most victims in LC accidents were car drivers or passengers both in fatal accidents (53.4%) and in accidents resulting in injuries (75.9%) (Table 2). The shares of LC accidents by type of victim presented in Table 2 were defined based on the 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 2. Share of LC accident severities by type of victim (Silla et al., 2017).

Type of victim	Fatalities (%)	Injuries (%)
Car drivers & passengers	53.4%	75.9%
Mopedists & motorcyclists	6.8%	4.6%
Pedestrians & cyclists	37.2%	16.2%
Other	2.6%	3.3%
Total	**100% (n=266)**	**100% (n=216)**

Most accidents (93.5%) at passive LCs were assessed to occur due to the situation awareness error, whereas for active LCs, the majority of accidents were related either to situation awareness error (53.5%) or to other human risk factors (34.9%) such as deliberate risk taking (Table 3). The categories for the behaviour were identified based on two sources: 1) An article written by Laapotti (2016) who analysed fatal motor vehicle accidents at level crossings in Finland during the years 1991–2011 (n=142), and 2) French LC accident data reported in deliverable D1.2 of this project (Silla et al., 2017).

Table 3. 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)**

2.3. SAFER-LC OBJECTIVES

SAFER-LC (Safer level crossing by integrating and optimising road-rail infrastructure management and design) is a EU-funded H2020 research project. Its main objective is to improve safety and minimise risks at and around 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 enable

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

The main output of the SAFER-LC project is a toolbox which is 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.

3. RISK EVALUATION AT LEVEL CROSSING

Nowadays, as a norm in most European railways, the tendency is to remove as many level crossings as possible, as the level crossings represent a significant proportion of accidents (with or without casualties) for this transport mode.

The associated cost of level crossing removal can be very high, as the different situations of level crossings make each removal process a unique case. Some LCs can be easily removed as they have a safer alternative not far from them and the only cost is the cost of removing the road surface in the track area, removing the LC installations (if any) and the installation of fix barriers and road signals to indicate the new route to be used to cross the railway lines.

In other cases, removal of the level crossing is not possible, independent of the associated cost. Social cost can make the elimination of a LC unacceptable due to the creation of physical barriers or other kinds of impact in the area. For these cases, the authorities in charge of managing the level crossings (road and/or railway infrastructure managers) need to evaluate the risks at level crossings to decide which level of protection should be installed in each of the existing LCs.

Also, in case of having budget enough to face the elimination of one or several LCs, the entity responsible of that should have a clear classification of the level crossings under their responsibility to determine the priorities to eliminate the riskiest ones in the first place. One possible classification is directly related to the history of incidents at the LC, and of course, this is taken into account and reviewed with each incident at a LC but is not the best way of classification.

To evaluate the risk and classify the LC, several aspects should be taken into account, such as the road traffic, the railway traffic, the visibility of the track from the road, the angle of the crossing between road and track, the slope of the road at the level crossing, the possibility to be blinded by sun light at sunrise or sunset, etc.

All these parameters are used in a formula which may be different from country to country, but with the common idea, to be able to categorise the level crossings based on a numeric estimation of the associated risk. This classification should be updated periodically, as some external factors could change (growing villages close to the LC, new roads in the area, etc.) and thus, modifying the categorization of the LC.

Within SAFER-LC project, an innovative method for risk assessment is proposed based on the acquisition of video data from a LC over long periods (several weeks) in order to perform off-line automatic analysis of video sequences to extract behavioural models of user-to-user and user-to-infrastructure interaction. A more detailed description of the “Level crossing risk assessment using video analysis and machine learning” is given in section 6.8.

Key recommendations regarding Risk assessment of LC

- Perform regular safety inspections of the LC
- Have a holistic approach for the risk assessment involving stakeholders from Rail, Road, environment, and authorities responsible for urban planning
- Build national databases of the results of LC safety inspections, past accidents and/or near accidents

4. ASSESSMENT OF THE MEASURES

4.1. HUMAN FACTORS METHODOLOGICAL FRAMEWORK

This framework was built based on a combined methodology covering a review of important Human Factors and psychological models which provide theoretical foundations, an identification of key safety indicators concerning human errors and violations at level crossings, previous evaluation studies on classification and evaluation criteria and behavioural safety indicators, and expert consultation.

The framework consists of three sets of criteria which are illustrated with different colours: Classification criteria (orange) as well as two sets of assessment criteria (Criteria to assess the behavioural safety effects – green –, and Criteria to assess user experience and social perception – blue) (Figure 2). Each of these categories is based on a set of criteria. Each criterion is further broken down into a set of more specific and measurable indicators which are transposed into evaluation checklists.

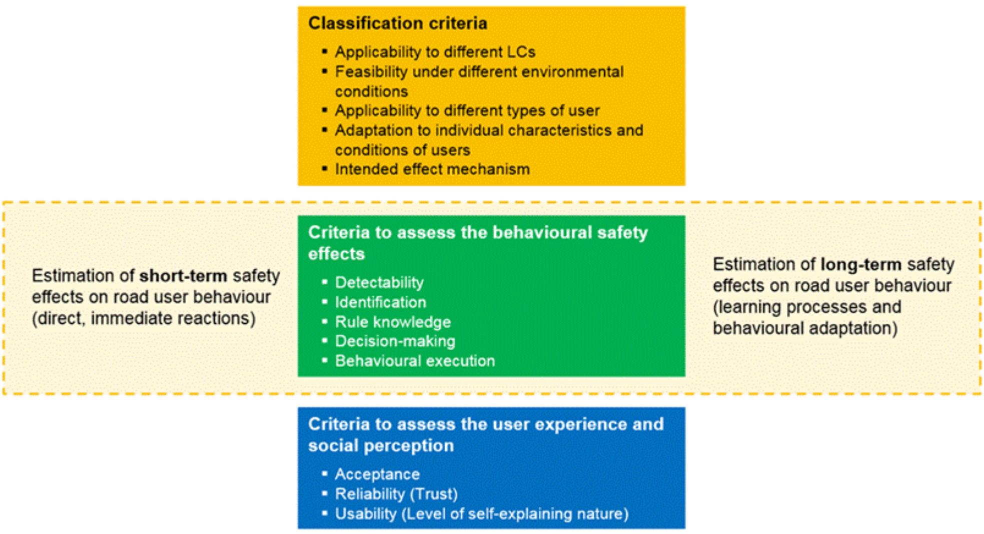


Figure 2 - The SAFER-LC HF methodological framework: Overview of the sets of classification and assessment criteria selected for the HF assessment tool (Havârneanu et al., 2020)

The upmost (orange) box of the assessment tool, Classification criteria, provides a description of the measure under assessment. It specifies the potential of the measure for integration within different LC types and environmental conditions as well as its applicability to different LC user types and characteristics. This set of criteria also classifies the intended effect mechanism via which the measure is expected to affect road and railway safety. These criteria are qualitative in nature and are used to define the context and environment in which the safety measure is expected to be effective. For example, if the safety measure is only installed at passive LCs and is targeted to improve the safety of children, the group of targeted LC accidents is rather limited and thus no high effects on Europe-wide LC safety performance can be expected, even though the effectiveness of that specific measure could be estimated as high.

In addition, the information gathered on the classification criteria can support road and railway stakeholders in deciding the locations where the specific safety measure could be implemented. For example, these criteria describe the types of LCs where the specific measure is implementable and in which circumstances it is most effective. Furthermore, if there are problems with specific road user groups at a given LC, this framework allows the identification of safety measures which are targeted to that problem behaviour (e.g. safety measures targeted to pedestrians).

The middle (green) box presents the criteria to assess the short and long-term effects of safety measures on road user behaviour. These criteria are categorized according to the area of psychological function involved. Once the estimated changes in road user behaviour have been identified (both short and long-term), the safety effects can be quantified, for example, based on Key Performance Indicators (KPIs) collected in the pilot tests of the SAFER-LC project, literature, expert assessment, LC statistics etc.

The lower (blue) box presents the three criteria to assess user experience and social perception regarding the safety measure. The indicators refer to the subjective opinions of road users and thus this information will most likely be collected through a questionnaire among relevant stakeholders and road users or through interviews with selected representatives of these categories. Social acceptance on the part of the end user and wider community is important, as it may affect their interaction and correct usage of the measure, potentially affecting safety. Information related to these indicators is proposed to be collected via a Likert scale, which means that the respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements.

The developed framework represents the theoretical backbone of the Human Factor Assessment Tool which can be applied in future evaluations of safety measures. The assessment tool and its evaluation checklists can be found in the SAFER-LC deliverable D2.5 (Havârneanu et al., 2020) and in the online toolbox.

4.2. SAFETY EVALUATION FRAMEWORK

In the safety evaluation framework, the share of LCs where a measure would be applicable and the effectiveness of the measure to prevent accidents were combined to produce safety estimates for each piloted safety measure. The evaluation was based on LC statistics, published literature and the results from the pilots conducted within the project.

The piloting of safety measures in WP4 was conducted in various level crossing environments and in different countries. In some cases, the selected measures were not suitable for piloting in a real-world experimental context, and/or the implementation in a 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. One of the measures was tested in two different environments to collect complementary information on their safety effects via two types of installation.

It was recommended to the pilot test leaders to carry out an evaluation:

- in a real experimental context (i.e. units are assigned randomly to a treated and an untreated group to control the potentially confounding factors), and
- by collecting evaluation data both in 'before' and 'after' conditions.

Pilot test leaders were encouraged to collect control data (i.e. data from similar location without any implementation) 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 time range in data collection for many of the pilots was 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 were needed for cost-benefit calculations, we made an attempt to draw these estimates via two different approaches. First, we assessed the applicability of safety measures to different LC types, road users and behaviours leading to LC accidents (based on the statistics presented in chapter 2.2. of this brochure) to demonstrate the targeted LC accidents by each safety measure. Then, the actual effectiveness estimates (i.e. accident reduction potential) were drawn based on pre-existing information on the effects of LC safety measures and findings from the SAFER-LC pilot tests. The main source for the effectiveness estimates used in our assessment was the study of Silla et al. (2015) where 37 LC safety measures suitable to the Finnish railway environment were assessed according to 15 criteria. The safety effects were assessed by using the following ranges: < 5%, 5–20%, 20–50%, > 50%, and 'No information'. These same ranges were used as a starting point when drawing the estimates on effectiveness of LC safety measures piloted during the SAFER-LC project.

The final estimates on safety effects for the cost-benefit calculations were formed by multiplying the effectiveness estimates with the share of relevant LC types. Such estimates were derived separately for all piloted safety measures that were estimated to have direct safety effects. The estimates of safety effects by measure are presented in Table 4. It is important to note that the 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 produced estimates assume that the functionality and reliability of the system is 100% at all times and that all the road users receive and/or notice the provided information and/or warnings. In practice, the above 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.

Measure	Share of relevant LCs (%)		Effectiveness estimate (%)		Safety effects (%)	
	Low	High	Low	High	Low	High
Sign ‘Look for train’	39.8	39.8	0.0	5.0	0.0	2.0
Road marking	39.8	39.8	0.0	5.0	0.0	2.0
Coloured road markings	100.0	100.0	0.0	5.0	0.0	5.0
Speed bumps and flashing posts	39.8	39.8	5.0	20.0	2.0	8.0
Funnel effect pylons	39.8	39.8	0.5	2.0	0.2	0.8
Noise-producing pavement	39.8	39.8	2.5	10.0	1.0	4.0
Proximity message via in-car device	25.5	25.5	0.0	5.0	0.0	1.3
Blinking amber light with train symbol	39.8	39.8	5.0	10.0	2.0	4.0
Blinking lights drawing driver attention (Perilight)	39.8	39.8	5.0	20.0	2.0	8.0
Traffic lights	25.5	25.5	0.0	5.0	0.0	1.3
In-vehicle train and LC proximity warning	39.8	100	10.0	15.0	4.0	15.0
Rings	39.8	39.8	2.5	10.0	1.0	4.0
Additional lights at the train front	39.8	100.0	15.0	30.0	6.0	30.0

It is acknowledged that many uncertainties are related to the estimates on safety effects. However, the assumptions used in the calculations are clearly documented in deliverable D4.4 (Silla et al., 2019) 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 the derivation of these estimates.

4.2. FINANCIAL EVALUATION - CBA BUSINESS MODEL

Economic science has mainly focused on commercial goods and demand oriented economies. However, there are several studies on whether life can have an economic value and how financial evaluation of such activities can take place. The value of life proposed by such studies includes only the economic activity that an average person produces during his/her life and ignores many aspects.

In the framework of the Cost-Benefit Analysis (CBA), the calculation of safety benefits of each SAFER-LC safety measure is based on the effectiveness estimates drawn as part of WP4 of the SAFER-LC project (Silla et al., 2019) and on the estimates of the value of life based on previous studies[1] . The partners were asked to identify the benefits separately for injuries avoided, environmental pollution avoided (fires, dangerous goods, etc.), infrastructure damages (rail, road – vehicles included), traffic delays (both primary and secondary) and rescue service costs avoided.

In the inquiry on cost, categories such as further development costs required for full deployment, installation costs, annual operational costs, maintenance costs and other general costs were considered. The interest rate calculated (as the opportunity cost of a safer investment) was estimated as 2% in all cases. It was not considered necessary to calculate alternative interest rates as in the case of road safety solutions the scope of economic analysis is not to compare different returns on investment but to define the sustainability and the benefits to the society by applying such measures.

1 Taking Safe Decisions - Safety-Related CBA (2019). RSSB.co.uk

The increase in safety can be more beneficial than estimated and it is highly possible to underestimate the values of the benefits (fatalities result in big negative impacts on families and societies). We can calculate only the value by terms of product a person can produce during his/her life but we cannot easily identify the impact they may have through other activities such as volunteering or the value brought to the person's family. A loss may have impact to other people's lives and this cannot easily be valuated.

Below, an example of the calculation for the CBA and the Net Present Value (NPV) applied to the measure of a sign "<-Is a train coming?->" with train symbols on LC approach.

> *The measure needs an initial investment of 80,000€ in the scenario (100 LCs equipped). The annual benefits are calculated as 23,220.17€ in the scenario of a 5% safety effect. The NPV of the solution was calculated on a 5-year basis (Table 5). In this case, the cost for the initial investment is low and the annual depreciation amount, too. The NPV was calculated at 10,593.47€. The BCR (benefit-cost ratio) was calculated at 1.16 which is greater than 1 and therefore the investment is beneficial for the stakeholders.*
>
> *The BCR for a 5-year investment period assuming a high effect in prevention of fatalities (5%) is 1.16 (which means that the benefits are 16% greater than the costs in a five-year scenario).*

Table 5. Example of CBA from deliverable D5.

NPV	
Message "Is a train coming?" written on the pavement	
Reduction 5%	
Interest Rate	2.00%
Initial Investement	80,000.00
Net Cash Flows	
Year 1	21,440.33
Year 2	21,440.33
Year 3	21,440.33
Year 4	21,440.33
Year 5	21,440.33
Output:	
NPV	**21,058.13**

The SAFER-LC business model is based on the Business Model Canvas as shown in Table 6 and is an organisational depiction of how the partners perceive the after-project exploitation of the solutions developed. In the business model, the reader can go through the value proposed by the SAFER-LC, the customer relationships and how they can be built, who are the customers (customer segments) and what channels can be utilised to reach them. The key partners on the left are the ones that SAFER-LC can rely on for the product to be delivered and the key resources required for the key activities to be executed. Last but not least, the main revenue streams and cost structures are presented at the bottom of the business model canvas.

Table 6. SAFER-LC Business Model Canvas

Key Partners

- Public authorities (regional, national or European level)
- Rail infrastructure managers
- Road infrastructure managers
- Hardware developers
- Software developers
- Research institutes
- Rail operators
- Road operators (commercial fleet managers)
- Rail users (passengers, train drivers, …)
- Road users (drivers, riders, cyclists, pedestrians, …)

Key Activities

- Consulting on the most suitable – applicable - efficient LC solutions
- Development of the solutions
- Installation activities
- Operational activities
- Maintenance of the solutions and updates
- General and/or other (updating, research for improvement etc.)

Key Resources

- Hardware devices constructed for some solutions.
- Software developed for the SAFER-LC needs
- Personnel (further research, installation, maintenance etc.)
- The SAFER-LC developed solutions - knowledge

Value Proposition

- Augmented safety in LCs during day and night
- Provision of low-cost solutions
- Providing mixed solutions for specific needs that can support numerous level-crossings with little or no need for employees to monitor – inspect
- Fit with the environmental and circulation needs
- Possibility for integration with digital systems – new technologies
- More efficient network operations
- Less costs on damages

Customer Relationships

SAFER-LC potential customers are limited – estimated approx. 100 (European level), so a special customer relationship should be established with emphasis on the needs of each one.

Channels

- conferences,
- networking,
- specialised magazines and websites,
- associations where rail infrastructure managers (or other potential customers are represented,
- tender calls (in regional, national or European level) for safety solutions
- salespersons etc.

Customer Segments

- Government, regional governments, cities, etc.
- Rail operators or rail infrastructure managers
- Road infrastructure managers
- Application and service providers

Cost Structure

- Product development costs
- Hardware development costs
- Personnel costs
- Installation costs
- Operational costs
- Maintenance costs
- General, administrative and other costs

Revenue Streams

- Consultancy fees to define the best solutions for LCs
- Studies on the suitability of the solutions, the results that could bring etc.
- Hardware sales
- Software – application sale / subscription
- Less realistic - taxes, tolls, charges from government

5. OVERVIEW OF THE TEST SITES

The LC safety measures studied within the SAFER-LC project’s framework were tested and studied at eight different sites, located in seven cities of four different European countries. Each site is classified either as a driving simulator, a test-track with controlled conditions or a real railway environment, as shown in Table 7.

Table 7. Overview of the SAFER-LC pilot sites.

Location	Pilot site classification	Tested measures
Braunschweig (Germany)	Driving simulator	↗ Blinking lights drawing driver attention ↗ Improved train visibility using lights ↗ Noise-producing pavement ↗ Sign ‘Look for train’
Chalon-sur-Saône (France)	Driving simulator	↗ Coloured road marking ↗ Funnel effect pylons ↗ Rings ↗ Traffic lights ↗ Speed bump and flashing posts ↗ Proximity message via in-car device
Tampere (Finland)	Two driving simulation environments & test-track	↗ V2X messaging system between automated vehicles (AVs) and passive LCs
Aachen (Germany)	Test-track	↗ Smart detection system ↗ Early detection and hazard information ↗ Smart communication system 1 ↗ Smart communication system 2
Rouen (France)	Test-track	↗ Monitoring and remote maintenance
Sääksjärvi (Finland)	Real rail environment	↗ Additional warning light system at front of the locomotive
Thessaloniki (Greece)	Real rail environment	↗ In-vehicle train and LC proximity warning
Braunschweig (Germany)	Real rail environment	↗ Blinking amber light with train symbol ↗ Road marking “<-Is a train coming?->

Figure 3 - Test sites and project partners leading the activities.

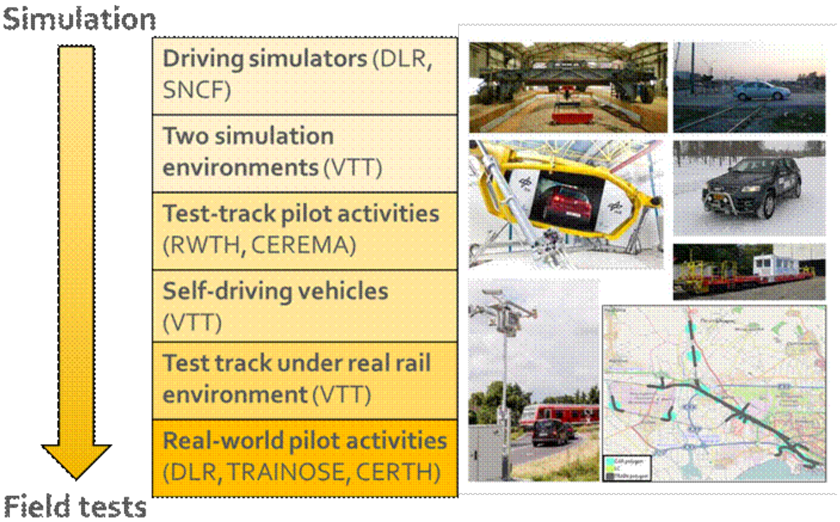
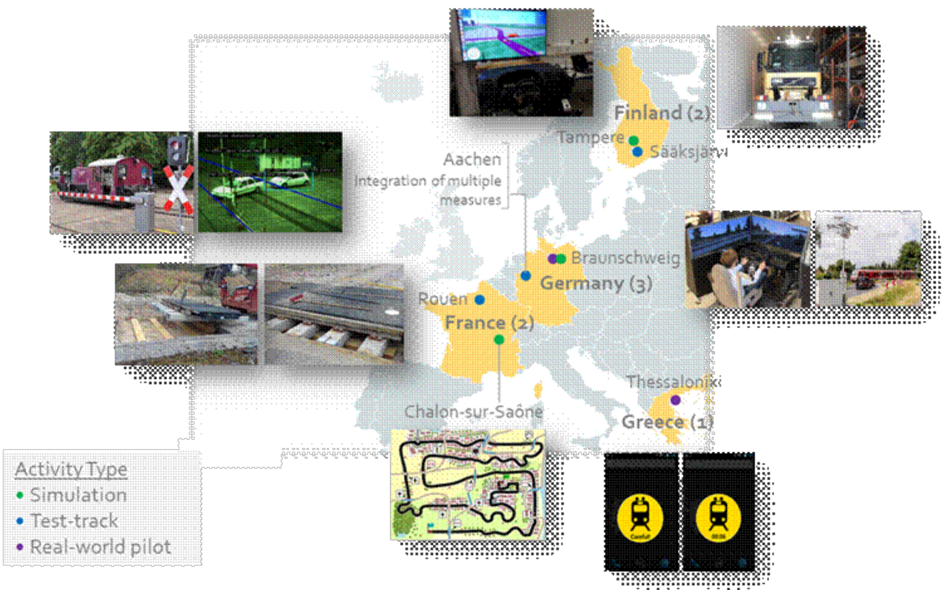


Figure 4 - Overview of test sites, locations and type of activity.



6. SOME EXAMPLES OF SAFETY MEASURES

6.1. BLINKING LIGHTS ON LOCOMOTIVE

Description: This system enhances the detection of a train by road users especially at passive LCs. Additional blinking lights are installed to the train according to the prevailing regulations (e.g. below the head lights). The blinking lights activate automatically at a set distance from the LC and shut down when the LC has been passed. A technical prototype consisting of three high-intensity LED lights was developed and tested in a real rail environment and in a driving simulator.

Targeted users	☑ **MRU** ☑ **VRU**
Type of implementation	☐ Road user ☐ Road infrastructure ☑ **Rolling stock** ☐ Rail infrastructure
Type of Level crossing	☑ **Passive** ☐ Light and/or Sound ☐ Half Barrier ☐ Full Barrier
Effect mechanism	☑ **Improves the detection of train**
Environment	☑ **Rural** ☑ **Urban**
Cost	☑ **Low (< 10 K€ per LC)** ☐ Medium (10 K€ to 100 K€ per LC) ☐ High (> 100 K€ per LC)
Cost (per LC)	☑ **Low** ☐ medium ☐ high
Evaluation studies	SAFER-LC: ☑ **field test** ☑ **simulation**

Potential benefits: Road users often cross passive LCs without having visually checked before whether a train is approaching (Grippenkoven & Dietsch, 2015). The blinking lights were estimated to improve visibility and detectability of trains as well as level crossing safety. The blinking lights appear to be a promising way to increase the detectability of approaching trains, especially in daytime conditions. The system takes advantage of an autonomous physiological mechanism, and therefore does not require any conscious effort of the road user to be effective. Moreover, the detection of blinking lights should not be subject to any considerable habituation effects, as the attraction of attention by flickering peripheral stimuli is a hard-wired feature of the nervous system that evolved because it represented an evolutionary advantage.

Potential criticalities: The blinking lights may be disturbing or could cause glare. Concerns on misinterpreting the flashing lights were also raised. The blinking lights were considered potentially disturbing or misleading especially in the night-time conditions. This could be addressed, e.g. by focusing the lights and adapting them to the prevalent lighting conditions. More research on this is needed.

Study results: The evaluation of pilot test in a real rail environment was carried out based on videos filmed during the pilot testing. The assessment of the videos was carried out with a web-based questionnaire directed to rail and road transport experts connected to the SAFER-LC project and to non-experts of the local university. Three alternative light configurations were compared to the standardly used reference configuration, both in daytime and night-time conditions. The pilot test in the driving simulator examined the effects of the blinking light on driver attention and behaviour, based on eye-tracking data and the driving speeds. The test also included a subjective judgement of the measure based on six-point Likert scales.

Based on the judgements on video data, the videos with the blinking lights were evaluated as better than the regular headlights. In daytime conditions, the experts clearly preferred the warnings lights with three consecutive blinks followed by a 3-s break (instead single blink every 1 s or double blink in every 2 s). In the night-time condition, none of the configurations was clearly preferred. The results suggest that the blinking lights caused more glare or were more disturbing during darkness. Also, in the night-time the train can be easily detected even without blinking lights. Among non-experts, the configuration 3 (triple blink every 3 s) was most preferred both in the daytime and in the night-time, but the configuration 2 (double blink every 2 s) was also popular.

Based on the questionnaire results, the blinking lights appear to be a promising way to increase the detectability of approaching trains, especially under daytime conditions. During darkness, the flashing lights might be disturbing or misleading. While blinking lights may improve detection of approaching trains, the results do not clearly show any influence on the reported crossing margins (the time at which road users would not cross the rails anymore).

The subjective ratings of the participants in the driving simulator study are in line with the subjective ratings of the video survey. Participants recognised the safety potential of the blinking lights mounted at the locomotive and estimated that this system supports an early detection of approaching trains. Specifically, the participants in the simulator study detected the train that was equipped with blinking lights earlier than the train with the regular headlights. Due to the earlier detection, the approach speed of the vehicle was reduced earlier as well.

Result of the Cost Benefit Analysis: “Blinking lights on locomotive” requires a low-cost initial investment of 40.000€ for the scenario of equipping 20 trains and a net benefit of either 58.980,65€ per year on the potentially prevented LC accidents scenario of 20%. The NPV of the solution was calculated in a 5-year basis. Therefore, the additional cost for the initial investment is low to medium and the annual depreciation amount, too. The NPV was calculated at 143,733.72€. The BCR (benefit-cost ratio) was calculated 1.72 which is greater than 1 and therefore the investment is beneficial for the users.

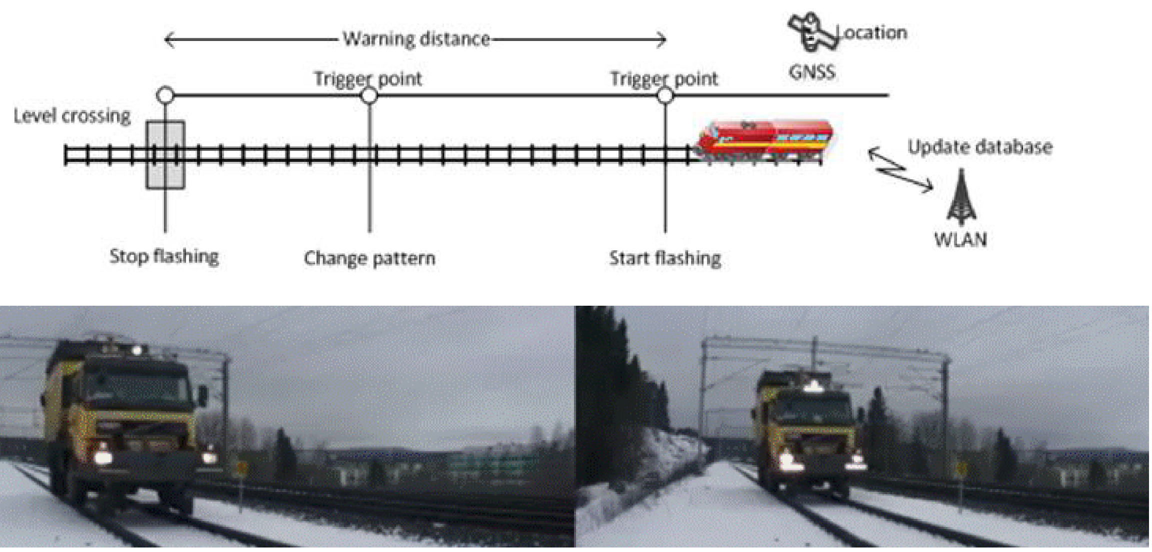


Figure 5 - Blinking lights on locomotive

6.2. PERIPHERAL BLINKING LIGHTS

Description: The "Peripheral blinking lights (PeriLight)" are a system to enhance the detection of approaching trains in road users at passive LCs. Two lights located near the tracks to the left and right of the road start blinking when a road user passes an in-road sensor on approach to the LC. The blinking lights appear in the periphery of the road user's visual field. This triggers an automatic and effortless visual orientation reaction in the road user towards the peripheral regions of the level crossing that need to be visually scanned to detect a train (exogenous attraction of attention; Yantis, 2000). A prototype of the system has been successfully tested in a real-traffic environment (Grippenkoven et al., 2016).

Targeted users	☑ **MRU** ☑ **VRU**
Type of implementation	☐ Road user ☐ Road infrastructure ☐ Rolling stock ☑ **Rail infrastructure**
Type of Level crossing	☑ **Passive** ☐ Light and/or Sound ☐ Half Barrier ☐ Full Barrier
Effect mechanism	☑ **Improves the detection of train**
Environment	☑ **Rural** ☑ **Urban**
Cost	☑ **Low (< 10 K€ per LC)** ☐ Medium (10 K€ to 100 K€ per LC) ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☑ **field test** ☑ **simulation** Other study: ☑ **field test** ☐ simulation

Potential benefits: Road users often cross passive LCs without having visually checked before whether a train is approaching (Grippenkoven & Dietsch, 2015). In a study examining car drivers' eye movements in a real traffic environment at a conventional passive LC, Grippenkoven et al. (2016) found that only a share as low as 27 % and 50 % of drivers looked out to the left and right, respectively, before crossing the tracks in daytime. At night, the shares were even lower overall (29 % and 35 %). With peripheral blinking lights in operation, visual checking behaviour is greatly increased (see section study results). As the system takes advantage of an autonomous physiological mechanism, it does not require any conscious effort of the road user to be effective. When the angle between road and rail tracks is not perpendicular, the measure should be even more effective, as long as the blinking lights appear within the maximum field of vision that extends up to 110° to the left and right from the central axis of the visual field. Moreover, as the attraction of attention by flickering peripheral stimuli is a hard-wired feature of the nervous system that evolved because it represented an evolutionary advantage, the reaction is unlikely to be subject to any considerable habituation effects. On the implementation side, as the measure is actuated through road users, it requires no connection to the railway signalling system and therefore needs no validation according to railway standards, which allows an easy and low-cost application.

Potential criticalities: For effective and hassle-free operation, the design and application of the measure need to take the conditions at a given LC into consideration. Criticalities that could arise from a neglect of a systemic view involve potential glare or disturbance of residents living nearby due to light emission at night. These issues can be prevented by appropriate design and application (e.g. using shading equipment, adapting the light intensity to the environmental lighting conditions). The applicability of the measure is of course restricted to situations that provide the minimum necessary sight conditions; i.e., the measure cannot be applied when heavy vegetation, buildings or other objects cover the view on the tracks. However, as road and rail regulations allow passive protection only at LCs where it is possible in principle to visually detect an approaching train in time, these restrictions will typically not apply to the envisaged application environments to an extent that would render the measure ineffective.

Study results: In SAFER-LC, the measure was tested in a driving simulation study in relation to two other infrastructural solutions for passive LCs (rumble-strips and a sign <-Is a train coming?->; cf Silla et al., 2020). Compared to the baseline condition (passive LC without any additional safety measures), the proportion of participants who visually scanned the tracks once or more often on LC approach increased from 65 % to 84 % on the left, and from 46 % to 65 % on the right side when the PeriLight was applied. With these results, it proved to be the most effective of the measures tested with regard to gaze behaviour. The PeriLight was also the only infrastructural measure for which a speed reduction was observed on LC approach. It gained high participant ratings on perceived usefulness to prevent LC accidents and moderate to high ratings on ease-of-use dimensions

For methodological reasons, the simulation environment involved an optimal LC approach (straight and flat road, 90° approach angle, no other traffic, very good sight conditions). Therefore, the rates of looking behaviour observed especially in the baseline condition are likely to be higher than they would be on average in a real traffic environment where sight conditions are typically less optimal (e.g. due to approach angle, weather, vegetation etc.). This circumstance likely makes the simulator test more conservative, i.e., it makes it harder for the measures tested to cause large effects in behaviour, compared to a real traffic environment. This assumption is corroborated by findings of Grippenkoven et al. (2016), who tested the peripheral blinking lights in a real traffic environment. By day, the share of drivers who looked to the left and right at least once on LC approach, was increased from 27 % to 73 % on the left, and from 50 % to 73 % on the right side when the measure was active, compared to the baseline. At night, the effects were even larger, with an increase from 29 % to 88 % on the left, and from 35 % to 88 % on the right side. Thus, the measure is expected to be even more effective under realistic and less optimal environmental conditions.

Result of the Cost Benefit Analysis: “Peripheral blinking lights” was estimated to require an initial investment of 400,000€ for the scenario of 100 LCs equipped and yield a benefit of either 23,220.16€ or 58,980.65€ per year depending on the potentially prevented LC accidents (low and high effect scenario of 5% and 20% reduction). The NPV of the solution was calculated on a 10-year basis and remained negative (-281,248.74€) for a small effect assumed, but becomes positive (39,972.94€) when assuming a strong safety effect. The cost for the initial investment is low and the annual depreciation amount, too. The BCR (benefit-cost ratio) was calculated as 0.46 and 1.18 in the two scenarios, respectively. Therefore, the investment can be characterised as economically beneficial when assuming high effectivity.

Figure 6 - The Peripheral blinking lights (PeriLight)

6.3. IN-VEHICLE LC AND TRAIN PROXIMITY WARNING

Description: The "In-vehicle LC and train proximity warning" safety solution is offered as 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 auditory 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 the next minute.

Targeted users	☑ **MRU** ☐ VRU
Type of implementation	☑ **Road user** ☐ Road infrastructure ☐ Rolling stock ☑ **Rail infrastructure**
Type of Level crossing	☑ **Passive** ☑ **Light and/or Sound** ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Improves the detection of train**
Environment	☑ **Rural** ☑ **Urban**
Cost	☐ Low (< 10 K€ per LC) ☑ **Medium (10 K€ to 100 K€ per LC)** ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☑ **field test** ☐ simulation

Potential benefits: The system is expected to mainly contribute to increasing safety at passive crossings 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, in real time, information about the existence and status of nearby level crossings.

Potential criticalities: The alert system can be used for all types of LCs, regardless of existing safety infrastructure. The estimated time of train arrival is only available when the moving trains are equipped with common tracking devices, in other cases the driver will receive the LC warning without further information on train proximity. The measure's applicability 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 activated location tracking on the end users' device. A final technical comment is that the non-professional, commercial tracking equipment utilized (smart mobile devices) is not purpose-built and cannot guarantee totally fail-safe operation. Location tracking accuracy and availability might cause the system to not operate as intended in certain environments or during unexpected events. Concerning the effects on road user behaviour, the design of the warning should be suitable to avoid distraction of visual attention from the road. No data are available yet concerning long-term effects and potential habituation.

Study results: The measure was tested in real-world conditions for several months by a demanding audience - professional drivers of more than 600 taxis.

User feedback was acquired after a survey study with three phases; before, during and after the test period. The responses were overall encouraging for all study criteria, including the detection and identification of LCs, rule knowledge, behavioural execution, user experience and social perception.

Positive results were reached by analysing probe vehicular data, as certain safety indicators (e.g. the mean vehicle speed when the distance from the rail is between 5 to 15 meters) were improved during the tests.

Geo-location sensors embedded in common mobile devices and gadgets have sufficient accuracy and therefore offer a high-penetration platform as a basis for large scale deployment.

Tracking trains with on board units enables highly accurate estimation of time of arrival at LCs

Result of the Cost Benefit Analysis: "In-vehicle LC and train proximity warning" needs an initial investment of 198,000€ in the scenario tested (95 trains equipped and 100 LCs connected). The net benefits (benefits-costs) distributed annually can be either 35,140.32€ or 47,060.49€ depending on the scenario. The NPV of the solution was calculated in a 5-year basis. In this case, the additional cost for the initial investment is medium and the depreciation amount, too. The NPV was calculated either -45,565.16€ or 10,620.03€ with the different benefits scenarios (10% and 15% safety reduction). The BCR (benefit-cost ratio) was calculated 0.83 and 1.11 in the two scenarios which is greater than 1 in the second scenario and therefore the investment can be beneficial for the users.

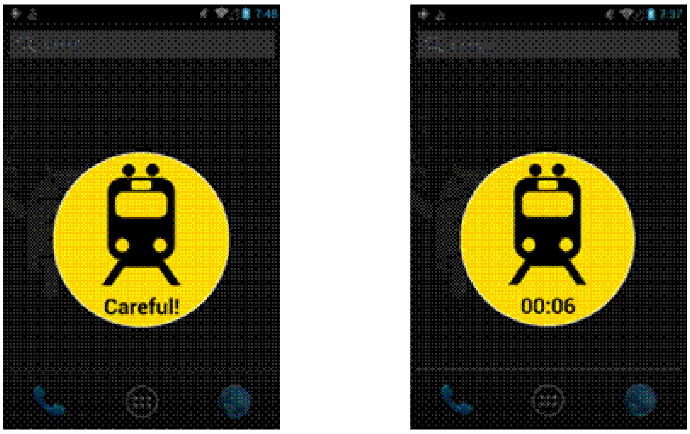


Figure 7 - The static visual LC warning (left) and the dynamic warning when the train is estimated to reach the LC in six seconds (right)

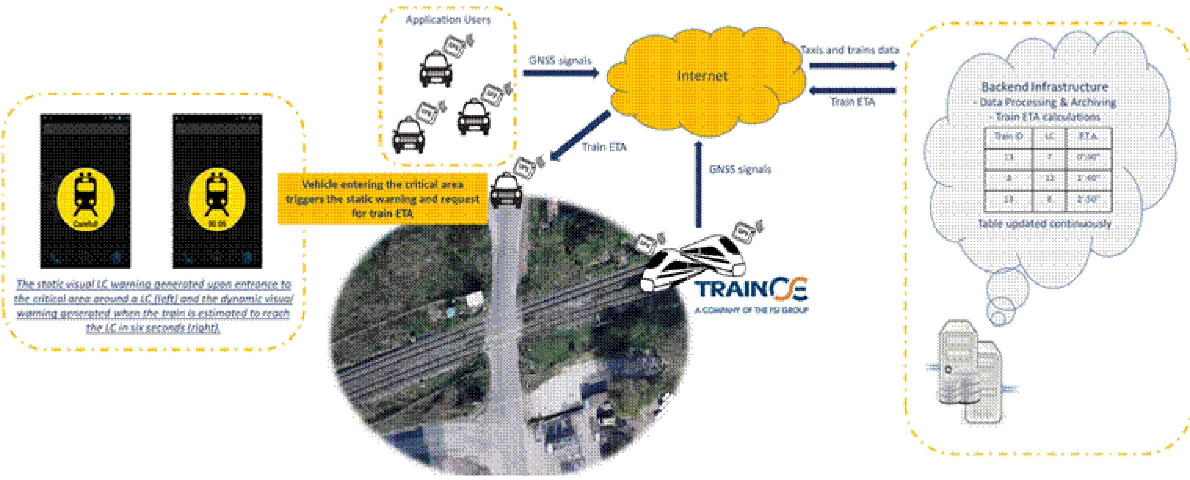


Figure 8 - The safety system's architecture

6.4. REMOTE MONITORING FOR PREDICTIVE MAINTENANCE

Description: This LC safety measure monitors the condition of LC infrastructure to ensure its safety performance by detecting potentially dangerous deteriorations. It utilizes several devices, for instance seismic sensors, photogrammetric systems and infrared thermography installed either on the track or road. The continuous and real time monitoring is feasible with the following two approaches:

- Using smart and embedded wireless sensor networks. Vibration and temperature sensors are installed on the relevant track/road components and data are transmitted with an alert threshold to the LC operator. The system also enables sending alerts to LC users.
- Using a photogrammetric device to monitor infrastructure surface condition and to detect any deterioration of the structure. This system could also measure displacement and deterioration of the road surface. In addition, the visible information combined with thermal infrared data enhances the interpretations of the potential disorders as fissuration. High permeability zones generated a thermal anomaly of several degrees.

Targeted users	☑ **MRU** ☐ VRU
Type of implementation	☐ Road user ☑ **Road infrastructure** ☐ Rolling stock ☑ **Rail infrastructure**
Type of Level crossing	☑ **Passive** ☑ **Light and/or Sound** ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Support LC safety action**
Environment	☑ **Rural** ☑ **Urban**
Cost	☐ Low (< 10 K€ per LC) ☑ **Medium (10 K€ to 100 K€ per LC)** ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☑ **field test** ☐ simulation

Potential benefits: This measure aims to detect infrastructure conditions and deteriorations of its structure, in order 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. Some railway managers already use topographic sections with a lower level of precision; thus, the photogrammetric method is expected to improve the detection of potentially dangerous changes in the infrastructure.

Potential criticalities: The photogrammetric method 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.

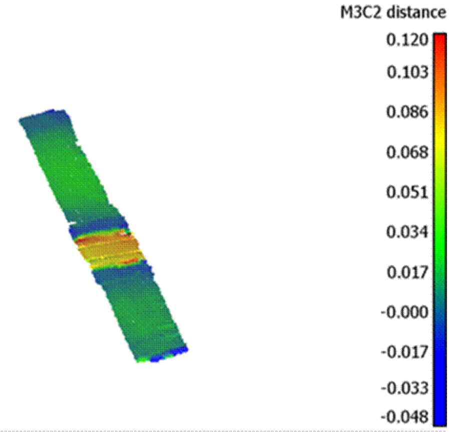
The fixed accelerometers vibratory method requires to instrument the LC and to set up a communication device with a control post, which carries a relatively high cost of deployment.

The vibratory method with the on-board accelerometers necessitates to set acceleration thresholds beyond which geometry measurements must be made on the LC in order to confirm the level of deterioration.

In all cases, on-sight measurement campaigns should be organized.

Study results: the different monitoring techniques were tested and evaluated on a level crossing mockup installed in Rouen. The results are positive; however, each technique has different characteristics, advantages and disadvantages. Therefore, the following recommendations should be considered to optimize future implementation:

- Photogrammetry is suitable for periodic monitoring with adjustable measurement accuracy. The measurement device carries a low cost.
- Fixed accelerometers carry higher implementation and exploitation cost, which is justified when real time monitoring of LC evolution is needed.
- Mobile accelerometers are cheaper than photogrammetry and suitable for periodic monitoring, but require additional measurements after detecting the threshold overshoot.
- Infrared thermography is justified only by the need for early detection of cracks in the transition zone between the railway and the road structure.



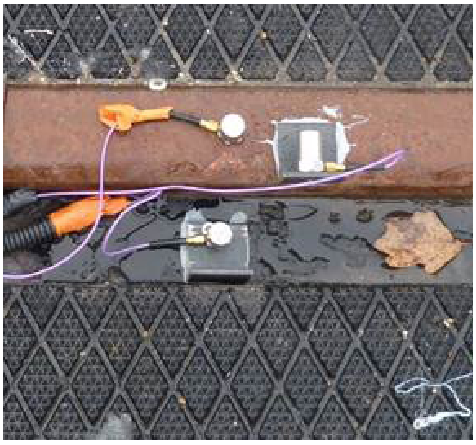


Figure 9 - Example of 3D photogrammetric model comparison – model bump 0 and 7 cm	**Figure 10 - Installed accelerometers**.

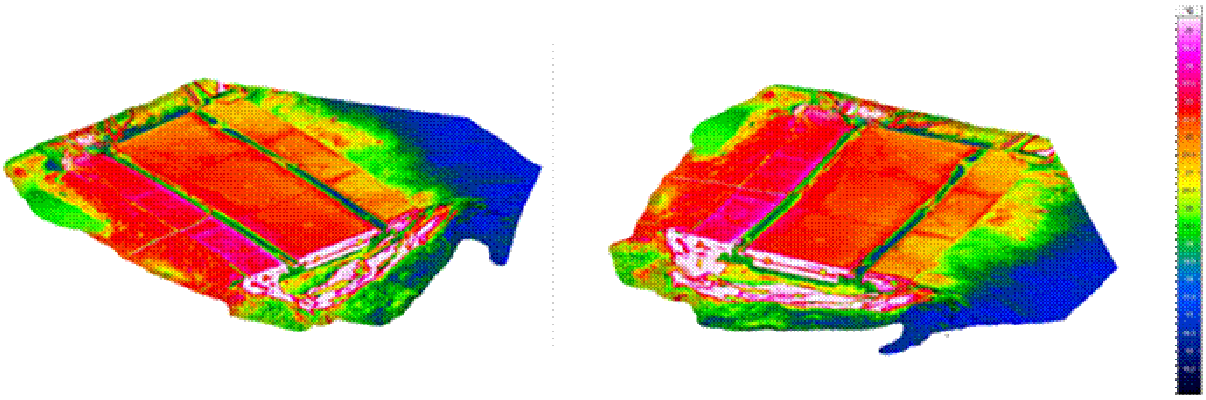


Figure 11 - Different views of the general 3D temperature map of the LC using the thermogram metric method.

6.5. SMART DETECTION SYSTEM (SDS)

Description: The "Smart Detection System (SDS)" is a warning system based on intelligent video detection of potentially dangerous situations occurring at LCs. An optimized Automatic Incident Detection is specified, implemented, and evaluated. The SDS allows for the accurate detection of hazardous events and localization of obstacles which are blocking the LC and that could jeopardize the safety of users especially vulnerable users.

The global architecture of the system used for the final test is represented below. It includes the smart detection system and the smart Roadside Unit with an interface which is able to send information to surroundings cars or to the train. The interface is connected also to a communication system:

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

The RSU receives all the information: events detected by the SDS, the corresponding video flow, the state of the lights, the state of the barriers. Then the principle is the following. According to the status of the lights and the status of the barriers, the RSU is choosing the adequate alerts to send to the control room or to the Onboard Unit installed in cars. Every alert sent to the control room is accompanied by the related piece of video.

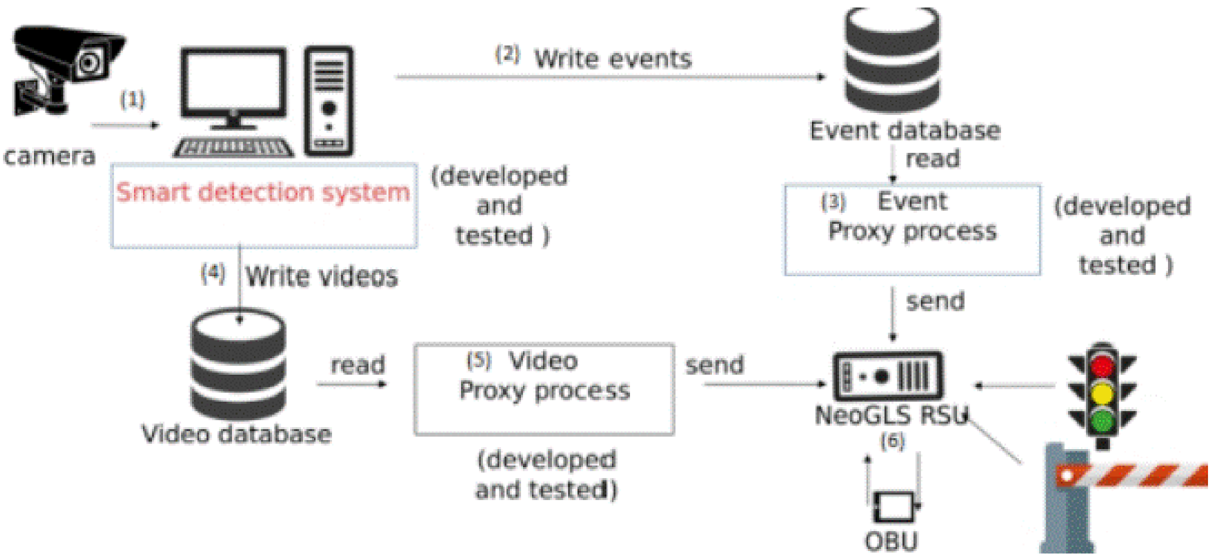


Figure 12 - Interaction of SDS with NeoGLS and IFSTTAR systems

Targeted users	☑ **MRU** ☑ **VRU**
Type of implementation	☐ Road user ☑ **Road infrastructure** ☐ Rolling stock ☑ **Rail infrastructure**
Type of Level crossing	☐ Passive ☐ Light and/or Sound ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Provides up-to-date information about the status of LC**
Environment	☑ **Rural** ☑ **Urban**
Cost	☐ Low (< 10 K€ per LC) ☑ **Medium (10 K€ to 100 K€ per LC)** ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☑ **field test** ☐ simulation

Potential benefits: An Intelligent Level-Crossing is a system which integrates functions of modern 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.

Potential criticalities: The video-based systems need to be evaluated in a long-term manner. A very good perspective could be to obtain from the railway companies the authorization to test a video imaging and communication systems during real exploitation periods. If we manage to do that, we will be able to measure the impact of these technologies on the improvements of safety at level crossings.

Study results: Good ability to detect events. The global events detection performance is around 84 % There is no real influence of the weather conditions on the ability to detect or recognize except when the illumination is very low. The results achieved are valid according with the limit of the datasets processed; these datasets being limited.

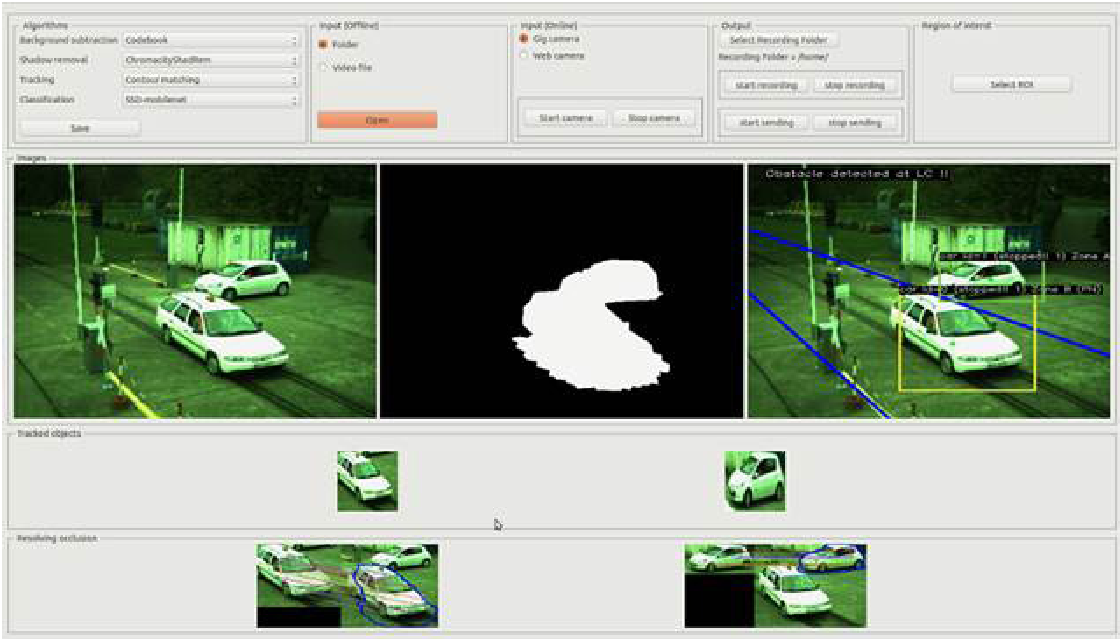


Figure 13 - User interface of the SDS

6.6. SPEED BUMPS AND FLASHING POSTS

Description: This safety measure consists of two parts: speed bumps and flashing posts located at 150, 100 and 50 m from the LC. The flashing posts are each equipped with three red LED lamps which flash in alternating flicker. The posts are located on the right edge of the road. In addition, the interior lines on the bump generate awareness sound at their crossing. The number of interior lines on each bump depends of its location from the LC (1, 2 or 3 lines). The objective of this measure is to improve visibility and detectability of an LC in order to improve the vigilance of drivers as they approach the LC and reduce driver speed.

Targeted users	☑ **VRU**
Type of implementation	☐ Road user ☑ **Road infrastructure** ☐ Rolling stock ☐ Rail infrastructure
Type of Level crossing	☑ **Passive** ☑ **Light and/or Sound** ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Reduces the approach speed of vehicles** ☑ **Improves the detection of LC**
Environment	☑ **Rural** ☑ **Urban**
Cost	☑ **Low (< 10 K€ per LC)** ☐ Medium (10 K€ to 100 K€ per LC) ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☐ field test ☑ **simulation**

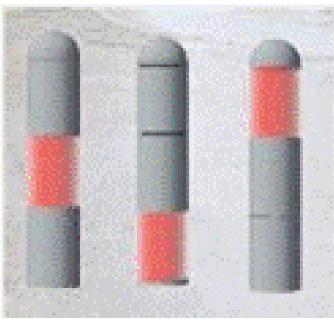
Potential benefits: Reduces LC approach speeds and hence improves the possibilities for the car driver to stop before the railway if needed.

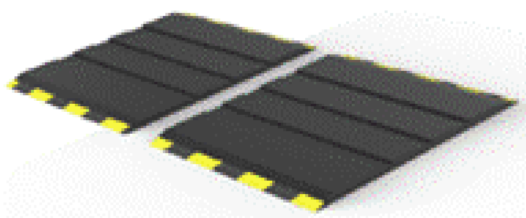
Potential criticalities:

- Speed bumps can be considered uncomfortable and they might be dangerous for motorcycles.
- They can enhance noise pollution, especially in unloaded trucks and tractors (proportion should be checked before implementation)
- According to a Finnish study (Seise et al. 2009) roughly half of the people who live near the LC equipped with speed bumps and use it frequently considered speed bumps very unpleasant, while the other half did not see any significant disadvantages.
- Due to the potentially poor road user acceptance of this speed calming measure, their attention may not be so directed towards safety signage or safe actions, but toward feeling frustrated or on how to avoid the bumps

Study results: over half of the subjects who participated in testing 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 flashing posts. Additionally, some subjects expressed their animosity regarding speed bumps. Speed bumps were considered dangerous for motorcycles and generally uncomfortable. The participants also noted that this safety measure should be accompanied by a sign announcing the bumps to avoid dangerous situations with sudden braking.

Figure 14 - Speed bumps and flashing posts





6.7. SHARING INFORMATION ABOUT LC STATUS

Description: The smart communication systems allow sharing information concerning the Level crossing LC status between LC, control room, train and road drivers. The smart communication system is realized using the communication technology (ITS-G5, LTE) and the new Cooperative Perception Messages (CPM)

ITS G5 standards defines the facilities layer which specifies requirements and functions supporting applications, communication, and information maintenance. Its most relevant standards cover messaging for ITS applications, such as CAM and DENM.

Cooperative Awareness Message (CAM) is a periodic message exchanged between ITS stations to maintain awareness of each other and support cooperative performance of vehicles. It is composed of several containers; the basic container conveys the station type and its position. Decentralized Environmental Notification Message (DENM) is an event driven safety information, exchanged in a specific geographical area surrounding the event. When an ITS station detects a dangerous situation, a DENM message is generated defining the specific event, its detecting ITS station, its lifetime and relevance area, among many others.

Collective Perception (CP) is the concept of actively exchanging information about locally perceived objects in the traffic environment between participants by means of advanced V2X communication technology. Perception is based on sensor data, provided by on-board and infrastructure sensors e.g., cameras, such as the one included in SDS, intersection surveillance systems, radars, lidars and other information sources. Collective Perception Service (CPS) is a novel V2X service which aims at disseminating this sensory information by letting vehicles and road infrastructure elements transmit data about detected objects (e.g., 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. SAFER-LC provided excellent conditions for field testing CP enabled V2X services whose standardization is currently ongoing at ETSI ITS.

Targeted users	☑ **MRU** ☑ **VRU**
Type of implementation	☐ Road user ☑ **Road infrastructure** ☑ **Rolling stock** ☑ **Rail infrastructure**
Type of Level crossing	☑ **Passive** ☑ **Light and/or Sound** ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Provides up-to-date information about the status of LC**
Environment	☑ **Rural** ☑ **Urban**
Cost	☐ Low (< 10 K€ per LC) ☑ **Medium (10 K€ to 100 K€ per LC)** ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☑ **field test** ☐ simulation

Potential benefits: the smart communication system allows:

- To transmit the incident information and its position to the road users
- To share information concerning the LC statue to trains/vehicles drivers approaching/arriving to level crossings and to workers at or near train passing zones.
- To inform all vehicle approaching to LC using multi hope approach: this approach allows to increase the range communication.

CPS decreases the ambient uncertainty of ITS communication stations by contributing information to their Field-of-Views, mutually, which may result in the improvement of the following collective safety capabilities:

1. Detection of not connected road users: Road users, typically not V2X capable and Vulnerable Road Users (VRUs), which are not able to signal their presence can be perceived by other road users' perception sensors.

2. Detection of safety incidents: there may be not wanted objects on the road or its immediate environment causing a potential safety risk for the traffic and the road users themselves. Road users which are not equipped with sensors or whose sensors are not able to detect non desirable objects locally are prone to accidents and represent a risk for the traffic.

3. Increased awareness: Information aggregation about the behaviour of other traffic participants in real time increases awareness of drivers.

Potential criticalities: Sensor data fusion and the overall concept of message dissemination are critical part of the mechanism which influence the performance of the whole V2X ecosystem. The evaluation of the results of field test trials, such as provided by SAFER-LC test sites, effectively contribute to the completion of the idea which can be utilized for the finalisation of the standards.

Study results: In the SAFER-LC project, ITS G5 communication systems was tested and evaluated in different scenarios in Aachen site. These testes show that these solutions respond according to the restrictions imposed by application. The methodology and key performance indicators (KPI) of these communication technologies were defined. The project provided excellent conditions for field testing CP enabled V2X services whose standardization is currently ongoing at ETSI ITS.

CPS was also extensively tested and evaluated in different LC traffic scenarios in the SAFER-LC field test environment Aachen. It was shown that CPS can effectively be used not only in native road environment but in intersection scenarios shared with rail systems and as such, the evaluation results will be disseminated in wide technology domains involving the design and harmonization of future rail-road communications.

The architectures of the smart communication developed in SAFER-LC context is given below.

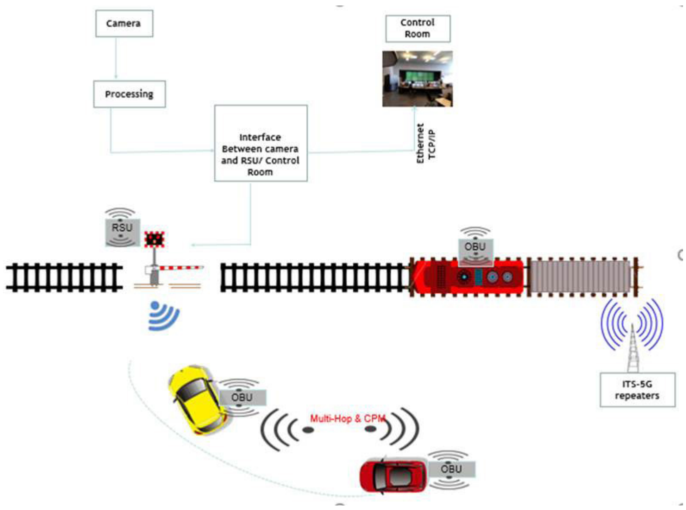


Figure 15 - Architecture of the measure developed based on ITS-G5: Detection of the incident and transmission to the room control

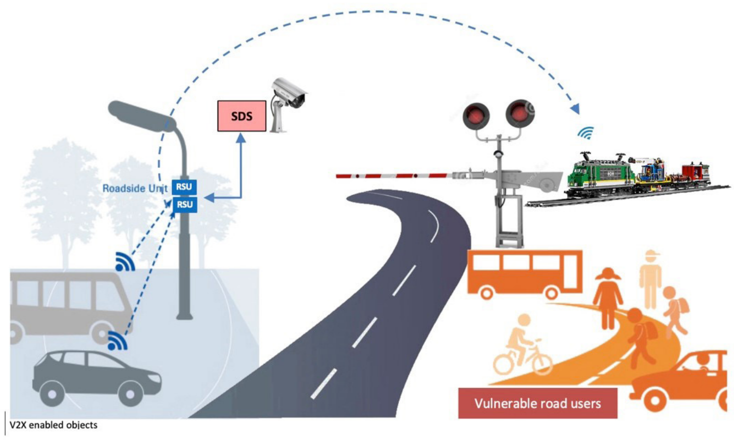


Figure 16 - Architecture of the measure developed based on ITS-G5: Detection of the incident and transmission to train driver

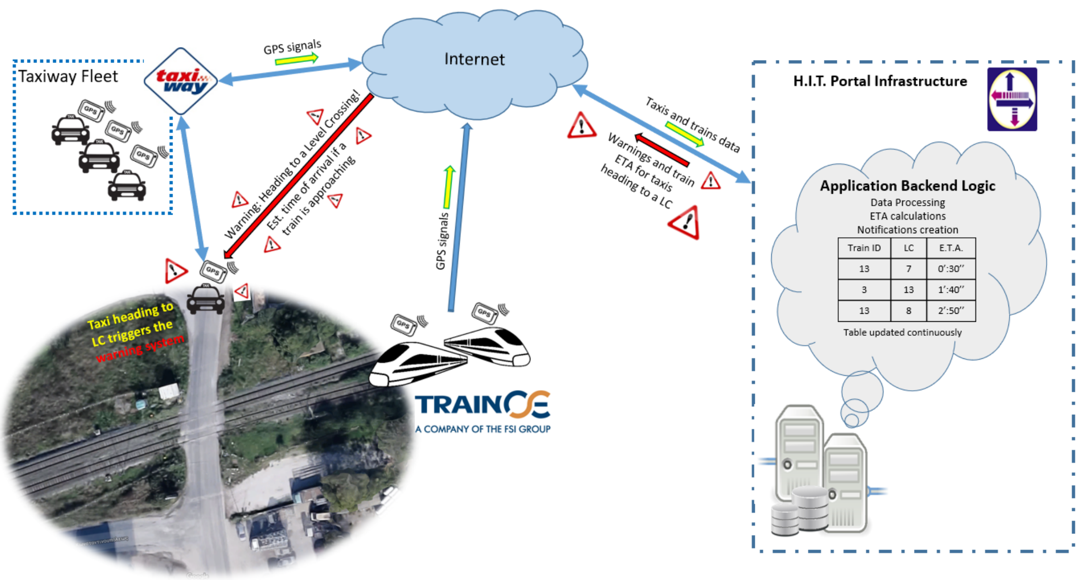


Figure 17 - Architecture of the measure developed based on LTE - Detection of the train and transmission to the road users

6.8. LC RISK ASSESSMENT USING VIDEO ANALYSIS AND MACHINE LEARNING

Description: This measure is a software application that analyses video recordings of level crossings and their surroundings, and extracts data about the occurrence of dangerous and/or anomalous behaviours. This analysis is performed off-line in a semi-supervised fashion and focuses on general motion, i.e., the analysis operates on space-time trajectories instead of directly analysing the images to recognize activities. The system builds a database of detected dangerous events and can export them in a format allowing a human operator to evaluate the dangerousness of the observed level crossings, calculate statistics and monitor the evolution of these events over time. It can also be used to evaluate the effectiveness of other safety measures implemented on the level crossings, by monitoring the evolution of the number and types of dangerous behaviours that occur before and after the implementation of the measures.

Targeted users	☑ **MRU** ☑ **VRU**
Type of implementation	☐ Road user ☑ **Road infrastructure** ☐ Rolling stock ☐ Rail infrastructure
Type of Level crossing	☐ Passive ☑ **Light and/or Sound** ☑ **Half Barrier** ☑ **Full Barrier**
Effect mechanism	☑ **Support LC safety action**
Environment	☑ **Rural** ☑ **Urban**
Cost	☑ **Low (< 10 K€ per LC)** ☐ Medium (10 K€ to 100 K€ per LC) ☐ High (> 100 K€ per LC)
Evaluation studies	SAFER-LC: ☐ field test ☑ **simulation**

Potential benefits

- Extracting data about the occurrence of dangerous and/or anomalous behaviors
- Evaluating the effectiveness of other safety measures

Potential criticalities

- Malfunction of the light system on a LC with no barrier will make the system ignore some dangerous events
- Data collection during night-time requires an infrared camera and the training of specific vehicle/pedestrian and barrier detectors

Study results

- Performance of the system was evaluated on a set of synthetic videos that were generated from an advanced simulator that combines lighting and weather simulation, realistic vehicle dynamics and artificial intelligence-based driver behaviour.
- Dangerous activity detection accuracy reaches 92% for the set of six predefined activities in the dataset, under varying lighting and weather conditions.

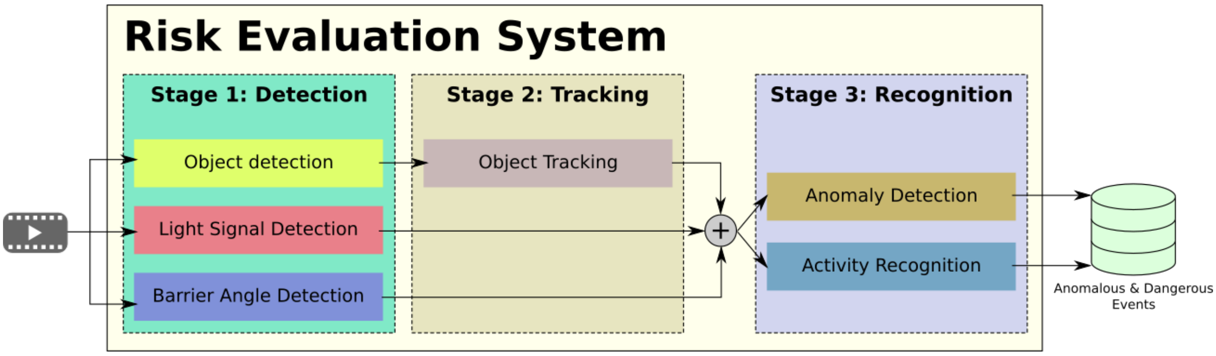


Figure 18 - Architecture of the risk assessment system

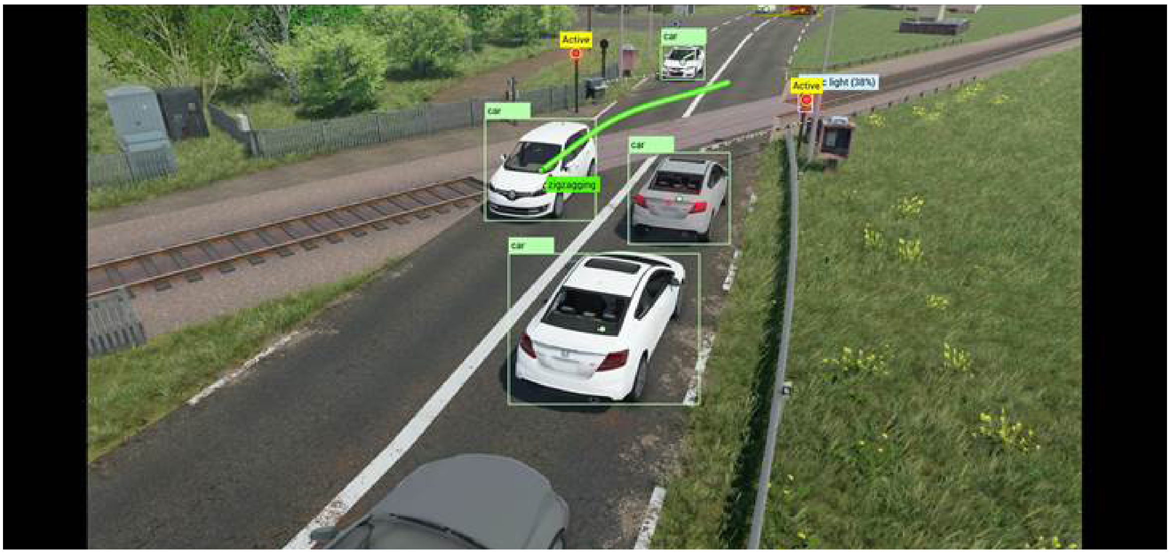


Figure 19 - User interface of the risk assessment system

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CONSORTIUM

17 partners from 12 countries

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Contact: Info@safer-lc.org
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Linked in : SAFER-LC