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

Deliverable D1.3

Needs and requirements for improving level crossing safety

Due date of deliverable: 31/12/2017

Actual submission date: 31/01/2018

Project details

Project acronym	SAFER-LC
Project full title	SAFER LC by integrating and optimizing road-rail infrastructure management and design
Grant Agreement no.	723205
Call ID and Topic	H2020-MG-2016-2017, Topic MG-3.4-2016
Project Timeframe	01/05/2017 – 30/04/2020
Duration	36 Months
Coordinator	UIC – Marie-Hélène Bonneau (bonneau@uic.org)

Document details

Title	**Needs and requirements for improving LC safety**
Work package	WP1
Date of the document	30/01/2018
Version of the document	08
Responsible partner	UIC
Reviewing partner	all
Status of the document	Final
Dissemination level	Public

Document history:

Revision	Date	Description
01	28/11/2017	First Draft
02	06/12/2017	Second draft including comments and contributions from WP1 partners
03	11/12/2017	Third draft including comments and contributions from WP1 partners during the 7th December web conference
04	08/01/2018	Final draft included comments from WP1 partners and discussions from December progress meeting in Aachen. To be reviewed by all participants before 23 January 2018
05	24/01/2018	Final draft reviewed by all participants
06	25/01/2018	Inclusion of the comments from WP3 and WP4 partners during the web conference held on the 25th January focussing on the scenarios
07	26/01/2018	Ethical review – Removing of the list of participants of the WS
08	30/01/2018	Final version ready to be submitted

Consortium - List of partners

Partner No	Short name	Name	Country
1	UIC	International Union of Railways	France
2	VTT	VTT Technical research centre of Finland Ltd	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 is the final output of SAFER-LC task 1.3 aiming at producing a list of needs and requirements which should be satisfied by LCs both during normal operations and degraded modes by also taking into consideration the digitalisation of railways.

The needs and requirements were identified through a mixed methodology which drew on both, primary and secondary information sources: the findings from previous tasks of SAFER-LC project (Tasks 1.1 and 1.2), the results of the Task 1.3 workshop on end-user's requirements, in-depth interviews with experts, and information gathered from the past SafeRail project.

Summary of the legal, organisational and technical requirements

At international level, a common framework exists in the form of non-mandatory treaties and recommended guidelines produced by international organizations and policy-making bodies such as the United Nations Economic Commission for Europe (UNECE), International Union of Railways (UIC) and the International Road Union (IRU).

At national level, each country follows a national legal framework which is mandatory and has its own policy options for LC safety. Based on the results of Task 1.1 the most important safety policy regarding the LC safety is removal or reduction of level crossings, followed by the improvement of the protection of existing level crossings. Other important policy is the organizational and strategic development. Furthermore, an additional policy is to raise public awareness around safety at level crossings, although it is indicated to be present in a smaller number of countries.

Organizational recommendations mostly concern the international cooperation and strategic partnerships, the design of LC safety, the safe operation of LCs, enforcement, the existence of dedicated government or independent LC safety body, and the safety arrangements attached to LCs.

From a technical point of view, there are series of standards produced by the CEN-CENELEC that are mandatory standards for several countries for any new product and system related to Railway Signalling Systems, including the LC context.

Lastly, the need of a harmonized accident database was identified and a general data model for LC accidents database has been designed within Task 1.3. This data model describes in a standardized way, the type and format of data to be collected to enable a more in-depth analysis of LC accidents in Europe.

Summary of end-user's requirements

Based on the findings, the members of the consortium agreed on specific priorities to be addressed within the project. These priorities were divided under four topics: human factors, LC design, railway operations and innovative solutions. The specific issues to be focussed under each topic are presented in the following.

Priorities regarding **road user human factors**:

- Attention:
- Inattentiveness of the users: Pedestrians/cyclists with headphones or using smartphones, road drivers using smartphones or GPS
- Non-observation of the road signage and rail tracks by road users or pedestrians
- Understanding: Special focus on lack of signage or too many signage at LCs and the special needs of impaired people.
- Behaviour: Special focus on excessive speed of road vehicles and deliberate violations at active LCs

Priorities regarding **LC design**:

- Design of the LC: Curves before and after the LC, bumps, slopes and high declivity should be avoided; difficult especially for buses and trucks
- Location of the LCs: LC located, for example, too close to a road crossing or at proximity to commercial centres could generate long waiting queue at the LC (and could also cause so called blocking back effect)
- Protection of the LC based on a risk evaluation
- Easy access through and around LCs or under the barriers for pedestrians/cyclists

Priorities regarding **railway operations**:

- Vehicle stuck on the level crossing
- Long-time of LCs closure
- Failure on rail devices: detection of train, LC control system, etc.

Priorities regarding **innovative solutions** resulting from the above priorities:

- Risk assessment: Risks at LCs shall be regularly monitored to adapt the safety measures at LC
- Communication
- Road users shall be informed about a LC he/she is approaching
- Road users shall be informed about a train approaching at the LC
- The train driver shall be informed in advance about obstacles at the level crossing and
- The train shall break when an object is detected in the hazard zone of the LC
- Maintenance
- All subsystems of the level crossing shall be inspected, maintained and repaired according to the regulations.
- IM shall be alerted in case of foreseen failures
- The train driver shall be informed in advance about failures of the LC
- Design of the LC
- Road users shall be protected by technical means from entering the hazard zone if a train is approaching

- The level crossing activation period shall be as short as possible in order to maximize fluidity
- All traffic signs and similar communication for information and warning shall be unambiguous, easily understood and giving clear (positive) instructions for a Road User paying moderate attention
- The design of the LC shall be adapted for all type of vehicles
- Cost-effective safety measures shall be preferred

Summary of the proposed scenarios

Using the priorities listed above, several scenarios were built by the partners concerning risk assessment, smart detection system, optimized closure time of the barrier, early detection of failures on the LCs, and communication systems to be further developed in WP3 and WP4.

Overall, the needs and requirements as well as the scenarios described in this deliverable should be considered as a starting point for the next WPs in the SAFER-LC project and they will be progressively adjusted along the project workflow.

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1. INTRODUCTION

1.1 Objectives of SAFER-LC project

The main objective of the SAFER-LC project 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 design of LC infrastructure. These tools will enable

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

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

1.2 Purpose of this deliverable

This deliverable is the final output of Task 1.3 aiming at producing a list of needs and requirements which should be satisfied by LCs both during normal operations and degraded modes by also taking into consideration the digitalisation of railways.

The deliverable combines i) the findings from previous tasks (Tasks 1.1 and 1.2), ii) the results of the workshop on end-user's requirements, and iii) information gathered from the past SafeRail project.

Recommendations are produced regarding:

- Legal and organisational issues
- Database harmonization by defining variables which should be taken into consideration during LC accident data collection and documentation
- Technical aspects related to LC automation, management and maintenance

A summary of end users needs and requirements as well as highest risks at LCs identified within Task 1.3 will be the basis for future work in SAFER-LC project.

The last part of the document focuses on the definition of scenarios to be considered in the development of safety measures in WP2 and WP3 and to be tested and evaluated in WP4.

1.3 Acronyms and definitions

Acronyms

AC	Alternating current
DC	Direct current
EMC	Electromagnetic compatibility
ERTMS	European Rail Train Management System
ESA	European Space Agency
ETA	Expected Time of Arrival
LED	Light Emitting Diode
LC	Level crossing
GPS	Global Positioning System
GSM-R	Global System for Mobile communications - Railways
N	Need
PO	Policy option (could be interpreted as a course of action/practice)
R	Requirement (in our context, the requirement is not necessarily mandatory)
IM	Infrastructure Manager
POC	Proof Of Concept
RU	Railway Undertaking
RAMS	Reliability, Availability, Maintainability and Safety
RINF	ERA Register of Infrastructure
SDB	UIC Safety Database
SIL	Safety Integrity Level
TC	Traffic Control
UPS	Uninterruptible Power Supply

Definitions

Advanced approach zone	At a Level Crossing, this is the zone, before the Level Crossing is announced by traffic signs. This means anything far away until typical 240m before the Level Crossing.
Approach zone	At a Level Crossing, this is the zone, where Road Users receive (traditional road-side) information about the type of the level crossing and is state. The Road User also perceives in this area the environmental situation of the Level Crossing. The Road user must take a decision if he passes or stops.
Non-recovery zone	Given a certain speed of the Road User, the non-recovery zone starts with the point where the Road User must have decided to stop - braking later will not lead to stand still before the level crossing. This depends on the Road User Speed and can be some 50m if driving fast and slippery road surface.
Hazard zone	At a Level Crossing, the road section between the barriers – or, if no barriers are present - between the St Andrews Crosses. The hazard zone must be cleared at activation of the Level Crossing
Clearance zone	The clearance zone is, from the perspective of an approaching Road User, an area of the opposite side of the Level Crossing. The clearance zone describes the space necessary for the Road User to occupy once he has entirely left the hazard zone. The clearance zone is as long as the longest truck (20m), no stationing and no takeover is allowed.

SAFER-LC

2. METHODOLOGY

Within Task 1.3, a list of recommendations is identified employing a mixed methodology which drew on both primary and secondary information sources, as listed below.

- Review of documents

First a set of documents available was reviewed to identify the most relevant recommendations:

  - Analysis of Task 1.1 and 1.2 results in order to identify inputs for Task 1.3 most notably related to legal and organizational issues and database harmonization.
  - Review of international rules and regulations regarding safety at level crossings
  - Review of UIC safety database and other relevant LC safety and road safety databases to inform recommendations regarding database harmonization
  - Identification of technical standards to be applied by new product/system related to Railway Signalling Systems, including the LC context.

- End user workshop

Then, a workshop was organised to identify LC user requirements, high risk situations and behaviours at LCs that can lead to accidents at LCs. Around 40 participants from 12 countries attended the workshop which was held on 28 September 2017 at the headquarters of UIC. The participants included road and rail representatives (RUs, IMs, road administrations) from Belgium, Finland, France, Germany, Greece, Hungary, Italy, Norway, Spain, Sweden, Turkey and UK. During the morning session, rail and road perspectives regarding safety at LC were presented by Network rail (Rail IM in the UK) and Trafikverket (Swedish Transport Administration). During the afternoon, a brainstorming session was organised and dedicated to identify risky situations at LCs and/or situations leading to dangerous behaviours at LCs as well as to identify innovative solutions to prevent these risky situation and behaviours from occurring. The aim of this brainstorming session was to work on a questionnaire (Annex 1) in small groups (7–8 persons) to prioritise the identified risks at LCs, to identify new ones both from the road and the rail perspective, and to discuss on possible innovative solutions to minimise the occurrence of these risks. In addition, the participants were asked to assess the criticality of each identified risky situation (high/medium/low perceived risk).

Each group worked around one of the five tables which were animated by one member of the SAFER-LC consortium. At the end, the animators presented short summaries of the findings to all participants. This workshop enabled the collection of some valuable contributions from the participants.

- Interviews and meetings

In addition, some interviews were held at UIC (with the safety unit manager and the rail system department director) and IRU to complement the results of the workshop on the needs and requirements from the road and rail perspective.

Based on the results of the review, workshop and interviews, several meetings were organised with the members of the consortium to identify and describe the scenarios that could considered be in WP3 and WP4.

3. LEGAL RECOMMENDATIONS

The objective of this section is to give an overview on the legal and policy context on LC in Europe. On the one hand, this may help other SAFER-LC work packages to understand the legal and policy context on LCs when developing innovative measures.

On the other hand, the identified recommendations can act as requirements or priorities to be aligned with or to be contributed towards the measures developed in SAFER-LC.

Based on a thorough cross-country analysis of adherence to international rules and national LC safety policy frameworks conducted in task 1.1, this section summarizes recommendations for

- National and international legislation for the safe design, operation and management of LCs (subchapters 3.1 and 3.2).
- Organizational aspects of safety in LCs in terms of roles and responsibilities for the design, operation, management and rule enforcement; including the stakeholders involved and the scope of their responsibility in addition to the existence of cross agency working and whether there is an independent or specific government body dedicated to promoting safety at LCs (subchapter 3.3).

The recommendations presented in the tables in the following subchapters have been classified as two types:

- Requirement (R): These are needed to guaranty the safety of LC users. These requirements can be either mandatory or not, depending on the countries and the signed conventions between the countries.
- Policy option (PO): These are plans, or actions adopted or pursued by the government or the railway companies.

3.1. International legal requirements for LC safety

The review of international rules and regulations related to LCs reveals that a common framework exists in the form of non-mandatory treaties and recommended guidelines produced by international organizations and policy-making bodies such as the United Nations Economic Commission for Europe (UNECE), International Union of Railways (UIC) and the International Road Union (IRU). In plenty of countries however, there are mandatory rules that should be respected while managing level crossings in the respective country. In addition, each country follows a national legal framework which is mandatory. The aforementioned treaties and guidelines are shortly described below.

- **Vienna Treaties of 8th November 1968: “Convention on Road Traffic” and “Convention on Road Signs and Signals”**

The Vienna Treaties on “*Convention on Road Traffic*” and “*Convention on Road Signs and Signals*” are multilateral treaties aiming at facilitating international road traffic and increasing road safety through the standardisation of road traffic signing systems. These legal tools, managed by the United Nations Economic Commission for Europe (UNECE), contain several LC safety provisions and specify the basic rules of behaviour for road users and pedestrians when crossing railway lines on a common basis. This regulation stipulates that the priority of trains at all LCs, with road users and pedestrians obliged to respect the road signs and signals and stop when the train is approaching.

- **European Agreement supplementing the Convention on road traffic**

This agreement supplementing the Convention on road traffic contains even stricter provisions on traffic at LCs. Many countries across the world have become Contracting Parties and benefit from the implementation of the above Conventions.

- **UIC leaflets 760, 761 and 762**

These UIC leaflets are International Railway Standard documents providing recommendations for railways regarding forms of LC protection and rules of application. Specifically, UIC Code 760 refers to Vienna Convention Road Signs and Signals (7^{th} Edition, September 2007), UIC Code 761 concerns guidance on the automatic operation of LCs (4th Edition, January 2004), and UIC Code 762 refers to safety measures to be taken at LCs on lines operated from 120 to 200 km/h (2nd edition, July 2005).

- **"Consolidated Resolution on Road Traffic" and "Consolidated Resolution on Road Signs and Signals"**

Consolidated Resolutions on Road Traffic (R.E.1) aims at supplementing the Convention on Road Traffic, 1968, and the European Agreement of 1971, addressing subjects not covered therein. Consolidated Resolution on Road Signs and Signals (R.E.2) in turn addresses the divergences between one country and another as regards to some of the regulations set out in the Convention on Road Signs and Signals of 8 November 1968 and the European Agreement supplementing the Convention of 1 May 1971.

In addition to these international recommendations directly linked to the safety of level crossing, there are European directives and standards related to rail and safety. These safety requirements are shortly described below:

- **Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety (recast) (Text with EEA relevance)**

This directive governs provisions to ensure the development and improvement of the safety of the Union rail system and improved access to the market for rail transport services. The directive applies to the rail system in the Member States and covers safety requirements for the system as a whole, including the safe management of infrastructure and of traffic operation and the interaction between railway undertakings, infrastructure managers and other actors in the Union rail system.

The following tables list the identified requirements related to legal needs. Table 1 summarises the requirements directly related to LCs and Table 2 lists more general requirements related to railway and LC safety.

Table 1: International requirements directly related to LCs.

R. No	Description	Source
R 1	Trains have priority at all LCs, road users and pedestrians shall respect highway code (road signs and signals) and stop when the train is approaching.	Vienna Treaties of 8th November 1968
R 2	Road signs and signals that shall be used at LCs.	UIC Code 760 based on the 1968 Vienna Convention
R 3	Fulfilment of LC system to basic UIC Code 761 conditions, including additional features to be considered when designing a LC	UIC Code 761
R 4	- No LCs shall be tolerated above a rail speed limit of 200 km/h - LCs shall be protected on lines operated with speed exceeding limit of 120km/h. - Recommendation on technical protection	UIC Code 762
R 5	Implementation of R.E.1 rules for approaching and going through a LC, including rules of behaviour to be followed by all road users, whether pedestrians, cyclists, moped or motorcycle riders, or drivers of motor vehicles with four or more wheels, when approaching and going through LCs and rules for overtaking.	Consolidated Resolution on Road Traffic (R.E.1)
R 6	Road user awareness of the dangers of LCs shall be raised through information campaigns and specific advice to road user groups: pedestrians; cyclists, drivers of mopeds and motorcyclists; drivers of motor vehicles; drivers of vehicles for the transport of goods and passengers.	Consolidated Resolution on Road Traffic (R.E.1)
R 7	Use of protection systems and additional automatic systems that detect and penalize infringement of the rules by users. No LC should be located on high-traffic thoroughfares (motorways and similar roads) or on railways where speeds can exceed 160 km/h.	Consolidated Resolution on Road Traffic (R.E.1)

Table 2: General requirements related to railway and safety.

R. No	Description	Source
R 8	Harmonisation of the regulatory structure in the Member States.	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety
R 9	Definition of responsibilities between the actors in the Union rail system.	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety
R 10	Development of common safety targets (‘CSTs’) and common safety methods (‘CSMs’) with a view to gradually removing the need for national rules.	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety
R 11	Setting of the principles for issuing, renewing, amending and restricting or revoking safety certificates and authorisations.	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety
R 12	Establishment, for each Member State, of a national safety authority and an accident and incident investigating body	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety
R 13	Definition of common principles for the management, regulation and supervision of railway safety.	Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety

3.2. Policy options for LC safety

Some clear themes emerged from Task 1.1 regarding LC safety policy across the different countries. A number of the policy actions are closely linked to each other and have been grouped under wider policy headings which are ‘LC removal and reduction’, ‘Improvement of the protection of existing LCs’, ‘Organisational strategic development’, ‘Education and enforcement’, and ‘Legal responsibility for LCs across administrative areas’.

According to Task 1.1 the most important safety policy across all responding countries is removal or reduction of LCs.Table 3 lists the specific policies related to this action[1].

[1] The Task 1.1. results may not be representative of the policies in all countries (i.e. some of these policies may exist in some countries even though it was not indicated in their Information Collection Form.

Table 3: List of policies related to LC removal or reduction.

PO No	Policy
PO 1	Long term target of zero LCs (i.e. the Netherlands)
PO 2	Encourage closing of crossing by assessment of risk reduction benefit in agreement between the rail and road IMs (i.e. UK)
PO 3	Contribute towards the LC removal/ reduction policy of replacement of LCs with grade separated crossings
PO 4	No LC authorized on sections where the train travels at or above a certain speed (The maximum speed varies from 160 km/h in Slovakia, Spain and Switzerland for example to 120 km/h in Greece)

The second most common safety policy is the improvement of the protection of existing LCs. The indicated policies related to LC protection are listed in Table 4.

Table 4: List of policies related to LC protection.

PO No	Policy
PO 5	Improvement of the protection of existing LCs, focusing on installing active protection measures at passive LCs (i.e. Romania, Slovakia, Norway, Austria, Ireland, Switzerland)
PO 6	Development of existing protection systems to be more cost-effective and energy efficient (i.e. Finland and Canada)
PO 7	Adoption of a safe systems approach with a focus on forgiving infrastructure rather than an onus on the user behaviour and correct usage as a way of ensuring safety (Sweden and Lithuania)

A third of the countries have a policy to improve LC safety with the help of different types of organisational and strategic development. The indicated policies related to organisational strategic development are listed in Table 5.

Table 5: Indicated policies related to organisational strategic development.

PO No	Policy
PO 8	Develop evaluation and risk management activities, LC safety strategy and action plans (i.e. Finland).
PO 9	Promote cross sector working to tackle safety at LCs (i.e. Finland, Sweden).
PO 10	Development of common safety targets ('CSTs') and common safety methods ('CSMs') with a view to gradually removing the need for national rules.
PO 11	Systematic LC monitoring (i.e. Finland, Sweden)
PO 12	Targeting of accident reduction, particularly in identified accident hotspots (i.e. France, Lithuania).
PO 13	Strategy or long-term action plan, and operational planning both on the rail and road side, setting out the priorities for LC safety (i.e. Slovakia, Finland, Netherlands).

Just over one fifth of the countries have a policy to raise public awareness on safety at LCs. The specific policies related to education and enforcement are listed in Table 6.

Table 6: List of policies related to education and enforcement.

PO No	Policy
PO 14	Raise public awareness around safety at LCs. This takes the form of inclusion within road traffic safety campaigns (i.e. Finland); public awareness and educational outreach activities and tools (i.e. Norway, United Kingdom, the Netherlands) and paper-based publications through booklets to promote awareness of rules and risks (i.e. Ireland).
PO 15	Increased education and enforcement

The indicated policies related to legal responsibility for LCs across administrative areas are listed in Table 7.

Table 7: List of policies related to legal responsibilities for LCs across administrative areas.

PO No	Policy
PO 16	Balance the interests of the different parties involved (road, rail, private and public authorities, individual users).
PO 17	Take into account the impact of local circumstances that affect the use of the crossing.
PO 18	Take into account the number and range of crossing types (including number of user operated crossings), density and length of the national railway network, which are all factors that raise safety concerns and call for an adequate response.

4. ORGANISATIONAL RECOMMENDATIONS

This section analysed the organizational aspects of safety in LCs in terms of roles and responsibilities for the design, operation, management and rule enforcement. The analysis included the involved stakeholders and the scope of their responsibility in addition to the existence of cross agency working and whether there is an independent or specific government body dedicated to promoting safety at LCs. The identified recommendations or policy options for organisational issues are presented in Table 8.

Table 8: List of recommendations for organisational issues by topic.

Topic	R No	Description of recommendation or Policy option
International cooperation and strategic partnerships	R14	Develop joint approach, with relevant national and international stakeholders from road user, education and training, law enforcement and LC design and operations working together to undertake coordinated actions. The end result should be the delivery of appropriate road user specific education, training and enforcement solutions and introduction of appropriate LC specific engineering solutions, in addition to reducing the number of LCs.
Design of LC safety	PO 19	The greatest level of responsibility for the design of LC safety is held by rail infrastructure managers, with sole responsibility or shared responsibility with the road administrator.
	PO 20	Elements on the road side of the LC fall within the domain of the road administrator, particularly design of road signs, whilst the elements making up the LC itself is responsibility of the rail administrator.
Safe operation of LCs	PO 21	Various stakeholders are responsible for the management of LC safety, principally the rail infrastructure manager but also the road infrastructure manager, rail operator, police, responsible ministry and national safety agency.
Enforcement of safety at LCS	PO 22	Harness cross agency working for the management and operation of safety at LCs utilizing tools such as multi-stakeholder working groups; joint rail and road LC inspections; and cooperative arrangements between involved partners.
Existence of dedicated government or independent LC safety body	PO 23	Encourage the promotion of LC safety by a government body or dedicated independent organization dedicated. In most cases in takes the form of existing government or non-government entities that carry out functions or activities as part of wider road safety or railway safety work.
Safety arrangements attached to LCs	PO 24	Use of specific risk management tools, safety management information systems and rules/guidelines to improve safety at LCs (i.e. Belgium, Ireland, Lithuania, the Netherlands, Norway, Switzerland, France, United Kingdom etc.).
	PO 25	Use of public education campaigns focused on users of passive LCs (i.e. UK)

5. TECHNICAL REQUIREMENTS

There is a series of standards produced by the CEN-CENELEC that are obligatory standards for several countries for any new product or system related to Railway Signalling Systems.

These standards state that the system developed must be fully compatible with the current systems, which are in operation and must comply with safety requirements as par the CENELEC standards and safety must be demonstrated in compliance with EN50126, EN50128 and EN50129. More specifically:

- EN50126 defines the terms of RAMS (Reliability, Availability, Maintainability and Safety), their interaction and a process based on the system lifecycle for managing RAMS. In addition, a systematic process for specifying requirements for RAMS and demonstrating that these requirements are achieved is defined.
- EN50128 specifies procedures and technical requirements for the development of programmable electronic systems for usage in railway control and protection applications, aimed at usage in any area where there are safety implications. In contrast to the EN 50126, it is applicable exclusively to software and the interaction between software and the system which it is part of.
- EN50129 specifies those lifecycle activities which shall be completed before the acceptance stage, followed by additional planned activities to be carried out after the acceptance stage. It is therefore concerned with the evidence to be presented for the acceptance of safety-related systems and is highly related to the EN 50126.

CENELEC Standard uses the concept of Safety Integrity Level (SIL) based on the Tolerable Hazard Rate. Four levels are defined with SIL4 being the most stringent.

Proposed technical solutions developed within the project will have to take these requirements into account.

6. RECOMMENDATIONS ON DATABASE HARMONIZATION

6.1. Background

The deliverable D1.2 of the SAFER-LC project (Silla et al. 2017) produced an in-depth review of LC accident data which were collected from seven countries, namely Greece, Finland, France, Italy, Norway, Spain and Turkey. The findings of D1.2 state, for example, that there is currently no harmonized database structure on LC accidents used in the Europe. The LC accident data collection procedures and the amount and details of documented data vary between European countries.

In addition, there is currently no clear link between road and rail accident databases and there is lack of variables that are needed for an in-depth analysis of the accidents at LCs. More specifically, little information is available on victims and the coverage of victim details varied between countries and in several cases, they were lacking. The detailed information about the victim profile such as type of victim, his/her qualities, motives and/or behaviour would provide valuable input data when assessing the possible effects of LC safety measures. In addition, the more detailed information on victims of LC accidents supports the authorities and railway stakeholders in their decision-making process when deciding on how to allocate the funds for the traffic safety work and to decide on which audiences to target. Based on the findings we could also conclude that little information is collected and documented on LC characteristics and circumstances. The detailed information of the surroundings of LCs and the types of LCs were the LC accidents occur, for example, allow the planning and identification of different safety measures to different types of level crossings.

The following recommendations were drawn in D2.1:

- Improve the involvement of the road infrastructure managers in the LC accident investigation process to collect and share information regarding LC accidents with railway stakeholders and/or independent accident investigation bodies.
- Increase the cooperation between the organisations conducting the in-depth LC accident investigations and the organisations which report the yearly accident numbers to the ERA database.
- Define European-wide recommendations on LC accident data collection including proposal on most useful variables to be collected. A more detailed European wide LC accident data would enable a more in-depth analysis of LC accidents and would lead to useful conclusions.

Based on these recommendations the objective of this section is to define a data model for LC accidents. This data model aims at supporting the development of information systems by providing the definition and format of data related to Level crossing accidents. These data will be defined and organised in a standardized way.

This data model will facilitate integration between different data collection systems: road accidents, rail accidents at national and international level.

6.2. LC accident Data Model

A data model is an abstract model that organizes elements of LC accident related data in tables and standardizes how they relate to one another and to properties of the real-world entities. For instance, a data model may specify that the data element (e.g. a table) representing a level crossing be composed of a number of other elements which, in turn, represent characteristics of the LC, the road section and the rail section it is belonging to.

The proposed data model is based on:

- UIC safety Database (SDB) which contains the rail significant accidents that occurred at level crossings from 2006 to 2016 covering 22 UIC members, representing 89% of the rail network within the European Economic Area (EU and EFTA). All information on the SDB coverage, definitions and reports is available at http://safetydb.uic.org.
- CARE database which is a Community database on road accidents resulting in death or injury in Europe (no statistics on damage - only accidents). The major difference between CARE and most other existing international databases is the high level of disaggregation, i.e. CARE comprises detailed data on individual accidents as collected by the Member States. (more information at https://ec.europa.eu/transport/road_safety/specialist/statistics_en# and https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/care_flowchart_a0.pdf)
- RINF database (Register of Infrastructure of ERA) which contains railway infrastructure information such as Section of line' (SoL) which is the part of line between adjacent operational points and may consist of several tracks (more information at http://www.era.europa.eu/Document-Register/Pages/RINF-Application-Guide.aspx).

The core of the model described in Figure 1 consists of two main tables: 1) ACCIDENTS (at LCs) which contain structured information related to each LC accident, and 2) LEVEL CROSSING which contains structured information related to each level crossing.

Both of these tables are linked to three additional tables. The two tables linked to ACCIDENTS table are called as CAUSES and VICTIMS whereas the three tables linked to LEVEL CROSSINGS are called as ROAD SECTION, RAIL SECTION AND LC CHARACTERISTICS.

In addition, there are several reference tables via which additional details can be linked to each LC accident such as type of train, involved railway infrastructure managers and undertaking, contributing factors etc.

Figure 1 present a general overview of the LC accident model, the different type of data included in the model and their relations between the main data tables.

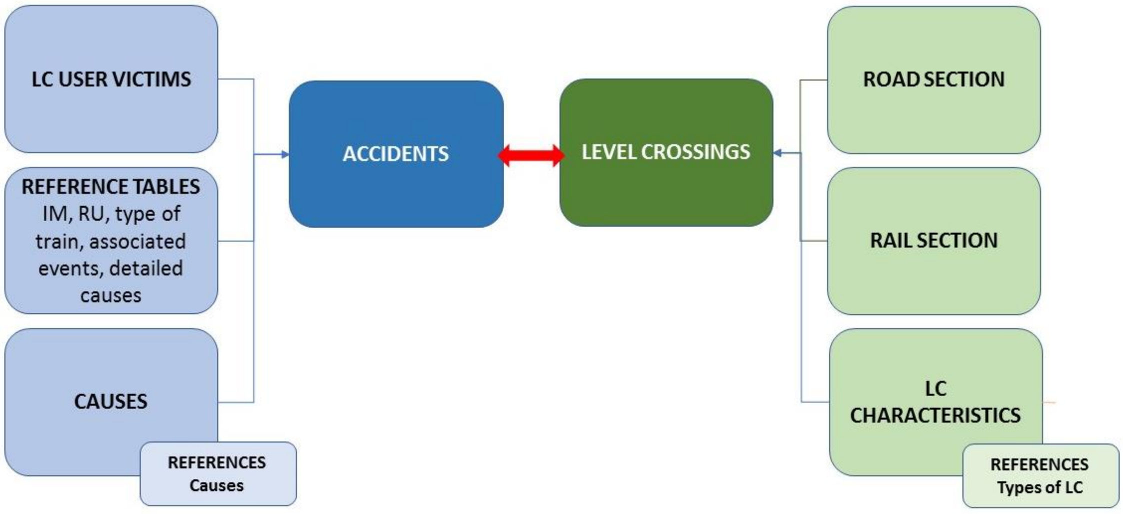

Figure 1: LC general data model.

Figure 2 presents the LC accident data model which contains a total of 14 tables. Each rectangle represents a table which corresponds to an object with attributes. The link between the rectangles represents the relationship between the objects. The indication (1, ∞) represents the cardinality: for example, at a LC, one or several accidents can occur or for a LC there 1 or several LC characteristics.

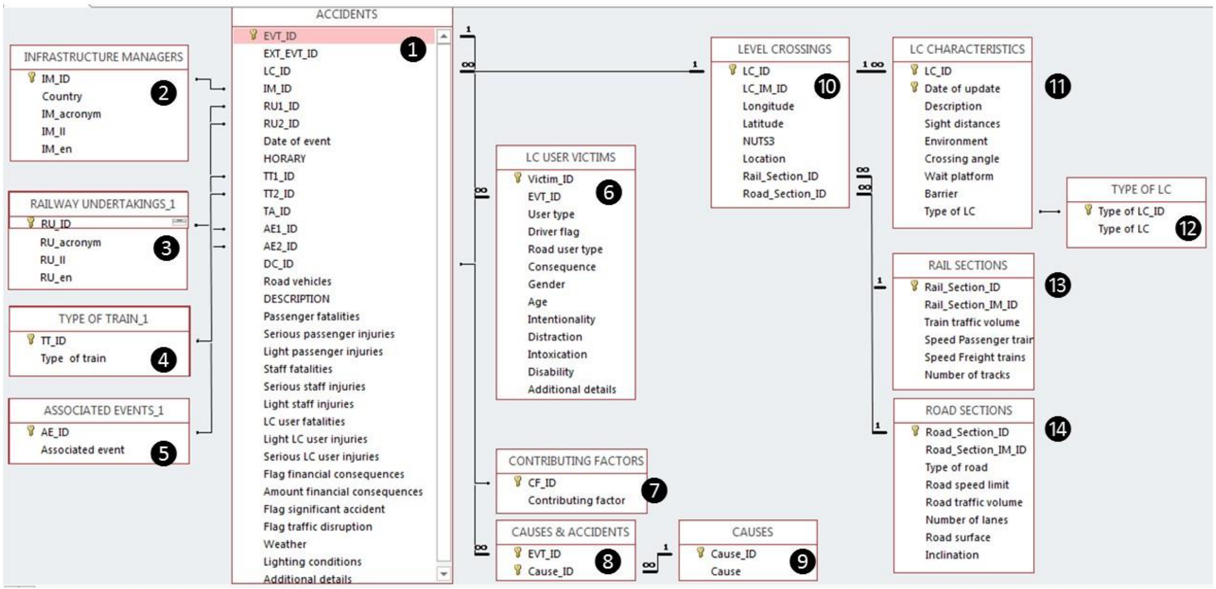

Figure 2: LC accident data model: detailed description of relations between tables.

6.1. Description of the tables

A table (represented in the figures above by a rectangle) is a set of data elements (values) using a model of vertical columns (identifiable by name) and horizontal rows, the cell being the unit where a row and column intersect. A table has a specified number of columns but can have any number of rows. Each row is identified by one or more values appearing in a particular column subset. The columns subset which uniquely identifies a row is called the primary key.

For example, for the table “accidents”: each horizontal row will be an occurrence of accident. Each accident will be identified by a primary key (EVT_ID). Each column represents a field (which could also be called indicator or variable) which contain a value.

Each table is described with the list of fields that it contains.

6.1.1. Table "ACCIDENTS"

According to the EU Directive 2004/49/EC, ‘Accident’ means *an unwanted or unintended sudden event or a specific chain of such events which have harmful consequences*. Accidents are divided into the following categories: collisions, derailments, LC accidents, accidents to persons caused by rolling stock in motion, fires and others.

According to the EU Directive 2009/149/EC, a significant accident means any accident involving at least one rail vehicle in motion, resulting in at least one killed or seriously injured person, or in significant damage to stock, track, other installations or environment, or extensive disruptions to traffic. Accidents in workshops, warehouses and depots are excluded.

Table **9** contains **rail significant accidents at level crossings** (collisions of a train with an obstacle and individuals hit by a train) following the Safety Directive, as well as **rail accidents with minor consequences** (light injuries, traffic disruption < 6 hours or financial consequences < 150 k€). The last column of this table indicates whether the field is present in the UIC Safety Database.

Table 9: Accidents at LCs.

Code	Description of the field	Format of the field	
EVT_ID	identification number of the event, following the rule of the UIC Safety Database (SDB)	number YYYY0000 if included in the SDB and YYYY000000 if not included	*
EXT_EVT_ID	identification number of the event within the contributor organisation	internal format	*
LC_ID	identification number of the level crossing → "LEVEL CROSSINGS"	alphanumeric Country ISO code and 5 figures	
IM_ID	identification number of the infrastructure manager following UIC leaflet 920-1 → "INFRASTRUCTURE MANAGERS"	numeric	*
RU1_ID	identification number of the railway undertaking which train is involved following UIC leaflet 920-1 → "RAILWAY UNDERTAKINGS"	numeric	*
RU2_ID	identification of the railway undertaking if a second train is involved in the accident → "RAILWAY UNDERTAKINGS"	numeric	*
Date of event	date of accident	DD/MM/YYYY	*
HORARY	time of accident	HH:MM:SS	*
TT1_ID	Type of train involved. SDB definitions → "TYPE OF TRAIN"	numeric	*
TT2_ID	Type of second train involved. SDB definitions → "TYPE OF TRAIN"	numeric	*
TA_ID	Type of accident. SDB definitions	1 = collision between a train and an obstacle 4 = individual hit by a train	*
AE1_ID	code of an associated event if necessary. SDB definitions → "ASSOCIATED EVENTS"	numeric	*
AE2_ID	code of a second associated event if necessary. SDB definitions → "ASSOCIATED EVENTS"	numeric	*
DC_ID	detailed cause → "DETAILED CAUSES"	alphanumeric	
Road vehicles	Number of road vehicles involved in the accident	numeric	
DESCRIPTION	open field where a description of the accident may be included	unlimited text	*
Passenger fatalities	Number of passengers who died in the accident. SDB definitions	numeric	*
Serious pax injuries	Number of passengers who were seriously injured in the accident. SDB definitions	numeric	*

Light pax injuries	Number of passengers that suffered light injuries.	numeric	
Staff fatalities	Number of employees or subcontractors who died in the accident. SDB definitions	numeric	*
Serious staff injuries	Number of employees or subcontractors who were seriously injured in the accident. SDB def.	numeric	*
Light staff injuries	Number of employees or subcontractors that suffered light injuries.	numeric	
LC user fatalities	Number of level crossing users who died in the accident. SDB definitions	numeric	*
Serious LC user injuries	Number of level crossing users who were seriously injured in the accident. SDB definitions	numeric	*
Light LC user injuries	Number of LC users that suffered light injuries.	numeric	
Flag financial consequences	Are financial consequences above 150 k€ ?	1 = yes 0 = no	*
Amount financial consequences	When known, amount of financial consequences in euros.	numeric	*
Flag significant accident	Is the accident significant in the sense of the EU Safety Directive 2004/49/EC?	1 = yes 0 = no	*
Flag traffic disruption	Did the accident result in a traffic disruption of more than 6 hours?	1 = yes 0 = no	*
Weather	choice among following items:	Rainy; Snowy; Cloudy; Sunny/bright; Foggy; Other; Unknown	
Lighting conditions	choice among following items:	Dawn; Light; Dusk; Dark; Unknown	
Additional details	open field where the correspondent may add details on the accident, such as links to official reports or newspapers	unlimited text	

6.1.2. Table "INFRASTRUCTURE MANAGERS"

According to the EU Directive 2004/49/EC, 'infrastructure manager' means anybody or undertaking that is responsible in particular for establishing and maintaining railway infrastructure, or a part thereof, as defined in Article 3 of Directive 91/440/EEC, which may also include the management of infrastructure control and safety systems. The functions of the infrastructure manager on a network or part of a network may be allocated to different bodies or undertakings.

Table 10 contains the list of Infrastructure Managers (IM).

Table 10: Infrastructure managers.

Code	Description of the field	Format of the field
IM_ID	identification number of the infrastructure manager following UIC leaflet 921-1	numeric
Country	Country ISO code 3166-1	alphabetic 2 positions
IM_acronym	Acronym of the Infrastructure Manager	text
IM_ll	Official name of the IM in own language	text
IM_en	Name of the IM in English	text

6.1.3. Table "RAILWAY UNDERTAKINGS"

According to the EU Directive 2004/49/EC, 'railway undertaking' means railway undertaking as defined in Directive 2001/14/EC, and any other public or private undertaking, the activity of which is to provide transport of goods and/or passengers by rail on the basis that the undertaking must ensure traction; this also includes undertakings which provide traction only.

Table **11** contains the list of Railway Undertakings.

Table 11: Railway undertakings.

Code	Description of the field	Format of the field
RU_ID	identification number of the railway undertaking following UIC leaflet 921-1	numeric
RU_acronym	Acronym of the railway undertaking	text
RU_ll	Official name of the RU in own language	text
RU_en	Name of the RU in English	text

6.1.4. Table "TYPE OF TRAINS"

Table 12 contains all the possible values for the type of train.

Table 12: Type of train.

Code	Description of the field	Format of the field
TT_ID	identification number of the type of train. SDB definitions	numeric
Type of train	name of the type of traffic	text

Table **13** contains all possible values for the type of train that are referenced in the UIC the safety database.

Table 13: Possible values for the type of trains.

Code value	Possible value	Code value	Possible value
TT_ID	Type of train	TT_ID	Type of train
1	Freight combined transport	8	Other passenger train
2	Freight block train	9	Shunting operation
3	Freight HS train	10	Locomotive running light
4	Other freight train	11	Infrastructure works train
5	Regional passenger train	12	Other train (infrastructure)
6	Long distance passenger train	13	Train not identified
7	High speed passenger train	14	Runaway vehicle

6.1.5. Table "ASSOCIATED EVENTS"

Table **14** contains all the possible values for the type of associated events to the accident.

Table 14: Associated events.

Code	Description of the field	Format of the field
AE_ID	identification number of the associated event. SDB definitions	numeric
Associated event	name of the associated event	text

Table **15** contains all possible values for the associated event that are referenced in the UIC the safety database

Table 15: Possible values for associated events.

Code	Possible value of associated event	Code	Possible value of associated event
1	Train collision with an obstacle	11	Serious braking failure
2	Train collision with another train	12	Poor adhesion
3	Derailment	13	Overheated axle box
4	Individual hit by a train	14	Runaway vehicle
5	Individual falling from a train	15	Track subsidence/track deformation
6	Electrocution by overhead line or third rail	16	Broken rail
7	Fire in rolling stock	17	Broken wheel or broken axle
8	Accident involving dangerous goods (no release)	18	Signal Passed At Danger (SPAD)
9	Accident involving dangerous goods (with release)	19	(Wrong-side) signalling failure
10	Dangerous over-speeding	20	Other

6.1.6. Table "LC USER VICTIMS"

Table **16** contains all information related to the LC user victim. It will give detailed information on victims of level crossing accidents that will be used for further analysis. Several victims may be linked to a single event.

Table 16: LC user victims.

Code	Description of the field	Format of the field
Victim_ID	identification number of the victim	To be defined
EVT_ID	Event ID → "ACCIDENTS"	numeric
User type	choice among following items:	Car (capacity <8); Bus (capacity >8); Lorry; Tractor; Pedestrian; Bicycle; Moped or Moto; Horse; Unknown
Driver flag	Was the victim driving?	Yes or No
Road user type	choice among following items:	Frequent user; Infrequent user; Unknown
Consequence	choice among following items:	Fatality; Serious injury; Light injury; Unknown
Gender	choice among following items:	Male; Female; Unknown
Age	choice among following items:	0-9; 10-19; 20-29; 30-39; 40-49; 50-59; 60-69; 70-79; 80-89; Unknown
Intentionality	choice among following items:	Suicide (intentional); Accident (unintentional); Unknown event
Distraction	Was the driver involved in tasks that may have distracted him?	Yes; No; Unknown
Intoxication	choice among following items:	Alcohol; medicines or drugs; No intoxication; Unknown
Disability	Was the victim disabled?	Yes; No; Unknown
Additional details		free text

6.1.7. Table "CONTRIBUTING FACTORS”

Table **17** contains all the possible values for the contributing factors to the accident. It is also very worthwhile information for the in-depth analysis of the accidents.

Table 17: Contributing factors.

Code	Description of the field	Format of the field
DC_ID	Detailed cause ID	alphanumeric
Detailed cause	Identification of the cause	text

Table **18** contains all possible values for the contributing factors to the accident.

Table 18: Possible values for for contributing factors.

Code	Possible value of detailed cause
V01	Driver accidentally turns onto track mistaking it for a junction
V02	Driver brakes too late to stop before the crossing (driver misjudgement (high approach speed, downward road gradient, crossing is hidden behind bend), ice, mud etc.)
V03	Driver has stopped in traffic on the crossing when the crossing activates (also known as blocking back)
V04	Driver is caught unaware of a second train approaching
V05	Driver is unaware of the crossing (e.g. unfamiliar with location, signage/warnings not clearly visible due to visual clutter, foliage, vandalism etc)
V06	Driver unable to see the crossing because of low sun
V07	Driver zigzags the barriers when the crossing is active
V08	Poor visibility of the crossing on approach to the crossing due to weather (e.g. fog)
V09	Train not expected at crossing because of technical failure or human error
V10	Vehicle has become grounded on crossing
V11	Vehicle has stopped foul of a crossing (could be with crossing in front or behind)
V12	Vehicle is involved in a road traffic accident on crossing
V13	Vehicle struck by crossing barrier
V14	Other vehicle accident cause
P01	Pedestrian caught unaware of a second train approaching
P02	Pedestrian falls on crossing surface
P03	Pedestrian struck by crossing barriers
P04	Pedestrian struck by unexpected train on crossing due to technical failure or human error
P05	Pedestrian unable to see approaching train due to poor visibility
P06	Pedestrian walks around protective barriers
P07	Other pedestrian accident cause

6.1.8. Table "CAUSES"

Table 19 contains all the possible values for the causes of the accident. According to the railway safety directive (2016/798) 'causes' means *actions, omissions, events or conditions, or a combination thereof, which led to an accident or incident*.

Table 19: Causes.

Code	Description of the field	Format of the field
Cause_ID	Identification of the cause	numeric
Cause	Description of the cause. SDB definitions	text

Table **20** presents the 63 registered causes for LC accidents, following the UIC SDB nomenclature.

Table 20: Possible values for causes.

Code	Possible value of associated event
100	Infrastructures
110	Infrastructures - Broken rail
120	Infrastructures - Track deformation
130	Infrastructures - Obstruction due to collapse of structures
131	Infrastructures - Obstruction due to collapse of structures - Bridge / viaduct collapsed
132	Infrastructures - Obstruction due to collapse of structures - Building collapsed
160	Infrastructures - Traffic operating equipment failures
163	Infrastructures - Traffic operating equipment failures - Level crossing equipment failure
200	Rolling stock
220	Rolling stock - Running gear
240	Rolling stock - Brake failure
260	Rolling stock - Other faults on tractive Rolling stock
270	Rolling stock - Other faults on hauled Rolling stock
300	Human factors (staff and contractors)
310	Human factors (staff and contractors) - Track and switch maintenance staff
311	Human factors (staff and contractors) - Track and switch maintenance staff - Communication problems
312	Human factors (staff and contractors) - Track and switch maintenance staff - Involuntary acts
313	Human factors (staff and contractors) - Track and switch maintenance staff - Voluntary acts
314	Human factors (staff and contractors) - Track and switch maintenance staff - Organisation problems
315	Human factors (staff and contractors) - Track and switch maintenance staff - Unauthorised occupation
330	Human factors (staff and contractors) - Traffic operating and signalling staff
331	Human factors (staff and contractors) - Traffic operating and signalling staff - Communication problems
332	Human factors (staff and contractors) - Traffic operating and signalling staff - Involuntary acts
333	Human factors (staff and contractors) - Traffic operating and signalling staff - Voluntary acts
334	Human factors (staff and contractors) - Traffic operating and signalling staff - Organisation problems
340	Human factors (staff and contractors) - Other IM staff
341	Human factors (staff and contractors) - Other IM staff - Communication problems
342	Human factors (staff and contractors) - Other IM staff - Involuntary acts
343	Human factors (staff and contractors) - Other IM staff - Voluntary acts
344	Human factors (staff and contractors) - Other IM staff - Organisation problems
350	Human factors (staff and contractors) - Train driver
351	Human factors (staff and contractors) - Train driver - Communication problems
352	Human factors (staff and contractors) - Train driver - Involuntary acts
353	Human factors (staff and contractors) - Train driver - Voluntary acts
354	Human factors (staff and contractors) - Train driver - Organisation problems
500	Weather and environment
510	Weather and environment - Weather
511	Weather and environment - Weather - Fog
512	Weather and environment - Weather - Wind

513	Weather and environment - Weather - Flood
514	Weather and environment - Weather - Storm
515	Weather and environment - Weather - Frost
516	Weather and environment - Weather - Snow
517	Weather and environment - Weather - Ice
518	Weather and environment - Weather - Heat
520	Weather and environment - Environment
521	Weather and environment - Environment - Animals
522	Weather and environment - Environment - Overgrown vegetation
523	Weather and environment - Environment - Fallen tree(s)
524	Weather and environment - Environment - Leaf mulch
525	Weather and environment - Environment - Fallen rocks / stones
526	Weather and environment - Environment - Landslide
527	Weather and environment - Environment - Earthquake
600	Third parties
630	Third parties - Pedestrian on level crossing
631	Third parties - Pedestrian on level crossing - Non-compliance with laws and regulations
632	Third parties - Pedestrian on level crossing - Inattention
633	Third parties - Pedestrian on level crossing - Alcohol or drugs
640	Third parties - Road vehicle on level crossing
641	Third parties - Road vehicle on level crossing - Non-compliance with laws and regulations
642	Third parties - Road vehicle on level crossing - Inattention
643	Third parties - Road vehicle on level crossing - Alcohol or drugs
999	Not identified

6.1.9. Table "CAUSES & ACCIDENTS"

Table **21** makes the link between the “accidents” table and “causes” table: an occurrence of accident can have many causes and an occurrence of cause can be attached to many accidents.

Table 21: Causes & accidents.

Code	Description of the field	Format of the field
EVT_ID	Event ID → "ACCIDENTS"	numeric
Cause_ID	Identification of the cause → "CAUSES"	numeric

Note: several causes may be linked to a single event

6.1.10. Table "LEVEL CROSSINGS"

Table **22** describes the location of the LC.

Table 22: Level crossings.

Code	Description of the field	Format of the field
LC_ID	Identification number of the level crossing	Alphanumeric Country ISO code + 5 figures
LC_IM_ID	Identification number inside the IM	

Longitude	WGS84	Decimal degrees
Latitude	WGS84	Decimal degrees
NUTS3	European nomenclature of regions, level 3	Alphanumeric Country ISO code + 3 figures
Location	Location of the LC	Open text
Rail_section_ID	Identification of the rail section → "RAIL SECTIONS"	
Road_section_ID	identification of the road section → "ROAD SECTIONS"	

6.1.11. Table "LC CHARACTERISTICS"

Table **23** contains the characteristics of the LC.

Table 23: LC characteristics.

Code	Description of the field	Format of the field
LC_ID	identification number of the level crossing → "LEVEL CROSSINGS"	Alphanumeric Country ISO code + 5 figures
Date of update		DD/MM/YYYY
Description		Free text
Sight distances	Meters	Numeric
Environment	Choice among following items	Urban; Rural
Crossing angle	Choice among following items	<70 degrees; 70-110 degrees; >110 degrees
Wait platform	Choice among following items	Good; Average; Poor; Unknown
Barrier	Choice among following items	Full barrier; half barrier; none
Type of LC_ID	Identification of the type of LC → "TYPE OF LC"	Alphanumeric 3 positions

Note: several records of this table may be linked to a single level crossing, depending on the date of update.

Table "TYPE OF LC"

Table 24 and Table **25** contains all the possible values for the type of LC according the European classification.

Table 24: Type of LC.

Code	Description of the field	Format of the field
Type of LC_ID	Identification of the type of LC	Alphanumeric 3 positions
Type of LC	European classification	Text

Table 25: Possible values for type of LC.

Type of LC_ID	Type of LC
A99	Active - Other or unidentified active LC
AA1	Active - Automatic - User side warning
AA2	Active - Automatic - User side protection
AA3	Active - Automatic - User side warning & protection
AA4	Active - Automatic - User side W & P + rail side protection
AA5	Active - Automatic - User side warning + rail side protection
AA9	Active - Automatic - Other or unidentified automatic LC
AM1	Active - Manual - User side warning
AM2	Active - Manual - User side protection
AM3	Active - Manual - User side warning & protection
AM4	Active - Manual - User side W & P + rail side protection
AM9	Active - Manual - Other or unidentified manual LC
PPP	Passive
ZZZ	Other or unidentified LC

6.1.12. Table "RAIL SECTIONS"

The description of “RAIL SECTIONS” refers to the section of line (SoL) of the RINF data model. It is the uninterrupted connection by rails between two adjacent operational points.

Uninterrupted means “no switches” and “the number of tracks remain the same”. But in many cases, it also means that a number of track characteristics remain unchanged (like structure gauge, max. axel load etc.).

Table **26** contains the characteristics of the rail sections.

Table 26 : Rail Sections.

Code	Description of the field	Format of the field
Rail_Section_ID	Identification of the rail section	Text
Rail_Section_IM_ID	Identification of the rail section for the Rail Infrastructure manager	
Train traffic volume	Average number of trains per day	Numeric
Speed Passenger trains	speed limit in km/h	
Speed Freight trains	speed limit in km/h	
Number of tracks	choice among following items:	1; 2; 3 or more

6.1.13. Table "ROAD SECTIONS"

The description of the “road sections” presented in Table **27** is based on the CARE database and, more specifically, the glossary of the Common Accident Data Set (CADaS).

Table 27: Road sections.

Code	Description of the field	Format of the field
Road_Section_ID	Identification of the road section	text
Road_Section_IM_ID	Identification of the rail section for the Road Infrastructure Manager	
Road type	Choice among following items:	Rural; Urban; Motorway; Other; Unknown.
Street lights	Choice among the following items:	Yes; None (or out of order); Unknown
Road surface markings	Choice among the followings items:	Present; Faded; Deleted; None; Unknown
Carriageway type	Choice among the following items:	Single carriageway (one way); Single carriageway (two ways); Dual carriageway (a line separates opposing lanes of traffic); Unknown
Total number of lanes	Choice among following items:	01; 02; 03…; Unknown
Road speed limit	Choice among following items:	<30km/h; 30-50 km/h; 51-80 km/h; 81-100km/h; 101-120km/h; >120km/h.
Road traffic volume	Choice among following items:	<100; 101-500; 501-1000; 1001-5000; 5001-10000; >10000; unknown
Road curve	Choice among the following items:	Yes; No; Unknown
Road surface	Choice among following items:	Asphalt; Gravel / unpaved road; Other; Unknown
Road grade	Choice among following items:	<1.5% (flat); 1.5% (slope); >1.5% (hill)
Work zone related	Work zone in the immediate surroundings	Yes; No; Unknown.

7. IDENTIFICATION OF RISKS AND END-USERS' REQUIREMENTS AT LCS

This section presents the results of the workshop together with the main findings of tasks 1.1 and 1.2 as well as the results from the past SafeRail project on a satellite-based train positioning system (https://business.esa.int/projects/saferail) for which UIC participated as end-user especially on task on needs and requirements at LC. Within the SafeRail project a series of workshops and expert interviews with users and other stakeholders were organised in order to establish a description of the current situation (and challenges) at LCs and to conclude on user needs and requirements.

This section aims at identifying the main risky situations at LCs and/or situations leading to dangerous behaviours at LCs as well as to identify innovative solutions to prevent these risky situation and behaviours from occurring. These findings will contribute to the definition of the main risks and user requirements to be addressed in later work packages of SAFER-LC project.

7.1. Findings of the workshop

In total 25 questionnaires were filled in during the workshop. The participants were asked to identify LC related high risk situations both from the road and the rail perspective. In addition, the participants were asked to assess the criticality of each identified risky situation (high/medium/low perceived risk).

The identified risks where divided into two categories: the risk from the road side and the ones from the rail side. In addition, the work considered both motorised and non-motorised road users including a special attention to the following user groups:

- Motorized road users: transport professionals; heavy vehicles; and farm vehicles
- Vulnerable road users: cyclist; pedestrians; ramblers; horse riders; persons with reduced mobility; users with vision loss and blindness; users with hearing loss and deafness; and users with different cultural and language background.

From the rail user side, the work covered railway undertakings, train drivers and infrastructure managers.

During the analysis of the results the assessments provided by the participants were converted into numerical values. This was done by adding the risk points for each of the perceived risks, being the results, as described in Table 28.

Table 28: Risk perception conversion.

Level of risk	Risk point
High Risk	5
Medium to high risk	4
Medium risk	3
Low to medium risk	2
Low risk	1

The results of the evaluation of risk are presented in Table 29 (Classification of risks from the road side) and Table 30 (Classification of risks from the rail side).

Table 29: Classification of risks from the road side.

Risks from the road side	Points
Long-time of LCs closure that can generate violation	152
Design of the LC (curve before and after, bumps, slopes, high declivity, difficult for buses and trucks)	138
LC too close to a crossroad	135
Drivers over speeding	133
Pedestrians/cyclists with headphones	131
Easy access through the barriers for pedestrians / cyclists	131
Pedestrians/cyclists using the LC as a shortcut to the neighbouring station or other points of interest	129
Bad weather conditions (rain, ice: slippery, fog: bad visibility etc.)	127
Barriers that do not open completely and close again rapidly because of trains running in both directions but not detected at the very same time	124
Distraction of the driver at the approach of a LC while driving	122
Drivers overtaking queuing traffic	115
Poor visibility of road signs	110
Works at certain LCs which are not reported on GPS, professional drivers take another route with a LC with a risky profile	102
Sounds of bells not audible because vehicles are better insulated to sounds and noises	101
Too many road signs, poor understanding	94

Table 30: Classification of risks from the rail side.

Risks from the rail side	Points
Vehicle stuck in LC	126
Train not crossing LC within expected time	114
No train detection: Failure on train detection device	104
Both barriers up (no start of down movement)	104
Barriers not opening after train crossing: failure on train passing LC detection.	101
No train detection: failure on LC control system (cabling, etc.)	100
Barriers not opening after train crossing: failure on LC control system, (cabling, etc.)	98
Lack of elements for investigation after the accident	98
One barrier up, one down (failure in one barrier movement)	92
Energy failure on LC (electric local supply, batteries, etc.)	88
Both barriers down but broken boom	87
Failure on sound warning device	83
Failure in road lights (all bulbs blown)	82

In addition to the identification of high risk situations at LCs, Table 31 presents some innovative solutions which were identified to target these high-risk situations. These innovative solutions were also discussed during the workshop.

Table 31 : List of identified innovative solutions.

Risks addressed	Innovative solutions
Overtaking queuing traffic	Lane separators, red light cameras
LC too close to a road crossing	Modify the road crossing to avoid queuing traffic from the neighbouring road traffic, put road traffic lights
Speeding	Speed strips, enforcement cameras
Poor visibility of signs and signals	Cut vegetation, improve the visibility by other signals, change the lights (put led lights as in the UK) particularly on LC crossing a road going in a West-to-East direction (sun set and sun rise)
Bad weather conditions (rain, ice: slippery, fog: bad visibility, etc.)	Japan (heating of LCs)
Too many road signs, poor understanding	Limit the number of road signs
Sounds of bells not audible because vehicles are better insulated to sounds and noises	Change bells (see example in Belgium)
Difficult profile of the LC (curve before and after, bumps, slopes, high declivity, difficult for buses and trucks	Improve the profile with tool of acquisition and software of analyse and simulation
Works at certain LCs which are not reported on GPS, professional drivers take another route with a LC with a risky profile	All LCs should be reported on GPS, and works or profiles of LC should be reported on GPS
Barriers that do not open completely and close again rapidly because of trains running in both directions but not detected at the very same time	Modify detection and closure time
Distraction is a major risk at the approach of a LC while driving	Application pushing information to users of the approach of a train, stop music or use of mobile phones when crossing
Long-time of LCs closure can generate illegal behaviour	Application pushing information to users of the approach of a train, stop music or use of mobile phones when crossing
Headphones	Put rumble strips
Use of the LC as a shortcut to the neighbouring station	Install anti-trespass panels, tested in Belgium, installed in Deuil-la-Barre in the suburbs of Paris, France
Works at certain LCs which are not reported on GPS, professional drivers take another route with a LC with a risky profile	Modify the road crossing to avoid queuing traffic from the neighbouring road traffic, put road traffic lights
Easy access through or under the barriers	Put skirts underneath barriers to impede pedestrians from walking under barriers (as in the UK)

7.2. Main factors behind LC accidents

Deliverable D1.2 produced an in-depth review of level crossing (LC) accident data collected from seven countries, namely Greece, Finland, France, Italy, Norway, Spain and Turkey.

Some of the main factors affecting the realisation of LC accidents identified in D1.2 are the following:

- Breakdown of the car at LC
- Car abandoned at LC
- Car driver violating the closed barriers
- Excessive speed
- Non-observation of road signage
- Overtaking the queueing traffic
- Distraction
- Limited visibility due to glare from the sun
- Loss of control (vehicles or bicycles)

7.3. Results of SafeRail project

The SafeRail project considered several user groups and stakeholder, which are listed in the following:

User groups considered:

- Road User
- Train Driver
- Train supervisor
- Rail Inspector

Stakeholders taken into account:

- Rail Infrastructure Manager (IM)
- Railway Undertaking RU
- National Rail Safety Authority (NSA)
- Road Safety Authority
- Railway Signalling Manufacturer
- Telematics (Data) Provider
- Road Vehicle OEM

The main findings of SafeRail project in terms of user requirements available at https://business.esa.int/projects/saferail were:

- Railway companies want to increase the percentage of road users who respect the traffic rules at level crossings.
- Road users want to be supported with appropriate hazard warnings if there is a specific danger while approaching the level crossing. The road user would like to pursue his journey without being obstructed and without feeling a lack of safety by the operations of the level crossing.

- Traffic safety specialists want to support road users in perception and appropriate action of the situation at the approached level crossing.
- Road users want to have in advance information regarding the status of the level crossing in order to perform an optimal routing.
- Secondary line operators want low cost, yet safety-compliant active level crossing installations (legal conditions require upgrading many passive level crossings to active level crossings due to increased traffic density).
- Secondary line operators and safety authorities prefer short closure periods (yielding less impatient road users crossing early).
- Infrastructure Managers want to support the level crossing inspection with seamless data management and remote inspection.

7.4. Summary

Based on the previously presented findings from workshop, deliverables D1.1 and D1.2 and the SafeRail project the members of the consortium agreed on specific priorities to be addressed within the project. These priorities were divided under four topics: human factors, LC design, railway operations and innovative solutions. The specific issues to be focussed under each topic are presented in the following.

Priorities regarding **road user human factors**:

- Attention:
    - Inattentiveness of the users: Pedestrians/cyclists with headphones or using smartphones, road drivers using smartphones or GPS
    - Non-observation of the road signage and rail tracks by road users or pedestrians
- Understanding: Special focus on lack of signage or too many signage at LCs and the special needs of impaired people.
- Behaviour: Special focus on excessive speed of road vehicles and deliberate violations at active LCs

Priorities regarding **LC design**:

- Design of the LC: Curves before and after the LC, bumps, slopes and high declivity should be avoided; difficult especially for buses and trucks
- Location of the LCs: LC located, for example, too close to a road crossing or at proximity to commercial centres could generate long waiting queue at the LC (and could also cause so called blocking back effect)
- Protection of the LC based on a risk evaluation
- Easy access through and around LCs or under the barriers for pedestrians/cyclists

Priorities regarding **railway operations**:

- Vehicle stuck on the level crossing
- Long-time of LCs closure
- Failure on rail devices: detection of train, LC control system, etc.

Priorities regarding **innovative solutions** resulting from the above priorities:

- Risk assessment: Risks at LCs shall be regularly monitored to adapt the safety measures at LC
- Communication
  - Road users shall be informed about a LC he/she is approaching
  - Road users shall be informed about a train approaching at the LC
  - The train driver shall be informed in advance about obstacles at the level crossing and
  - The train shall break when an object is detected in the hazard zone of the LC
- Maintenance
  - All subsystems of the level crossing shall be inspected, maintained and repaired according to the regulations.
  - IM shall be alerted in case of foreseen failures
  - The train driver shall be informed in advance about failures of the LC
- Design of the LC
  - Road users shall be protected by technical means from entering the hazard zone if a train is approaching
  - The level crossing activation period shall be as short as possible in order to maximize fluidity
  - All traffic signs and similar communication for information and warning shall be unambiguous, easily understood and giving clear (positive) instructions for a Road User paying moderate attention
  - The design of the LC shall be adapted for all type of vehicles
- Cost-effective safety measures shall be preferred

8. SCENARIOS

For each task in WP3, a scenario is proposed taking into consideration the summary of the findings presented in the previous chapter.

8.1. Scenario for risk assessment

The objective of this scenario is to evaluate the risks at LC to help rail and road stakeholders to deploy the most suitable safety measures at LCs. Based on the frequency of different types of LCs in EU's railway network and the European LC accident statistics, the focus of this scenario is on passive LCs and actively protected LCs with automatic barriers (half or double barriers).

In several railway companies in Europe, the decision on the level of protection for a LC is typically done following a method called the "danger index" currently used by some infrastructure managers. The danger index calculation typically takes into account several parameters, such as the angle between track and road, the track visibility from the road, the slope of the road, the number of tracks, the road width and surface, the train speed and the combined traffic (road and track). An example of danger index calculation can be found in Annex 2.

Within SAFER-LC project, an innovative method for risk assessment will be 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 (LC). This analysis should give clear insight into accident risk evaluation to be conducted in WP2.

These observations will enable, on the one hand, to establish the behaviour of the safety model inherent to LC and, on the other hand, to provide WP3 with relevant use cases to be automatically detected by a smart detection system.

8.1.1. Risk evaluation based on user behaviors using automatic video data analysis

The risk evaluation system (Task 3.1), based on detecting and classifying user-to-user / user-to-infrastructure behaviors using image video processing, should give statistics and indicators that may qualify (in terms of dangerousness) the monitored LC. As the number of situations is unlimited, three representative scenarios are proposed to illustrate typical dangerous situations. They are described as follows:

- **Scenario 1:**

A vehicle approaches the LC while the barriers are closing or closed, and the vehicle driver attempts to cross but collides with the barrier (Figure 3).

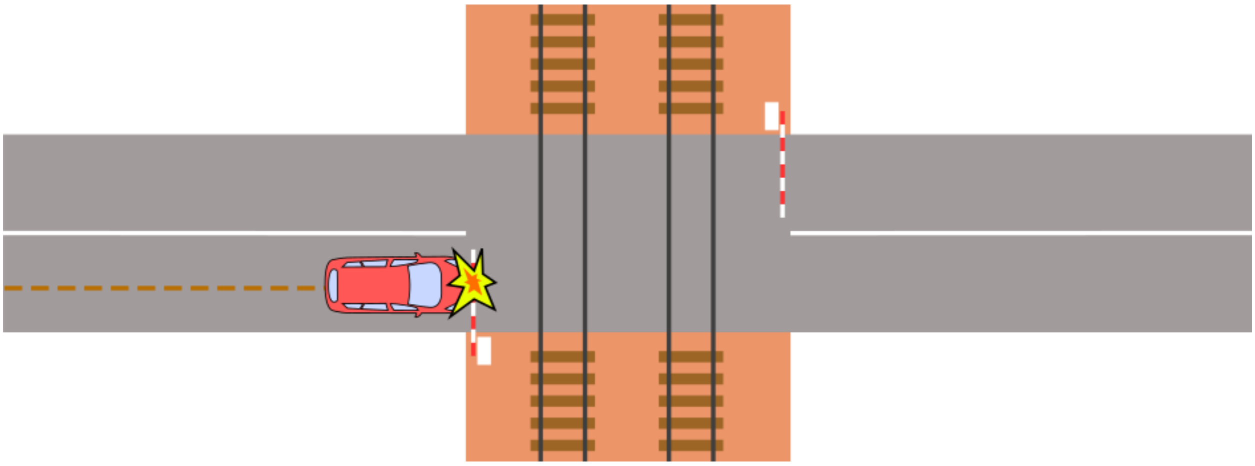

Figure 3: Graphical illustration of scenario 1.

- **Scenario 2:**

A vehicle approaches the LC while the barriers are closing or fully closed. The vehicle driver attempts to cross the LC by zigzagging, and then stops on the tracks (because of a mechanical malfunction for example) (Figure 4).

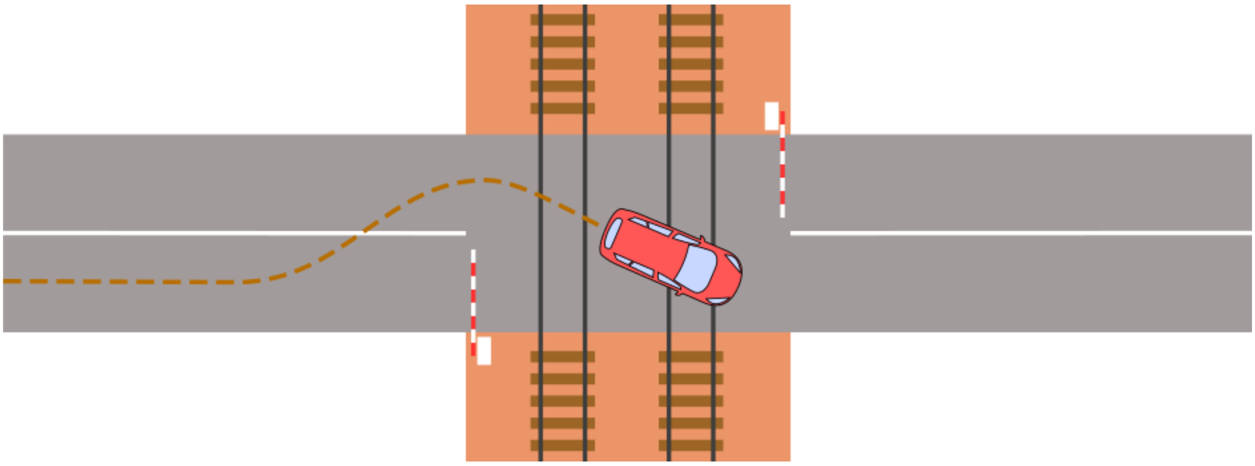

Figure 4: Graphical illustration of scenario 2.

- **Scenario 3:**

A vehicle approaches the LC while the barriers are closing or fully closed and another vehicle is stopped in front of the barrier (Figure 5). The vehicle driver attempts to cross the LC by overtaking the stopped vehicle, and then stops on the tracks (because of a mechanical malfunction for example).

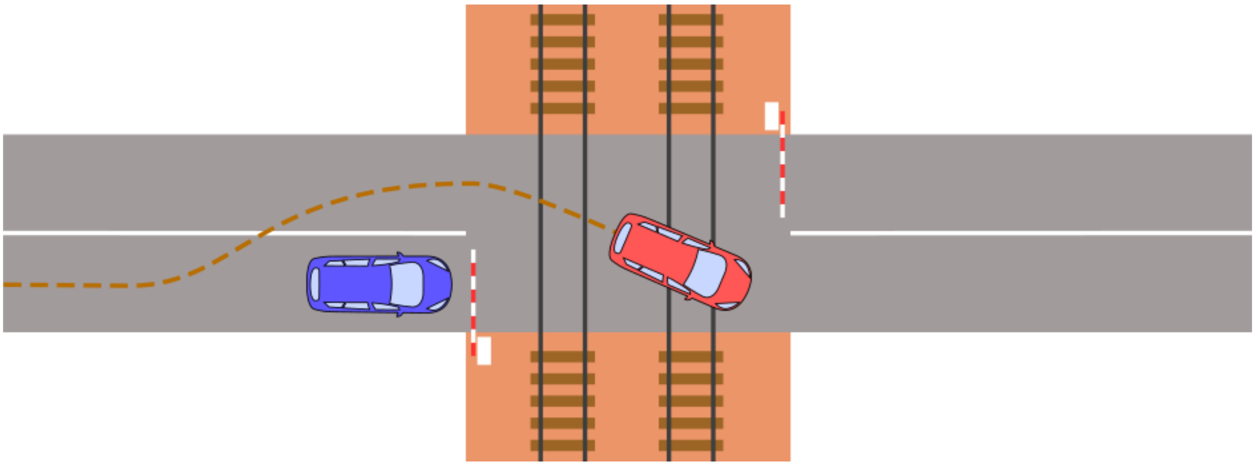

Figure 5: Graphical illustration of scenario 3.

Scenario 1 describes the situation of a car crashing against a railing barrier, which can be used to evaluate whether the system can correctly differentiate between the trajectory of the accident vehicle (the red car in the figure of scenario 1) and the normal trajectories of vehicles properly crossing the LC. For the latter, most cases fall into the situation in which the light signal is off and the barriers are fully open.

Scenarios 2 and 3 can be used to test whether the system can correctly differentiate between the single user behavior in the former (scenario 2) and the interaction of the two users in the latter (scenario 3), even though the trajectories of the vehicles involved in the dangerous situations (the red car) are similar in shape. Proper risk assessment may require classifying these two situations as different. For example, the situation in Scenario 2 would be classified as a zigzagging without user-to-user interaction, and instead, the one in Scenario 3 as a zigzagging with user-to-user interaction (i.e. overtaking in our case).

In addition to these scenario, some examples of risky behaviour at LCs have been listed below with the associated video:

- Risk taken by vehicles zigzagging in France: http://www.20minutes.fr/lille/1628851-20150611-video-filme-voitures-franchissent-barrieres-passage-niveau-pres-arras and https://www.dailymotion.com/video/x5bi4s7
- Risk taken by a Polish car at a LC with 4 barriers and lights (PKP CCTV camera): https://www.francetvinfo.fr/monde/europe/video-la-sncf-polonaise-diffuse-les-images-d-un-accident-evite-a-un-passage-a-niveau-en-guise-d-avertissement_2323291.html
- Risk taken by a vehicle at a Polish LC with lights only http://www.non-stop-zapping.com/actu/divers/pologne-une-camionnette-violemment-percutee-par-un-train-video-66330
- Risks taken by a truck in Studenka, Eastern of Czech Republic: https://youtu.be/TQLhslqr-lw
- Risks taken by a truck (bad weather) in Utah USA : http://edition.cnn.com/videos/us/2017/01/25/utah-train-crash-fedex-truck-sje-orig.cnn

- Exceptional convoy, accident in Mesvres with a truck carrying blades of wind turbines: http://www.dailymotion.com/video/xj141q
- Risks taken by cyclist during the run Paris Roubaix in France: https://www.youtube.com/watch?v=sNP6ctSHDvo
- Risk taken by cyclist in the UK by British Transport Police: https://youtu.be/KjCNVDS8E0M https://youtu.be/QoS8tOeVFgQ
- Risks taken by a cyclist in Opole in Poland:
- https://www.koreus.com/video/cycliste-vs-train.html
- Risks taken pedestrians jumping over barriers or crossing at red lights or vehicles filmed by CCTV cameras/Network rail: https://youtu.be/F0Y3Cp7owIQ
- Risks taken pedestrians jumping over barriers or crossing at red lights or vehicles filmed by CCTV cameras/Network rail: https://youtu.be/F0Y3Cp7owIQ
- Risks taken by people taking selfies on railway tracks (CCTV NETWORK RAIL): http://mashable.com/2015/10/26/railway-track-selfies-warning/#ikIt3okZbPqR ; https://youtu.be/HWIKWk57HHY
- Risks taken by cars, pedestrians, tractors, buses, in UK: https://www.youtube.com/watch?v=3PcscQTlbFI&t=15s
- Best CCTV images (NETWORK RAIL): https://www.youtube.com/watch?v=tI8mXzEJFfE
- Risks taken at the level crossing of Deuil la Barre (video of RFF): https://www.youtube.com/watch?v=7ewz0DbTIxc
- Pedestrian near miss Auckland: https://youtu.be/0023HNnj9Jg (CCTV camera of Auckland transport)
- Risk taken by a pedestrian in France: https://www.youtube.com/watch?v=6gscnGOd8kQ

8.2. Scenario for Smart detection system

8.2.1. Main principles

Based on the workshop results, it seems that the most perceived risk at LC is the one resulting on a vehicle stuck on the LC due to, for example, traffic jam or vehicle malfunction. Therefore, the detection and alert of such situations should be the focus of the smart detection system.

Since the equipment and the operation rules are different from a country to another in Europe, the proposed scenario for smart detection system will be as open as possible in order to be used in different situations meanwhile being adaptable for the different specificities.

For the risk of a vehicle stuck in LC, two levels of alert can be defined: early warning and urgent warning.

- Early warning

Once an obstacle is detected at the LC for more than x seconds (x depends on the type of traffic using the LC; 15 seconds can be used as an example), an early alarm can be sent to the traffic control centre so that the staff at control centre can react to this event on time before the dangerous situation occurs. Since the traffic control centre is aware of the position of the train, the traffic manager can make a decision on how to behave for the next train approaching the LC based on the analysis of the images received from the LC. This early alarm system can be integrated in the traffic management system to support the traffic manager in his/her decision-making process.

At that stage the video system installed at the LC can provide several information: the detection of the event generated by the system and some video footage available which can be sent to the operator. We can choose to send only numerical data to the operator and/or send also video in order for him to begin to make a first diagnosis.

- Urgent warning

Once the obstacle is detected (shorter time than the previous case) and the “approaching train signal” is received at the LC, an urgent warning should be sent from the LC to the different actors around the LC. This urgent warning should be received by the train driver, by the approaching cars and by the traffic control centre. For the control centre it is planned, if possible, to send also some images in order to make a first diagnosis. If it is possible the braking signal (or any other information) should be sent to the train with whatever automatic train protection system is available or even through an ad-hoc system on board. In addition, a pre-alert can be launched in case extraordinary traffic intensity or other events can be detected in the area nearby the LC.

The aim of this system is to brake the train and to avoid the collision or to minimize the effects if the collision is unavoidable.

Figure 6 illustrates the synoptic of a LC and the different elements and functionalities planned in the project.

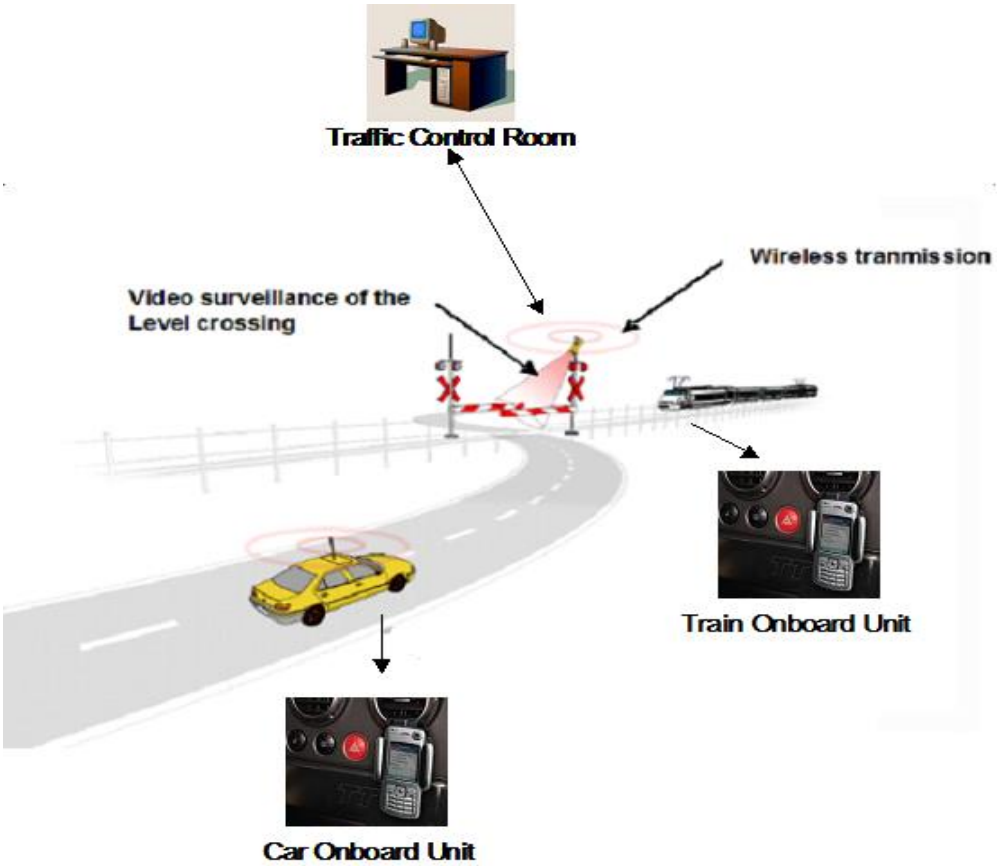

Figure 6: Smart detection system.

Table 32 provides the different sequences in the case of a car stuck on the LC.

Table 32: Smart detection system alarms.

LC Type	Pre-alert	Early Alarm			Urgent alarm	
		Train presence	Obstacle on track	Action	Train presence	Action
Half Barriers	High traffic on area	No train	unmoving vehicle > 15 s	Send alert to TC	Train detected at warning point	Send alert to train & vehicle
Full barrier	High traffic on area	No train	unmoving vehicle > 15 s	Send alert to TC	Train detected at warning point	Send alert to train & vehicle
Passive LC	High traffic on area	No train	unmoving vehicle > 30 s	Send alert to TC	Train detected at warning point	Send alert to vehicle

8.2.2. Scenario for a car stuck or stopped at LC.

The following text presents the evolution of alert messages in different scenarios in a situation where the car is stuck or stopped at LC.

Current situation: detection of a car stopped in the middle of the LC and the train is still far

- After 15 seconds, if the vehicle moves and leaves the LC, in this case, the video system lists this event in a database of events for statistical purposes the database contains the list of incidents.
- Beyond 15 seconds and if the vehicle is still motionless, we consider that we enter a degraded mode of LC.

Several scenarios can then be considered:

- With open barriers

The first entity to be alerted is the control room (here we send we can send a message, an audio message, one or several images of the field, etc. The staff will assess the situation in case of a fixed obstacle has been identified to be at LC for more than 15 seconds. Possible video images would help the manager to assess the situation.

The second entities to be alerted are the vehicle drivers who approach the LC. The barriers at the LC are open, which means that the situation is not yet critical and in this case a message like "*Warning you are approaching a LC with a potential obstacle, slow down*" can be sent to in-vehicle devices or approaching cars.

- With train proximity activated

The first entity to be contacted with the telecommunication system available is the train driver. In this case, the information on the presence of the obstacle goes directly to the train (this is useful if the train is still far enough to brake). If possible, this message also activates the automatic braking of the train.

The second entity to be alerted is the control room. The staff will assess the situation in case of a fixed obstacle has been identified to be at LC for more than 15 seconds. Possible video images will help the manager to assess the situation.

The third entities to be alerted are the road vehicle drivers approaching the LC. The barriers are closed, which means that the situation is critical and in this case a message such as "*Warning you are approaching a LC, stop your vehicle or change your direction*" can be sent to the On-Board units (ITS-G5) of approaching vehicles and can be displayed using a GPS terminal for instance.

The fourth entity to be managed is the obstacle itself. After 15 seconds, if the train could not be alerted either by the communication system or by the control room and the barriers begin to close, the event must be managed locally, that means at the level crossing level. This means that for example a voice message is activated asking the driver to leave the decking area of the LC immediately.

The earlier examples illustrated written messages transferred between entities. It should be noted that all messages exchanged between the LC and other entities may be accompanied by audio or video information. This depends on the capabilities of the telecommunication systems used in the project.

This scenario can be enriched or modified in case the position of the train is continuously known. This location information relatively to LCs can be sent to the LC by the equipped train or it can be obtained by the control room.

In this scenario, the detection is achieved with video sensing and image processing technologies. In order to reduce false alarms which would cause disruption to the normal operation, it will be envisaged, if possible, to complement these detection technologies with additional sensor based on lidar technology. The combination of both technologies will ensure a very low rate of false alarms.

8.2.3. Scenario for information sharing in case of a train approaching

Another application of a smart detection system, could be a system based on a map matching with the locations of all the road and rail vehicles to a set of pre-defined polygons (Figure 7).

If there is a match (a train and a vehicle in the same polygon group) an alert will be generated. The alert will inform the road vehicle driver about the approaching train and the expected time of arrival (ETA) to the LC, which is calculated using the speed of the train and the distance to the LC. Three advices will be generated, when the distance between the train and the LC are 1,000, 500 and 200 meters, providing the ETA as estimated using the speed of the train.

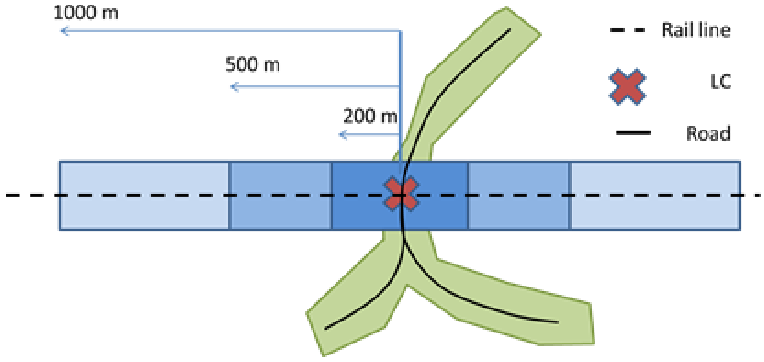

Figure 7: Polygons definition near a LC.

8.3. Scenario for early detection of failures on the LC's equipment

8.3.1. Main principles

Several parameters can be used to detect abnormal behaviour of the LC. Some of them cannot be predicted (as broken booms), but early detection of the failure can lead to a quick maintenance response, minimizing the time the LC is out of order.

The main parameters to be monitored at LC are:

- Energy supply: To follow the presence or absence of main energy source, battery status, battery charger operation, etc.
- Broken boom detector: To follow the status of the boom. The booms can be broken due to several reasons such as high winds. The information of broken boom is needed before the train arrival.
- Condition of road lights: To know if the traffic lights are in good condition and whether they are bulbs or led based. This information is needed to monitor the energy consumption in order to change and/or repair the road lights before they stop working.

- Condition of barrier motor: A possible motor failure can be foreseen by checking the energy consumption (if the current used is out of the boundaries, comparing with previous records).
- Train detection devices: With the installation of additional devices, we can improve the train detection and trace track circuits behaviour, sending alerts to maintenance teams (UIC Shunting booster POC)
- Monitoring of sound warning devices: LCs equipped with sound warning devices should be monitored in order to alert the maintenance teams of their malfunction.

In addition to the above-mentioned monitoring devices, LC equipment can be monitored (depending on the LC type) via additional control devices such as wind speed measurement, obstacle detection loops and blinking LEDs on barriers.

8.3.2. Technical aspects

LCs have typically several power sources, while the most commonly used is the power line from the electric company or a dedicated power line from the infrastructure manager. To increase the certainty that electricity is available, LCs are often also equipped with batteries or UPS system (DC or AC equipment).

Traffic lights to the road are also varied in technology (from incandescence bulbs to LED composed lights). The monitoring of the functioning of the traffic lights is important since the non-functioning of these lights can lead to dangerous situations, due to lack of awareness of the potentially dangerous situation by the road user. By monitoring the energy consumption of these lights, maintenance teams can be informed of the situation before it becomes a dangerous one.

Because of strong winds or by vehicle accident, barrier booms can be broken, with the consequent risk when they are supposed to be lowered to protect a train crossing the LC. By monitoring the correct position of the boom within the barrier, maintenance teams and traffic control can be informed of this problem before a train crosses the LC.

Several types of motors are used to lower and raise the barriers. The motors can have different electrical problems which can be foreseen, by detecting anomalous energy consumption on them. As soon as a strange behaviour is detected, maintenance teams must react to keep the LC on service.

Sound warning devices are another important part of the road users warning. The lack or malfunction of this device can confuse the road users if the usual sequence is not followed (sound + lights for 6 /7 seconds before start of barrier movement). The sound warning devices (regardless if the sound is produced mechanically or electronically) must be monitored to keep maintenance teams aware of their performance.

8.3.3. Scenario description

A level crossing equipped with dual energy sources, light and sound warning devices and automatic barriers should be equipped with monitoring devices mentioned in the previous chapter and summarised in **Erreur ! Source du renvoi introuvable.**.

Table 1: Monitoring of LC.

	Warning to be sent when	Alarm to be sent when
Energy supply	Battery UPS ON	Low battery UPS alarm
Road traffic Lights	1 blown bulb / 33% blown LEDs	2 blown bulbs / 50% blown LEDs
Broken boom detector	Broken boom detected	Broken boom detected + train arrival
Motors monitoring	Motor parameters (consumption) out of threshold 1	Motor parameters (consumption) out of threshold 2
Sound warning devices	1 device off	2 devices off

The following failures should be reported to the selected receiver of the corresponding alarm:

- Any problems with energy supply, road traffic lights, motor status and/or sound warning devices should be reported to the maintenance teams
- Information on broken boom should be reported to traffic control and maintenance teams. Additionally, a wind speed detection device could be installed to LC to inform maintenance teams about the risk of a broken boom because of high wind speed.

8.4. Scenario for surveillance of the road and rail surface at the LC

8.4.1. Main principles

In recent years there have been several collisions at LCs between trains and heavy vehicles stuck at LCs, with varying severity of consequences (train derailments, multi-vehicle collisions with passing trains; fatalities or injuries). The issue of vehicles stuck at LCs relates to the longitudinal section on either side of the LC. Up to now, managers have been able to take profile surveys which are taken topographically i.e. with a lower level of precision. A possible consequence of this is that a point of conflict may not be detected and may result in a vehicle becoming stuck on the LC's longitudinal section.

On the basis of these readings, tools can be used to analyse the way that a given vehicle type travels on the longitudinal section. Road or rail infrastructure managers may take certain actions on the basis of this information, such as implementing adapted signalling systems, prohibiting certain vehicle types, or recovering the section in order to upgrade it.

The challenge for infrastructure managers is to have a mobile, non-intrusive system that does not require intervention on the part of a road or rail agent, enabling acquisitions at 200 metres on either side of the level crossing. The data must be delivered in standard format with metadata for the acquisition area (e.g. GPS coordinates).

The solution developed may also be used for preventative maintenance purposes, such as in cases of snowfall or vegetation growth. A permanent mechanism or weekly survey would facilitate planning so that maintenance staff can schedule works without the "warning" threshold being reached.

8.4.2. Scenario description

Step 1: Acquisition of the detailed profile by photogrammetry
The solution shall be a mobile, non-intrusive system that does not require intervention on the part of a road or rail agent, enabling acquisitions at 200 metres on either side of the level crossing. The data must be delivered in standard format with metadata for the acquisition area (e.g. GPS coordinates).

Step 2: Analysis of the data

- Assessment of the profile and determination of the risk for heavy/long vehicles (Bus, tractor etc.): Simulation with different types of vehicles. Parameters of the vehicle to be considered are i) front and back overhang, ii) wheelbase and iii) ground clearance.
- Evolution of the profile within a period. Situation to be detected could be:
  - Railway maintenance operations such as tamping or track renewal, which may raise the height of the rail platform in relation to the road
  - Road maintenance operations on either side of the LC, compounding the effects of dips or humps on one side or the other of the LC
  - Poor weather conditions causing damage to bitumen and potholes or other subsidence
  - Scrape marks (specification in cm) sometimes occur as a precursor to vehicles becoming stuck; it is important to be able to identify them on planking's and on the road.

8.5. Scenario for Optimized closure time

8.5.1. Main principles

Currently there exist two main systems for detecting the train approaching the LC (detection, or announcement point) and triggering the closure of barrier: 1) Mechanical detection with pedal system and 2) Electronic detection with track circuits or axel counters.

In general, the detection point is fixed based on the maximum speed of the line. However, in following cases, the closure time for the LC could be inadequate to the type of situation:

- Same detection points for trains with different speed using the same line
- Train "in distress": For some reason the train is stopped after detection point
- Two trains at a concomitant moment generate two successive closing intervals and the LC is kept open a very short time.

In optimal case (to be considered in SAFER-LC pilots) the closure of the barrier should be based on the location and speed of the train.

- **Use case 1: trains with different speed using the same line**

If railway vehicles with different speeds are using the same line, the closure time for the LC can be inadequate for some slow speed trains. Therefore, an adaptive closure time for the LC can lead to a safer LC, by reducing the waiting time for road vehicles and thus the probability of misconduct during the waiting period.

A train detection system with speed detection should be in place, sending the speed information to the LC which can then adjust the closure time according to the observed train speed.

- **Use case 2: concomitant trains**

The time interval between two successive closing intervals could be very short. In fact, the currently used control architecture opens the LC to road traffic as soon as a train leaves the crossing zone and no other approaching train has been detected meanwhile.

However, in some cases another train from the opposite direction can approach the LC a few times later, and in this case the LC is kept open for a very short time. This short open time could cause panic for car drivers who are engaged through the LC. A potential improvement is not to open the LC if a minimum opening duration cannot be guaranteed. This could be implemented if we know, in real-time, the location of trains in the vicinity of LC (cf. Ghazel, 2017).

- **Use case 3: Train "in distress"**

In this use case, the train is stopped for any reason in the announce area (between the detection point and the level crossing (See Figure). After passing the detection point the LC is commanded to close, but if the train stops because of a failure, the level crossing will not complete the normal cycle, so barriers will be kept closed for a long-time period.

To avoid excessive closure time for the LC, usually, the LC barriers opens after some time (depending on the country, this time can be variable from two minutes, to ten or more). Later, once the train starts moving again, the barriers can be commanded to close again.

To reduce risks for the road users, the LC barriers can be commanded to close if movement is detected again in the train, through the positioning system. Additional measures must be taken by the IM, setting traffic rules for this special situation, assuring the LC has enough time to close after the train starts moving again.

Regardless of the different train detection system used by the different IMs, a new train detection system should be designed to send information to the LC to close the barrier on time, depending on the train speed and position (See Table 33: Adaptive closure for LC barriers at page 56 and Figure 8 at page 55).

The train detection device should be located 2,002 m away from the LC, as this is the distance considered to have enough time to stop a train running with a speed of 160 km/h (see Table 34 at page 56). For higher or lower speed lines, this distance can be adapted according to values presented in Table 34. The acceleration capabilities of the trains using the line must be taken into account to avoid short warning times or the operation rules should not allow speed increments within the LC proximity area, or a continuous train positioning device should be used.

For achieving the expected results and being able to optimize the LC closure time, the detection system should follow the principles hereafter:

- the system should be installed outside of the track to facilitate the maintenance works and for better safety of workers
- the system should be installed at the detection distance corresponding for the line speed (2,002 m for a 160 km/h line)

- to be able to detect the train speed and direction,
- to be a SIL 4 system (as it's related to LC safety)
- to be able to communicate in a safe way with the LC box.

A reliable positioning system with the ability to send the train position information can also be tested. The LC should receive the proximity warning in the way it was receiving it before the installation of the device, to minimize the modifications at the LC box. The communication system should be coded and reliable enough to avoid jamming and/or hacking, so no intentional or unintentional signal could affect the information transmitted. This information should be transmitted ideally wireless, to reduce the civil works needed for the installation and the power of the system should also be as autonomous as possible.

The system should calculate, based on the train speed, the delay to send the proximity warning to the LC box (see Table 33: Adaptive closure for LC barriers at page 56). This should be treated as if it was the original proximity warning; controlling a relay to send the LC control system a 24 V activation signal or whatever the needed signal was.

8.5.2. Requirements for the test

Regardless of the use case, the requirements are as follows:

- Solutions must be adaptable to relay technology (electro mechanic contact)
- Detailed RAMS characterization must be provided for the proposed system. Black area (area without GPS coverage) shall be managed
- System redundancy with downgraded mode definition shall be provided
- Tracking system reliability and precision; in particular, to distinguish between trains in the event of double tracks or different lines adjacent to each other
- Ensure data integrity, by means of cybersecurity on the network used in particular
- Latency and calculation times in milliseconds
- EMC restrictions on equipment with catenaries/rail's traction current return circuit
- EMC non-interference restrictions on the relays

8.5.3. Scenario description

On an active LC protected with half barriers, system should be installed at the detection point (see Figure) and the receiving system should be installed at or nearby the LC box it if it is based on external detection devices. Satellite positioning systems do not need additional external devices.

Not to affect the LC, a new "improved proximity warning device" such as indication light should be installed at LC to allow the measurement of time between the new proximity warning and the train arrival at LC to confirm the adequacy of the system.

The sequence of facts for the scenario is the following:

- Train speed is detected at detection point.

- Following the column called “Delay to adapt closure time to train speed” in Table 33, the system can wait to send the “train arrival” signal to LC box, the time stated in the column, based on the train speed.
- After the “train approaching” signal is received at the LC box, 15 s are considered as the total time for considering the LC protected (6/7 s for sound and lights warning, 7/8 s for closing barriers) this time should be increased in case of 4-half or full barriers.
- At this moment, if an obstacle is identified on the track an alarm can be sent to the train, to stop the train either automatically or manually to minimize or avoid the possible damages for running over a vehicle.
- Column “time to reach the LC once closed the barrier” indicates the time the LC should be kept closed until the train crosses the LC with the optimization of closure device, in comparison with the time of the column “Time to LC after detection point” which is the time without optimization, before deducting 15 seconds for closing barriers (i.e. 129 seconds in the worst case)
- In case local laws require more delay between the LC closing and the arrival of the train, it can be easily adapted.

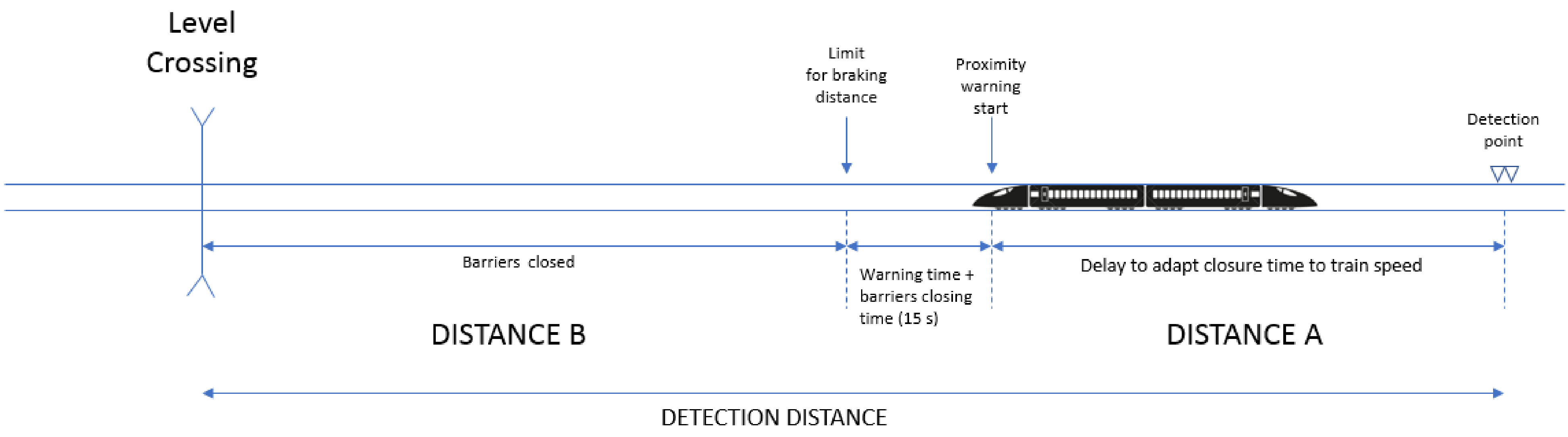

Figure 8: Adaptive proximity warning.

Table 33: Adaptive closure for LC barriers.

Speed (km/h)	Speed (m/s)	Emergency Braking distance (m) DISTANCE B	Braking distance (m)	Time to reach LC once closed the barrier (s)	Delay to adapt closure time to time speed (s) on 160 km/h line	Initial time to reach LC after closing barriers (s) on 160 km/h line	Time to reach LC after proximity warning point (s)	Distance from train detection point, to warning start point on 160 km/h line (m) DISTANCE A	Distance to install the train detection point based on max line speed DETECTION DISTANCE
50	13.89	304	500	22	107	129	37	1,489	512
60	16.67	394	504	24	81	105	39	1,358	644
70	19.44	488	670	25	63	88	40	1,222	780
80	22.22	555	760	25	50	75	40	1,113	888
90	25.00	667	910	27	38	65	42	960	1,042
100	27.78	815	1,100	29	28	57	44	770	1,232
110	30.56	873	1,180	29	22	50	44	670	1,331
120	33.33	908	1,230	27	18	45	42	594	1,408
130	36.11	939	1,280	26	14	40	41	521	1,481
140	38.89	984	1,350	25	11	36	40	434	1,567
150	41.67	1,160	1,570	28	5	33	43	217	1,785
160	44.44	1,335	1,800	30	0	30	45	0	2,002

8.6. Communication system for information sharing

8.6.1. Main principles

The exchange of information is critical in all of the previously presented scenarios, as one of the main objectives of the protection systems cannot be fulfilled unless all participants in these scenarios have adequate information on the status of LC. More specifically:

- For the warning in case of obstacles on the track, a warning to the train driver is needed if there is no automatic train protection system in place, so the train can stop if there is an obstacle at the LC. Also, some warning to the vehicle stuck at the LC can be sent to indicate to abandon the vehicle in case of extreme danger.
- Information related to the status of LC (open, closed, in maintenance, out of order, etc.) should be sent to navigation devices and/or to mobile applications, to allow the automatic route tracing systems to find the quickest and safest route to destination, taking into account the status of the LC on real time. Also, applications for pedestrians could include warnings on approach of a LC, even disconnecting the sound output of mobile phones to allow them to hear the sound alerts at LC.
- Low cost measures could be studied to detect the proximity of the train to passive LCs, to be able to send an alert to personal devices (GPS, mobile phones) and maybe with the inclusion of the alert on existing apps, or to a specific application. This system could be the same or similar to the one developed to warn visually or hearing-impaired road users which should also be defined.
- All the monitoring and remote maintenance systems at the LC should send relevant information to maintenance teams and even allow remote access to digital devices.

8.6.2. Technical aspects

Table 34 describes the communication channels which need to be stabilized depending on the event and the type of alarm.

Table 34: Communications systems.

Communication channel	Type of alarm
Smart detection	
Detection system -> Traffic control	Send pre-alerts and warning to Traffic control centre
Smart detection system -> Road vehicle	Send alert to road vehicles with train approaching
Smart detection System -> Train	Send alert to train when track is blocked
Monitoring system	
LC Box -> Maintenance	Send LC monitoring information to Maintenance teams
Train detection device -> LC Box	Send Detection device monitoring to LC Box
Sensors -> LC Box	Send LC sensors information to LC Box
Optimised closure	
Detection device -> LC Box	Send train speed and direction to device in charge of LC closing (LC Box)
Information sharing	
LC status -> Road users	Send LC status info, to Navigation devices &/or mobile apps to improve route calculation
LC status -> Pedestrians	Send LC status to mobile devices with warnings in case of LC closure
LC status -> visual & hearing handicapped	Send LC status to special apps for handicapped people
Train detected -> passive LC users	Low cost device to send info to a next area about train proximity

- **Smart detection system**

Depending on the event detected and the kind of alarm, several communication channels must be established. Pre-alerts and warnings must be sent to the traffic control centre and alerts to the train and traffic control centre. This can be integrated on the existing communication system or being specific for the system designed, depending on the characteristics and specificities of the available infrastructure. The train alert can be integrated on the GSM-R system or ERTMS if it is possible. For road vehicles, existing systems can be used or adapted if it’s feasible or a new developed system can be used to send the alert to mobile phones or other devices.

- **Monitoring system**

The monitoring system communications can be integrated into the existing communications network (at the LC box) or mobile communications system can be used in case there is no other method available. Also, the receiver system for the alarms should be defined. It can consist on a computer with the appropriate software, a tablet or mobile app for better mobility for maintenance teams, etc.

- **Optimized closure**

As already commented, communication established between detection point and LC box, should be reliable and secured, as the safety at LC depends on the accurate reception of this information. In addition, the communications system should be fail safe. In case of communications failure, either the LC shall remain closed or the original detection system should be on service.

- Info**rmation Sharing**

The information sharing, when not related to railway safety, is not so restrictive in terms of safety and availability, although the system has to be reliable enough to give confidence to users. Already existing technologies must be used to allow easy integration on personal devices, adapting existing apps or creating new specific ones.

8.6.3. Scenario description

This subchapter describes the communication related scenarios for low-cost protection measures, for hearing and visually impaired road users and for information sharing in case of a train approaching. For smart detection, monitoring of the LC system and optimized closure time, the scenarios are already defined in their respective chapters, as communications are an important part of these scenarios.

- **Low-cost protection measures**

The accident statistics show that a high share of LC accidents occurred at passive LCs. Therefore, the safety improvement directed for this kind of LCs can have a high impact in terms of LC safety improvement.

Taking advantage of the technologies used for the adaptive LC closure system, a low-cost train detection system could be installed at passive LC with the capability to send messages to personal devices (navigation devices, mobile phones) and thus alerting the road users on trains approaching the LC. The use of this technology requires that simplified train detection devices are installed on both sides of the passive LC around 500 m from the LC (or a more suitable distance), depending on maximum line speed (Table 35). Furthermore, the communications system should be able to reach the LC, to inform the user of the proximity of a train and should be directional to avoid sending the information for LC in other directions. For the ease of installation, the system should be autonomous to reduce the needed infrastructure (installation civil works) and therefore the cost.

Table 35: Time from detection point to LC.

Time to LC (s)		Detection point distance (m)				
		100	**200**	**300**	**400**	**500**
Speed (km/h)	50	7.2	14.4	21.6	28.8	36.0
	60	6.0	12.0	18.0	24.0	30.0
	70	5.1	10.3	15.4	20.6	25.7
	80	4.5	9.0	13.5	18.0	22.5
	90	4.0	8.0	12.0	16.0	20.0
	100	3.6	7.2	10.8	14.4	18.0
	110	3.3	6.5	9.8	13.1	16.4
	120	3.0	6.0	9.0	12.0	15.0
	130	2.8	5.5	8.3	11.1	13.8

This system can be rather easily installed on a test site, as it is completely independent from the current protection system regardless if the LC is active or passive.

- **Aid system for hearing and/or visually impaired road users**

The device for sending an alarm to personal devices for warning the hearing and/or visually impaired road users, can be triggered with the same signal which is used to trigger the road traffic lights. Therefore, the alarm would be sent during the period the traffic lights are active. The signal should start the mobile phone vibration system as well as a visual and sound alarm to be useful for those with hearing or viewing problems.

The system with all the components could be installed in the LC box, with a range as small as possible, not to send alerts to non-LC users.

The selected LC should be an actively protected LC since the installation requires the triggering signal and the power supply.

9. CONCLUSIONS

The aim of this deliverable was to propose a list of needs and requirements which should be satisfied by level crossings (LCs) both during normal operations and degraded modes by also taking into consideration the digitalisation of railways.

The needs and requirements were identified through a mixed methodology which drew on both, primary and secondary information sources: synthesis of needs and requirements from previous deliverables, organisation of a workshop with rail and road representatives, in-depth interviews with experts, information gathered from the past projects, and scenario development.

Based on this collection of data and the knowledge of the partners regarding LCs, a list of specific priorities to be addressed in WP2 and WP3 was established. These priorities were divided under four topics: human factors, LC design, railway operations and innovative solution.

Then a set of scenarios has been described to reflect important LC configurations, issues, and technologies that could be further considered in WP3 and WP4.

Overall, the needs and requirements as well as the scenarios described in this deliverable should be considered a starting point for the next Work Packages in the SAFER-LC project and they will be progressively adjusted along the project workflow.

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Annexes

ANNEX 1 – QUESTIONNAIRE ON RISKS AT LCS

Your country:

RISKS FROM THE ROAD SIDE	**High** **Medium** **Low** *(to be completed)*
Level crossing too close to a crossroad	
Poor visibility of road signs	
Bad weather conditions (rain, ice: slippery, fog: bad visibility etc.)	
Too many road signs, poor understanding	
Sounds of bells not audible because vehicles are better insulated to sounds and noises	
Design of the LC (curve before and after, bumps, slopes, high declivity, difficult for buses and trucks)	
Works at certain LCs which are not reported on GPS, professional drivers take another route with a LC with a risky profile	
Barriers that don't open completely and close again rapidly because of trains running in both directions but not detected at the very same time	
Long-time of LCs closure that can generate violation	
Drivers over speeding	
Drivers overtaking queuing traffic	
Distraction of the driver at the approach of a LC while driving	
Pedestrians/cyclists with headphones	
Pedestrians/cyclists using the LC as a shortcut to the neighbouring station or other points of interest	

Easy access through the barriers for pedestrians / cyclists	
TO BE COMPLETED:	
OTHER RISKS FROM THE ROAD SIDE	**High Medium Low**

RISKS FROM THE RAIL SIDE	**High** **Medium** **Low** *(to be completed)*
No train detection: Failure on train detection device	
No train detection: failure on LC control system (cabling, etc.)	
Energy failure on LC (electric local supply, batteries, etc.)	
Failure in road lights (all bulbs blown)	
Failure on sound warning device.	
Both barriers up (no start of down movement)	
One barrier up, one down (failure in one barrier movement)	
Both barriers down but broken boom.	
Vehicle stuck in LC	
Train not crossing LC within expected time.	
Barriers not opening after train crossing: failure on train passing LC detection.	
Barriers not opening after train crossing: failure on LC control system, (cabling, etc.)	
Lack of elements for investigation after the accident	
TO BE COMPLETED :	
OTHER RISKS FROM THE ROAD SIDE	**High** **Medium** **Low**

ANNEX 2 – DANGER INDEX CALCULATION

Danger index calculation. Country A

To decide which kind of protection is needed for a LC, is useful to have some indicators of the risk level at a LC. A used indicator can be the "danger index". It's based mainly on the traffic density (both road and railways), visibility from both sides of the road and other parameters, such as train max. speed, angle of the crossing, slope of the road, etc.
To determine the danger index of a LC, the following formula is used:

$$P = \frac{T \cdot V}{4 \sin \varphi} \cdot \left(\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3} + \frac{1}{F_4}\right) \cdot (1 + b)$$

Where:
T is the number of trains within 12 h with higher traffic.
V is the number of road vehicles within 12 h with higher traffic.
F_1, F_2, F_3 and F_4 are the visibility factors.
φ is the crossing angle between track and road.
b is a parameter.
For calculating visibility factor, both left and right sides visible track, from an observer placed 15 meters away from the closest rail for unpaved roads or placed 30 meters away for paved roads, shall be considered (distance d at Figure 6 - Distances diagram for calculating danger index.)
The formula to calculate visibility factors is:

$$F_i = \frac{\sum l_i}{5 \cdot v}$$

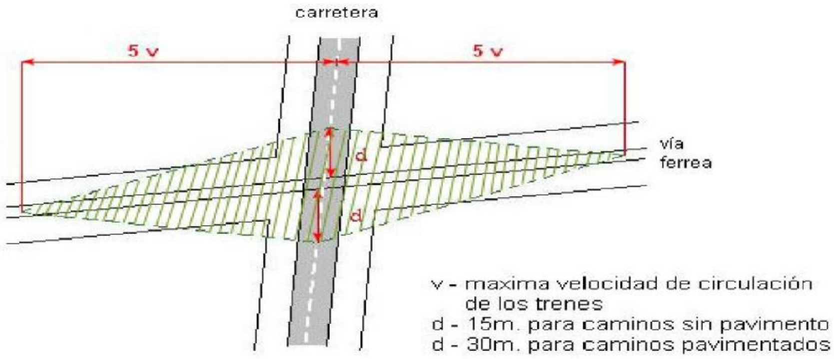

Figure 6 - Distances diagram for calculating danger index

Where:
v is the train speed in km/h
l_i is the length of visible track up to a distance equivalent to 5·v for each one of 4 directions. So if there's no obstacle, visibility will be equal to 1
b will be a parameter from the following table.

Table 36 b index

Total slopes	Up to 8% on both sides	0,30
	Up to 4% on one side	0,15
Narrow crossing		0,10
Lateral roads leading to LC road within 20 m from LC		0,15
Multiple lane road	Two lanes	0,10
	Three lanes	0,20
	Four or more lanes	0,30
Sun reflection		0,15

Once calculated P (danger index), protection type for LC can be established.

- If $P < 12.000$: LC shall be protected with fixed signages.
- If $12.000 \leq P < 50.000$: LC shall be protected with active sound and light warning.
- If $P \geq 50.000$: LC shall be protected with barriers.
- If $P \geq 150.000$, is recommended to build an overpass/underpass