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

Deliverable D2.3

Definition of new human-centred low-cost countermeasures

Due date of deliverable: 31/10/2018

Actual submission date: 31/10/2018

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Project details

Project acronym	SAFER-LC
Project full title	SAFER Level Crossing 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	Definition of new human-centred low-cost countermeasures
Workpackage	WP2
Date of the document	31/09/2018
Version of the document	10
Responsible partner	DLR
Reviewing partner	CERTH, FFE, INTADER, UIC, VTT
Status of the document	Final
Dissemination level	Public

Document history:

Revision	Date	Description
01	22/08/2018	First Draft
02	18/09/2018	Included subsections in results part
03	27/09/2018	Included template for CM description in results part, new sections 1.3, and 1.4.
04, 05	05/10/2018	Included inputs from CERTH, DLR, FFE, UIC and VTT
06	17/10/2018	Added DLR inputs to section 1
07	18/10/2018	Integrated review results on V05 from CERTH, FFE, UIC and VTT (focus CM tables and section 4) with V06
08	19/10/2018	Integrated section 4 and summary draft
09	30/10/2018	Integrated WP2 partners' feedback on section 4 and summary, UIC input to section 5.2, and final feedback from SAFER-LC partners on all parts of the document
10	31/10/2018	Ethical and final review

Consortium - List of partners

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

Executive summary

This deliverable describes the methods applied and the results achieved during the first phase of Task 2.3 within the SAFER-LC project: the design of new human-centred low-cost measures to improve safety at level crossings (LCs). The European project *SAFER-LC* – Safer level crossing by integrating and optimizing road-rail infrastructure management and design – aims to improve safety in road and rail transport by minimising the risk of LC accidents, focusing on both technical solutions and human processes. Within the project, the objective of Work Package 2 (WP2) is to enhance the safety performance of level crossing infrastructures from a human factors perspective, making them more self-explaining and forgiving.

Task 2.3 specifically aims to design concepts of human-centred low-cost countermeasures to enhance the safety of current LC infrastructures and, in a later step, to evaluate these countermeasure designs from a human factors perspective. A two-stage process, consisting of a collection phase and a selection phase, was adopted to define the countermeasure concepts presented in this report. In the first phase, a large pool of design ideas was collected from three different sources: (1) a comprehensive review of the research literature, (2) an analysis and selection of theoretical models relevant to explaining and predicting road user behaviour at level crossings, and (3) a design workshop with road and rail experts. In the second phase, three steps were undertaken in order to systemize and prioritize the measures collected: (1) an elimination of measures based on redundancy, feasibility, and expert ratings of their effectiveness and cost, (2) a classification of the remaining measures with respect to their applicability to different LCs and road user types, and their effect mechanism, and (3) a ranking of the measures based on their prospects for accident risk reduction and the need for further research.

The design process was based on operational descriptions of different types of road user behaviours observed at LCs that challenge safety and hence need to be defined as the target of safety measures. The presence or absence of active controls and barriers at LCs was identified as a particularly significant factor with regard to what types of behaviour need to be supported or prevented. Therefore, the design thinking process and organization of measures drew upon the basic distinction between passive and active LCs.

Measures for passive LCs were mainly to address the problems of road users insufficiently scanning the tracks for trains, insufficiently adapting their approach speed to the need of scanning and the potential need to stop, and road users getting stuck on the rails. Measures for active LCs were mainly to prevent road users from circumventing closed barriers (climbing over / below; swerving around half-barriers), passing the LC in spite of active light signals (e.g. flashing red light), passing the LC after pre-signalling has begun or while barriers are closing, and, again, getting stuck on the rails. Apart from the differences, a range of common possibilities to support safe road user behaviour at both active and passive LCs was identified (e.g. by improving LC conspicuity, using common means of conveying behavioural recommendations adapted to the respective LC type, and helping road users not to enter the tracks when they cannot be sure to leave in good time). In all cases, design considerations included vulnerable (VRU) as well as motorized road users (MRU).

The process resulted in a list of 89 design solutions that can be applied in LC design. The complete list is given in Annex A of this report. The ten measures achieving the best ranks in each of the aforementioned use cases were:

Passive LCs: *Active inverted speed bumps, laser illumination of the crossing, image process warning, blinking peripheral lights drawing driver attention, light markings in the road to highlight the waiting line, speed bumps on approach to the LC, on-road flashing markers, road swivelling, LC attention device*, and *coloured marking of the danger zone*.

LCs with barriers: *Adapting the timing of LC closure to the actual speed of the passing train, camera based enforcement (prosecution of violations), additional display "Two Trains", second chance zone, sound warning indicating an approaching train, lane separation in front of half barriers, increasing the length of the barrier, audible signal while in the danger zone, information countdown to closing the barrier* and *complete open / close cycle.*

All types of LCs: *Proximity message via connected device (in- vehicle display, satnav, mobile device), improving train visibility using lights, audible warnings about LC, extended "no stop" zone, message on smartphone / -watch to warn on approaching train (VRU), coloured pavement markings to mark the danger zone (MRU), satnav intelligence, countdown to train arrival, LED enhanced traffic signs* and *warning sign to avoid blocking back*.

The next steps within the SAFER-LC project will be to conduct empirical tests on selected measures to evaluate their effects on road user behaviour and LC safety, and to integrate the project's practical results and recommendations in a toolbox to be accessed through a user-friendly interface to support rail and road stakeholders in improving safety at LCs.

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List of abbreviations

CWA	Cognitive Work Analysis
D	Deliverable (related to project SAFER-LC)
HF	Human factors
ITS	Intelligent transport systems
LC	Level crossing
LED	Light-emitting diode
MRU	Motorized road users
GNSS	Global navigation satellite system
T	Task (related to project SAFER-LC)
VRU	Vulnerable road users
WP	Work package (related to project SAFER-LC)

1. BACKGROUND AND OBJECTIVES

1.1. Purpose and structure of the document

This deliverable describes the methods and results of the first phase of Task 2.3 in the SAFER-LC project: the design of new human-centred low-cost measures to improve safety at level crossings (LCs). For this purpose, a short introduction to the scope and objectives of the project is given in section 1, followed by a presentation of the specific objectives of Task 2.3 and an introduction of the behavioural patterns shown by road users at LCs that challenge safety and that have been targeted in the design of countermeasures. In section 2, the methods used in the collection, design and selection of measures is described. With regard to the results, thirty of the measures collected that earned the highest ranks in the preliminary evaluation will be introduced in detail in section 3, while a comprehensive overview of all measures collected is given in the appendices A to E. Sections 4 and 5 contain reflections on the process, an outlook on the further evaluation of proposed safety solutions in SAFER-LC – involving empirical tests in simulated environments, protected areas and real traffic –, and an outlook on the planned dissemination of the results in the form of an open-access toolbox.

1.2. Background and objectives of the SAFER-LC project

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

The solutions and tools that are in development in the SAFER-LC project will enable road and rail stakeholders to find more effective ways to: (1) detect potentially dangerous situations leading to collisions at level crossings, (2) prevent incidents by innovative user-centred design, and (3) mitigate the consequences of disruptions due to accidents or other critical events. The main output of the SAFER-LC project is a toolbox which will be accessible through a user-friendly interface which will integrate the project's practical results, tools and recommendations to help both rail and road stakeholders to improve safety at LCs.

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

Within the project, the objective of Work Package 2 (WP2) is to enhance the safety performance of level crossing infrastructures from a human factors (HF) perspective, making them more self-explaining and forgiving.

1.3. SAFER-LC Task 2.3: Design and evaluation of human-centred low-cost measures

1.3.1 Objectives

The two superordinate objectives of SAFER-LC Task 2.3 are to (1) design concepts of human-centred low-cost countermeasures to enhance the safety of current LC infrastructures and (2) to evaluate these countermeasure designs with a human factors perspective.
The first objective was to be achieved by identifying knowledge gaps, new approaches and out of the box ideas concerning LC design and, on this basis, proposing new technological and non-technological measures to enhance LC safety. The process was to be inspired by the insights gathered on the state of the art of LC design and measures in previous work in SAFER-LC (WP1 and WP2), the consultation of experts from road and rail transport, and the findings of worldwide research in the field of human factors applied to level crossing safety. The conception and selection of promising countermeasures were envisaged to encompass entirely new ideas as well as upgrades of existing measures to enhance their innovation potential as well as their self-explaining and forgiving nature.
The second objective encompasses the evaluation of proposed measures to understand their effectiveness in enhancing LC safety, using the criteria defined in the human factors methodological framework developed in Task 2.2 and involving empirical tests at the project test sites (see SAFER-LC Consortium, 2017).

1.3.2 Definitions and specification of measures to be addressed

Summing up the specifications for countermeasures to be designed and collected according to the objectives of Task 2.3, the proposed measures to enhance LC safety are to be (1) human-centred, (2) low-cost and (3) new or innovative, and they are supposed to work by making LC infrastructures more (4) self-explaining and (5) forgiving. For a common understanding, these five concepts were further defined as follows:

(1) *Human-centred* measures are measures whose effect is achieved by influencing road user behaviour at LCs, especially by enhancing adaptive behaviour (e.g. looking for a train before crossing instead of crossing without looking; waiting in front of barriers instead of trying to circumvent them). While the term could also refer to other human agents in the railway system (train drivers, signallers, workers on the tracks, etc.), these were excluded from the scope of the task. The focus on measures that influence road user behaviour was chosen as the vast majority of LC accidents is caused by maladaptive behaviour on the side of road users (DB Netze, 2016; Grippenkoven & Dietsch, 2015; Grippenkoven, 2017).

(2) *Low-cost* measures are measures that cost less than a classic upgrade (e.g. equipping a formerly passive LC with half-barriers; installing full-barriers at a former LC with half-barriers) when applied to a large number of LCs.

(3) *New* or *innovative* measures are measures that are not already in common use to protect LCs in the European countries.

(4) *Self-explaining* refers to the clear and appropriate design of safety measures implemented at the LC which supports adequate situation awareness, meaning that it supports (1) the detection and perception of the situation; (2) the understanding the meaning of signs and measures; and (3) the ability to project the current status of the traffic situation at the level crossing into the future (Havârneanu, Silla, Whalley, Kortsari, Dreßler, & Grippenkoven, 2018).

(5) *Forgiving* means that the safety measures implemented at a LC include appropriate measures to counteract road user misbehaviour (e.g. errors, violations, or deficient behavioural adaptation), and if misbehaviour occurs, the system is able to mitigate the consequences (Havârneanu et al., 2018).

Furthermore, taking into account the infrastructure focus expressed in the objectives, the task was specified to focus on measures that can be applied or have a direct effect on road user behaviour at the level crossing itself. This includes, for instance, traffic infrastructure elements that can be installed at a crossing (e.g. road elements like speed bumps or lane dividers, light markings, signs), law enforcement measures noticeable at the LC (e.g. cameras) as well as changes in operational procedures that lead to a direct change of the situation at the crossing (e.g. shortening and equalizing closure times by adapting the timing of closure to the speed of the respective train). Measures that are not applied at the crossing itself (e.g. the revision of driving education) were excluded from the focus of the task.

1.4. Main issues concerning road user behaviour at different LC types

Taking a human factors perspective on the action of encountering and crossing a level crossing, there are five steps of information processing that road users need to complete for the purpose of a safe traverse (Graab, Donner, Chiellino, & Hoppe, 2008; Grippenkoven, 2017; Havârneanu et al., 2018):

(1) to *detect* at least parts of the safety layout of a level crossing (e.g. signs),

(2) to correctly *identify* the kind of level crossing that these parts of the safety layout belong to,

(3) to *retrieve* schemas and scripts connected to passing the LC from memory (or other sources),

(4) to *decide* on an appropriate action, i.e. to form an intention that matches the current situation, and finally

(5) to properly *execute* the intended action.

Things can go wrong in each of these stages, leading to errors or violations. A wide range of environmental factors as well as individual conditions and traits influence the probability of errors and violations occurring at LCs (e.g. sight distances, road layout, weather conditions, road and rail traffic density; reduced sensory or motor capacities, distraction, time pressure, fatigue or individual propensities in risk assessment). However, when considering the *quality* of maladaptive road user behaviour that LC safety measures seek to tackle, there is one factor exerting a major influence: the type of protection applied at the respective crossing. The reason for the crucial role of the protection type is that it is the primary determinant of behavioural demands imposed upon road users in the aforementioned phases of information processing after LC detection. The most basic distinction concerning these behavioural demands depends on the presence or absence of active controls and barriers at the LC. Closed barriers represent a strong and almost impossible-to-misunderstand cue to road users that they should stop in front of the crossing. In contrast, on approach to passive LCs, road users need to determine on their own whether they need to stop and grant the right of way to an approaching train, and therefore must enter into another loop of visual search and potential detection after detecting the crossing itself. Thus, there are fundamental differences in the action schemata that need to be activated and executed facing passive LCs compared to LCs that are equipped with barriers (Grippenkoven & Dreßler, 2018).

The differences in behavioural demands are associated with differences in the main issues that arise in road user behaviour at passive and active LCs, respectively, and that need to be defined as the target of safety measures. The focus of problematic behaviour at passive LCs is an insufficient preparation of the traversing action in terms of obtaining information and putting oneself in a position to stop in good time if necessary. While these aspects are much easier to accomplish with the help of active signals and barriers at active LCs, the main challenge for road users at this type of crossing is the extrinsic imposition of waiting time that comes into conflict with the individual's mobility goals and potentially provokes violations (Seehafer, 1997). Apart from these motivationally induced issues, problems with anticipatory action planning could lead to a situation in which a road user gets stuck on the rails or "trapped" within the barriers because of a wrong estimation or omitted consideration of the time needed to cross (e.g. due to traffic tailback or an overestimation of their own achievable speed in light of an imminent closure; Pelz, 2011). Though this problem is accentuated by the presence of barriers that represent an additional obstacle in leaving the tracks, it equally needs to be considered at passive LCs.

Table 1 summarizes the challenges in road user behaviour observed at passive and active LCs that were used as a basis for the design thinking and search for safety measures in Task 2.3.

Table 1. Challenges with road user behaviour at passive vs. active level crossings

Passive LCs	▪ Insufficient visual scanning of tracks for train ▪ Insufficient adaption of approach speed to scanning needs and potential requirement to stop ▪ Getting stuck on the rails
Active LCs (full-barriers, half-barriers, lights)	▪ Circumventing closed barriers (climbing over / below; swerving around half-barriers) ▪ Passing the LC in spite of active light signals (e.g. flashing red light) ▪ Passing the LC after pre-signalling has begun / while barriers are closing ▪ Getting stuck on the rails

Apart from the differences that have been pointed out, passive and active LCs also have a number of things in common in terms of how road users can be supported in successfully dealing with them. Looking at the first stage of information processing, LC detection, measures that enhance the conspicuity of the LC will be beneficial in either case. In the following stages, although the specific design needs to be adapted to the demands at the respective crossing type, common measures could be used to support them. For example, the activation of the correct action scheme (either to slow down and look left and right for a train or to watch the status of active controls and take heed of the signals) could be helped by providing cues and information through the same channel (e.g. an in-vehicle information system). Furthermore, similar measures could be applicable at either kind of LC to support road users in refraining from entering the track area when they cannot be sure they can leave it in good time (Cale, Gellert, Katz, & Sommer, 2013).
Minding the differences as well as the similarities of different LC types, the presentation of safety solutions in this deliverable is structured around the three basic use cases resulting from these considerations: (1) passive LCs, (2) active LCs and (3) all LCs.

2. METHOD

2.1. General approach

The identification, design and innovation of LC safety measures conducted as part of Task 2.3 consisted of several steps (see Figure 1):

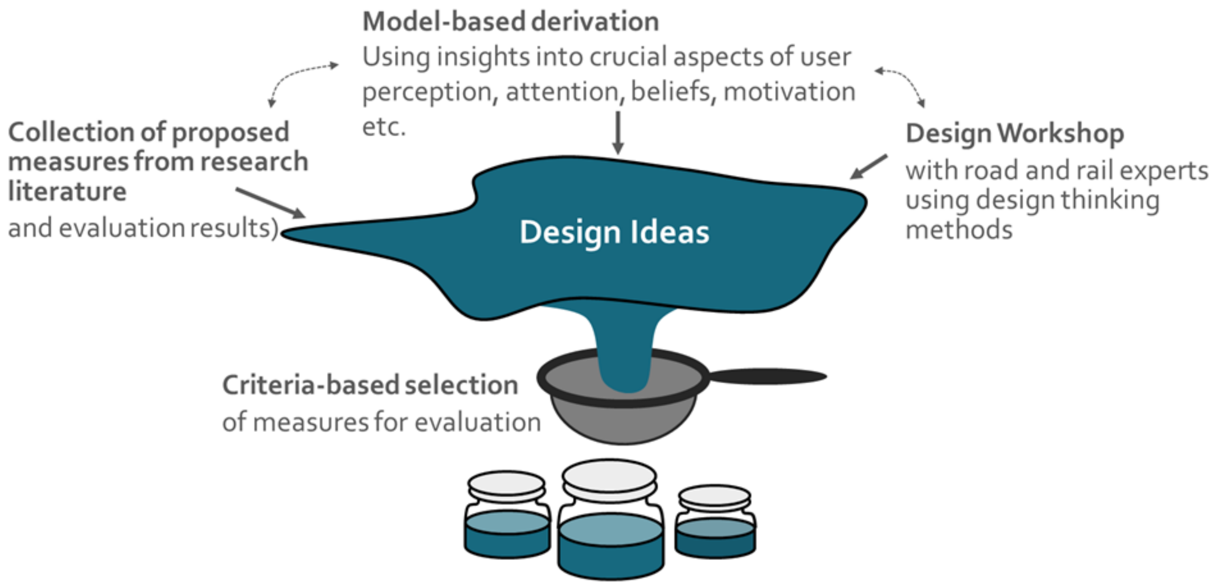


Figure 1. Approach in the definition of new human-centred low-cost countermeasures.

- **Collection of proposed measures from research literature:** Identification of LC safety measures based on the review of existing studies, reports and experiences collected nationally and internationally in the field of human factors applied to LC safety. This review partly exploited the work conducted at earlier stages of this project, focussing especially on the results of WP1 (SAFER-LC Consortium, 2017) and Task 2.1 (SAFER-LC Consortium 2018). In addition to the identification of LC safety measures, the partners collected available information on the effectiveness of these measures and documented the results in a shared document. These evaluation results will be utilised later in WP2 when the effectiveness of selected LC safety measures will be evaluated.
- **Model-based derivation:** Collection of LC safety measures from models of user experience and road user behaviour. This identification process made use of the review conducted as part of Task 2.2 of the most important human factors and psychological models, which were assessed to provide additional theoretical foundations for the human factors methodological framework in the LC context (Havârneanu et al. 2018).
- **Design workshop:** A workshop was organised to collect additional inputs regarding LC safety measures from the SAFER-LC Advisory Board and from other LC experts (both rail and road experts). The aim of the workshop was to use the experience and the creative

potential of road and rail traffic experts to conceive innovative measures to make level crossings safer by positively influencing road user behaviour. The workshop participants were instructed to consider all LC types and road user groups in their brainstorming.

- **Criteria-based selection:** The most promising LC safety measures were selected from the long list of LC safety measures (identified in the three previous steps) for piloting and evaluation, which will be done in the later phases of the SAFER-LC project. The procedure for this ranking and selection of measures is explained in detail in chapter 2.3 of this deliverable.

The three steps taken as part the collection phase and the method adopted to evaluate and prioritize measures in the selection phase are described in more detail in the following sections

2.2. Collection of LC safety measures

2.2.1 Review of the research literature

As a first step in the approach to generating countermeasure design ideas, information was collected from the research literature. This task was performed in coordination with the literature review undertaken as part of Task 2.1 (towards D2.1 State of the Art of Level Crossing Safety Analysis) which proved an efficient way to obtain information serving both tasks.

A total of 125 documents were included in this human factors literature review, previously identified by WP2 partners and listed in a shared bibliographic database. Partners were asked to identify documents with a focus on human factors at level crossings, with no limits to the geographic scope or type of literature included (e.g. scientific articles, research papers, projects, communications, analytical tools etc.). The documents were collected from online scientific databases and web tools, ResearchGate, websites of related research projects and cited references listed in the bibliography of other publications.

The listed publications were distributed for analysis between all task partners. The review form used in the analysis of the documents included a field to capture information on countermeasures. In addition to gathering some basic information on the measure(s), it contained a link to a detailed countermeasure spreadsheet which sought to identify:

- Measure designation
- LC type
- Description of intended function
- Picture (if available)
- Theoretical and empirical evidence of effectiveness
- Literature where measure is cited
- User groups aimed at
- Recommendations for application
- Possible negative effects
- Contributor / Editor

This review process resulted in 71 entries, with some overlap between the countermeasures cited. Some more innovative measures were listed, along with a number of classic upgrades of existing measures. Evidence of effectivity was included only in some cases. The results of this review process constitute the first stage in defining countermeasure design ideas based on the research literature.

2.2.2 Ideas based on human factors models and partner expertise

The collection and development of LC safety measures were also based on existing publications, data sources, and analytical tools in the field of road and railway safety, traffic and transport psychology, and human factors (HF) research. The work to collect such information was conducted in line with D2.1 (development of the "State of the art of LC safety analysis: identification of key safety indicators concerning human errors and violations") and D2.2. (development of the "Human Factor methodological framework").

Ideas about safety measures were identified and selected based on rail human factors literature, published studies, and suitable approaches from related research projects. In addition, ideas were driven from applied studies and lessons learnt in practice by the consortium members and external experts (see next section 2.2.3).

The theoretical basis for developing and evaluating LC safety measures from the human factors viewpoint can be found in Sociotechnical Systems Theory (Cherns, 1987; Emery, 1959; Trist, 1981). Human Factors and Ergonomics use systems-based methods to support the design of complex and safe systems. An increasing number of researchers are supporting the use of a systems approach when analysing and redesigning rail LC systems (e.g. Read et al., 2013; Salmon and Lenné, 2015; Stefanova et al., 2015). The advantage of the systems approach is that it considers all the relevant components within a LC context and the complex interactions between these elements: level crossing users (e.g. pedestrians, older drivers); vehicles (e.g. heavy vehicles, rolling stock); level crossing infrastructure (e.g. sight distances, signage); and the broader environment (e.g. weather conditions) (Searle et al., 2012). This is important as road users with different individual characteristics interact with the various technologies in different LC environments. Countermeasures adopted through the safe systems approach seek to make the characteristics of level crossings more forgiving of human error, and to minimise the level of unsafe road user behaviour (Searle et al., 2012).

The HF methodological approach is in line with the Cognitive Work Analysis (CWA) framework (Vicente, 1999) which has emerged as a promising approach for supporting the design of safe LC systems. The literature review reported in D2.1 (SAFER-LC consortium, 2018) conducted on 125 publications found that of those publications applying analytical models (n=14), Cognitive Work Analysis (CWA), was the most commonly cited approach. CWA refers to a 5-step analysis which can also be successfully applied in the LC context:

(1) **Work Domain Analysis:** describes the environmental constraints on behaviour (e.g. LC type: passive/active, LC context: urban/rural, etc.)

(2) **Control Task Analysis:** describes the needed decisions and tasks (e.g. decision ladder, information queues, etc.)

(3) **Strategies Analysis:** identifies various strategies to fulfil the tasks (e.g. violations at active LC, personal motivations, habits due to exposure over time, etc.)

(4) **Organisational Analysis:** refers to the social organisation, cooperation, division of work, allocation of functions between humans and technology (e.g. technology or design compensates for the human errors at LCs, etc.)

(5) **Competencies Analysis:** refers to the skills required by the actors operating within the domain (e.g. individual differences and capabilities of different users of LCs, VRU – vulnerable road users, cultural differences, differences between frequent and infrequent LC users, etc.)

From these principles, one can derive further ideas to define and evaluate new human-centred low-cost measures: the suitability for all kind of road users (MRU – motorized road users, as well as VRU), acceptability by involved parties, or the ability to make the LC infrastructure self-explaining. In addition, the applicability to various environmental contexts and types of LCs are very important (e.g. passive/active, rural/urban etc.). Whilst both errors and violations should be considered, one should bear in mind that violations are mostly if not only relevant at active LCs, and that safety measures should be targeted accordingly.

The theory and model-based derivation enabled additional insights into essential aspects of the road user perception, attention, beliefs, motivation, etc. The human factors and psychological models reviewed in D2.1 (SAFER-LC consortium, 2018) and D2.2 (Havârneanu et al., 2018) provided additional theoretical foundations in the LC context, enriching the mainstream CWA approach with aspects that can be manipulated through safety measures implemented at LCs. Overall, the models and theories reviewed propose a set of factors that can be considered at specific levels of the CWA. They highlight the importance of: (1) the main individual capabilities which shape the road user's performance at a LC; (2) the hierarchical behaviour precursors where errors can occur (e.g. skills, rules, knowledge); (3) the factors influencing the subjective risk perception and risky decision-making; and (4) the individual and external motivational factors affecting the risky behaviour at LCs and the behavioural adaptation in the long term. The inclusion of motivational aspects in the human factor analysis is important especially since the criteria on motivation, habits and systematic violations as voluntary unsafe behaviours are theoretically interrelated. This points to the fact that new human-centred low-cost measures should be able to play an effective role on one or several of these factors.

During the process of analysing the models and theories of user experience and road user behaviour from relevant publications, some innovative ideas emerged concerning human-centred low-cost safety measures. The relevant ideas and examples of interventions were documented and collected in a spreadsheet along with the results from the review of the research literature. This was the second stage in defining countermeasure design ideas, based on the models and theories from the research literature.

2.2.3 Design workshop with road and rail experts

Apart from the identification of measures for level crossings from the research literature and models of user behaviour, it was considered essential to also involve experts from both the railways and the road sector in this discussion. For this reason a dedicated workshop, entitled

"Design Workshop on Human-Centered Safety Measures" was held in Paris on the 27th of March 2018 at the UIC Headquarters. The overall goal of this workshop was to use the experience and the creative potential of road and rail traffic experts to conceive innovative solutions to make level crossings safer by positively influencing road user behaviour.

In total, 38 road and rail systems experts from 12 countries (Belgium, Finland, France, Germany, Greece, Hungary, Italy, Norway, Poland, Spain, UK, and USA) participated in the workshop. The experts were separated in six groups, each one including six to seven participants. One human factors expert (partner of the SAFER-LC Project) was assigned to moderate the work done in each group. Given that problematic road user behaviour varies based on the type of LC considered, the groups worked on creating countermeasures to enhance safety for three different scenarios regarding LC protection: active level crossings with full barriers (groups 1 and 2), active level crossings with half-barriers and / or light protection (groups 3 and 4), and passive level crossings (groups 5 and 6).

The workshop was organized in two main phases, namely conception and evaluation. The conception phase started with the groups familiarizing themselves with their specific assignment, guided by the moderator and using a written assignment sheet. The assignment included an introduction to the specific scenario and typical examples of problematic road user behaviour observed at this LC type. Moreover, two groups of road users (VRU – vulnerable road users, MRU – motorized road users) were introduced with example images (e.g. pedestrians, cyclists, children, people with sensory and motor impairments, motorcyclists, car drivers, truck drivers, drivers of agricultural vehicles). Participants were asked to devote about half of their time in the conception phase to take the perspective of a vulnerable and a motorized road user, respectively, when thinking about ways to make their LC type safer for these persons. The groups were instructed to brainstorm in order to generate about 20 ideas. Before starting the evaluation phase, half of each group's members joined the other group dealing with the same scenario, to encourage a fresh perspective on the ideas generated. Following this, each group was provided with five additional profile sheets depicting promising LC safety measures, coming from the literature review conducted earlier in the course of WP2. Finally, group members proceeded with the rating of each measure ([1] *How effective?*, [2] *How low-cost?* and *[3] How innovative?*) on a Likert scale ranging from *1 - not at all* to *5 - most*) and chose one "best" measure on each dimension. The design ideas derived from the workshop were edited in a tabular format to be joined later with the ideas collected from the literature review and the human factors modelling.

2.3. Criteria-based ranking and selection of measures

The design and collection activities described in the previous section resulted in a pool of potential countermeasures to enhance LC safety that contained 185 entries altogether. All proposed measures were compiled in a spreadsheet with one line per measure and multiple columns containing information on the measure (name, description, depiction, etc.). The next step on the way to identifying the low-cost human-centred measures most worthwhile to be recommended and further tested empirically in the evaluation phase of Task 2.3 was to review, systemize and prioritize the measures in the pool. For this purpose, three steps were undertaken:

- **Reduction** based on redundancy, practicability, project scope and expert ratings

- **Classification** of applicability and effect mechanism
- **Ranking** based on prospects for accident reduction and research need.

The procedure is described in detail in the following sections.

2.3.1 Reduction based on redundancy, practicability, project scope and expert ratings

The goal of the first processing step was to cleanse the pool of countermeasures by combining redundant mentions into one, eliminating entries that appeared to be impracticable or outside the project scope or received extremely low expert ratings concerning effectivity or cost-efficiency.

The identification of redundant mentions was based on a comprehensive review of the countermeasure list that was done individually by all WP2 partners as a first step. Subsequently, the measures that were marked to be potentially redundant by any of the partners were jointly discussed, and decisions were made concerning the retention of single mentions or the combination of two or more repeated mentions into one. In the latter case, if there was an aspect included in one of the repeated mentions that was not given in the instance that was kept, this aspect was added to the instance that was kept. All entries that were excluded for redundancy are listed in Annex E.

Another subgoal of the data cleansing process was the identification and exclusion of measures that appeared impracticable. Reasons for impracticability could be problems with regard to applicable law, social acceptability, ethics or other. For this purpose, all WP2 partners were asked to provide individual practicability ratings for all measures in the spreadsheet. The basic assessment to be made was: Is the measure practicable, yes or no. In case of a no, partners were asked to add a short comment on the reasons. For cases that did not appear absolutely impracticable, but in which partners wanted to make a qualification to a yes answer because of perceived challenges to putting the idea into practice, the instruction was to use the answer yes* and add a short comment on the reasons (example: a measure is not compatible with current law, as e.g. in Germany combining the Stop sign with the St. Andrew's cross, but it is imaginable that the law could be changed accordingly). Ten partners provided practicability ratings. A measure was eliminated from the list if half or more of the partners answered the question about its practicability with no. Excluded measures are listed in Annex B.

The identification of out-of-scope measures followed the procedure of individual review and notation as a first step and joint discussion and decision as a second step, in the same way as that applied to the identification of redundant mentions. For any measure found to be out of scope, the reason for this assessment was noted accordingly in the spreadsheet (e.g., classic upgrade [not innovative], not clearly defined measure, not directed at human road users [not human-centred], not testable in project; see Annex C).

To support the identification of potential measures for the evaluation, another rating collected from the SAFER-LC partners concerned the testability of measures in the project concerning their effects on road user behaviour. At the time of the inquiry, the following sites were projected for tests in SAFER-LC at which an evaluation of the human-centred effects of LC safety measures was conceivable: the living lab of TRAINOSE and CERTH in Thessaloniki, the research facilities of the DLR consisting of driving simulators in Braunschweig and a mobile traffic data acquisition platform, five LCs in Turkish cities intended for real-world tests by INTADER, the protected railway testing area of the RWTH in Aachen, a driving simulator to be used by the SNCF in Chalon-sur-Saône, and the technical test site of VTT in Tampere (cf. SAFER-LC Consortium, 2017). The leaders of each of these test sites were asked to provide information about the testability of each measure at their site (How well could a test be arranged at your site to test the respective measure for its effect on road user behaviour at LCs [or particular aspects of this behaviour]?). The scale for the answer consisted of three levels: good, challenging, and impossible. Some partners used combinations of these, e.g. good/challenging. A measure was eliminated from the list if all of the test site leaders answered the question about its testability with impossible. Exclusions are listed in Annex C, together with the measures that were not within the project scope.

The last criterion for reduction made use of the expert ratings obtained in the design workshop (cf. section 0): Measures that received extremely low mean experts ratings in effectivity or low-cost (i.e. rating <=2 on a scale from 1 to 5) were eliminated from the further process (list of measures and mean ratings in Annex D).

The result of the reduction was a list of 89 potential LC safety measures, including testability and practicability ratings to support the prioritization of measures in the further steps.

2.3.2 Classification of applicability and effect mechanism

The goal of the second step in the processing of the countermeasure pool was to provide a consistent basic categorization of the measures in terms of their applicability for different LC and road user types as well as the mechanisms by which the intended behavioural effect is to be attained (cf. the classification criteria in the human factors methodological framework, Havârneanu et al., 2018). Besides the attainment of an application-oriented structure for this deliverable and the foundation of a more detailed classification system for the later presentation of measures in the toolbox, the classification mainly served the purpose of preparing the third step of the selection process (cf. section 2.3.3). This involved comparing the scope of a measure with common causes of LC accidents in order to assess the potential of the measure to reduce accident risk.

Using the countermeasure spreadsheet, the following classifications were made:

- **LC type applicability**: *full-barrier* (yes/no), *half-barrier* (yes/no), *passive* (yes/no)
- **Road user type applicability:** *MRU - motorized road users* (yes/no), *VRU - vulnerable road users*
- **Effect mechanism:** 1 - *improves train detection*, 2 - *improves LC detection*, 3 - *controls the access to LC*, 4 - *reduces approach speed of vehicles*, 5 - *increases awareness of correct behaviour / dangerousness of LC*, 6 - *improves physical environment of LC*, 7 - *provides up-to-date information about LC status*, 8 - *supports LC safety actions (risk analysis)*, 9 - *improves possibilities of VRU to cross the LC safely*, 10 - *Other*
- **Main psychological function involved in the measure's effect:** 1 - *Detection* (focus on visual / auditory perception), 2 - *Identification* (focus on attention and workload), 3 - *Rule*

knowledge (focus on knowledge retrieval), 4 - *Decision-making* (focus on risk-perception, subjective judgment, and motivational factors), 5 - *Execution* (focus on motor execution of action)

The effect mechanism categories were defined according to Silla, Seise & Kallberg, 2015. The classification of the main psychological function involved in the measure's effect followed the theoretical model of human information processing at LCs (Grippenkoven and Dietsch, 2015; Grippenkoven, 2017; Havârneanu et al., 2018). The classifications of LC type and road user type were prepared by one WP2 partner and subsequently discussed and jointly decided upon by all partners. The classifications of effect mechanism and psychological function involved were made by two WP2 partners each. All results were included in the countermeasure spreadsheet. The classifications were used to facilitate the comparison of measure scope and accident characteristics in the next step and can further be used for sorting the pool of measures under different aspects in future tasks.

2.3.3 Ranking based on prospects for accident reduction and research need

The goal of the third processing step was to enable a ranking of the measures concerning their prospects to increase LC safety. A second aspect to be considered in the ranking was the need for more research: Especially very innovative measures do not typically have a rich record of research evidence showing their effectiveness even though they might be promising to reduce accident risk. To prepare the ranking of measures, two expert ratings were collected from each of the organizations participating in WP2 of the SAFER-LC project:

- **Prospects for accident risk reduction**: 1 – Not at all, 2 – slightly, 3 – moderately, 4 – strongly, 5 – very strongly
- **Need for more research**: 1 – Not at all, 2 – slightly, 3 – moderately, 4 – strongly, 5 – very strongly

For achieving valid assessments of a measure's prospects for accident risk reduction, all contributing experts needed to have good awareness of the kind and frequency of accidents happening at LCs under various circumstances (e.g. protection type, road users involved, road characteristics, crossing angle, sight distances etc.). The contributors had previous experience in research on LC safety and could be assumed to have an overview of accident occurrence at LCs in Europe (as deep as the current documentation practice allows) as well as the specifics of their own country. Moreover, as a common basis for this awareness, the experts were instructed to once again study the results of the in-depth review of LC accident data from seven European countries (Silla, Peltola, Aittoniemi, Sintonen, Kortsari, Taillandier et al., 2017) that had been prepared in SAFER-LC WP1. Beyond this (e.g. in cases where a higher degree of differentiation was needed), experts were advised to draw upon their previous knowledge and additional sources to complement the picture. The question to be answered by the rating was: *Considering the accident data compared to the scope (LC type, road user type) and assumed effect (effect mechanism, psychological function aimed at) of the measure: To what extent will this measure probably reduce accident risk?*

Likewise, the rating about the need for further research was made based on a common foundation of knowledge consisting of the information about studies on the measure and evidence of effectiveness collected in the spreadsheet. However, as the entries in these columns could not be assumed to be exhaustive for all measures, experts were requested to make a heuristic judgement and additionally draw upon their previous experience where needed. The question to be answered in the rating was: *Considering the existing data on the effects of the measure: To what degree does the measure need further research?*

Overall, nine experts participated in the rating procedure. The inputs of all partners were collected, and the mean value was calculated for each of the ratings. The list of measures was then sorted in descending order by (1) the mean of the *prospects for accident reduction* rating and (2) the mean of the *need for further research rating. A rank* variable was created based on the resulting order.

The result of the third processing step is a list of 89 LC safety measures in which the measure rated with the highest prospects for accident risk reduction ranks first, while measures with lower prospects for risk reduction appear in a later position. If two measures score equally on this criterion, the one with the higher need for research ranks better than the other.

2.3.4 Mode of presentation in the deliverable

In order to provide the reader with a clear and easy-to-review presentation of the results, only a subset of the 89 measures that resulted from the selection process will be introduced in the following sections. The complete list is available in Annex A. In chapter 3, we will present the 30 measures that reached the highest ranks for the three different LC use cases introduced earlier, i.e.:

- Measures for passive level crossings
- Measures for level crossings with barriers (half-barrier, full-barrier)
- Measures for use at all kinds of level crossings

In each category, the 10 highest-ranking measures[1] are introduced in tabular form, including a description of the measure, followed by information on the target road user group, the proposed effect mechanism, potential negative effects or restrictions, recommendations for application, and, where available, an illustration.

[1] Compared to the ranking table in Annex A, one entry will however be skipped here because it represents a combination of measures that also appear as single entries (cf. 4.2)

3. RESULTS

3.1. Measures for passive level crossings

This section presents the measures that have been evaluated as most effective in improving LC safety when applied at passive LCs. The countermeasures described in this section aim to increase the safety of passive LCs, for example, by helping the road users to detect the approaching LC in time, by helping them to adjust their approach speed so that they have enough time to scan for approaching trains, and by helping them to adjust their approach speed so that they are able to stop before the LC if needed.

3.1.1 Active inverted speed bumps

Illustration	
Measure description	An inverted speed “bump” that is activated only if an approaching vehicle exceeds a defined speed. During the activation, a hatch (integrated into the road) lowers the pavement surface by a few centimetres, creating an inverted speed bump. (The system is currently being tested on a road with 50km/h speed limit in Sweden; Frost, 2018). Reportedly produces less noise than a conventional speed bump.
Road users aimed at	Motorized road users.
Prop. effect mechanism	Reduces approach speed of vehicles.
Psychol. functions	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and execution (focus on motor execution of action).
Potential negative effects / restrictions	– More difficult to implement in areas with heavy snow, unknown yet how the structure deals with adverse weather conditions (e.g. excessive rainfall, snow and ice). – Requires more regular maintenance and is more expensive than a conventional bump. – Safety considerations for vulnerable road users such as motorcyclists and cyclists (e.g., might the dip, surface material and surprise element of encountering this measure destabilise these road users?).
Recom-mendations for appli-cation	– Specific guidelines might be needed for the maintenance of actively inverted speed bumps. – Road users should be made aware of the active inverted speed bumps well in advance.

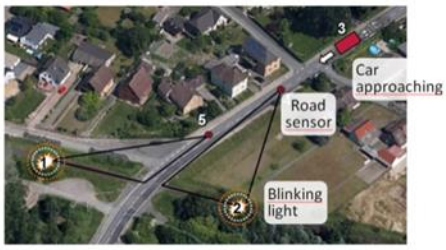
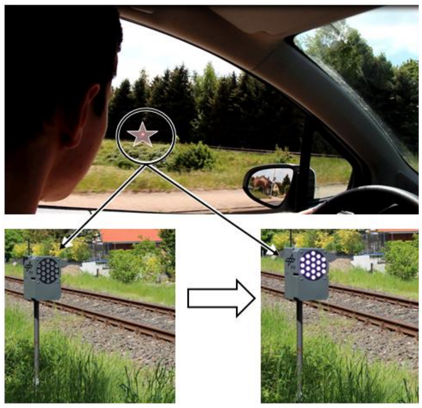
3.1.2 Laser illumination of crossing

Measure description	LC illumination with solar-powered laser to increase its conspicuity (will also work on top of snow). Low power requirement (could use battery). Can produce pattern like a laser light show. This measure could be activated on approach of train and/or road users.
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Improves LC detection.
Main psychological functions involved	Detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Effectiveness may vary under different weather and light conditions.
Recommendations for application	– Road users need to be made aware of the functioning of the measure (i.e. they understand the aim of the measure and it is not a surprise to them). – Illumination parameters could be dynamically adjusted to different lighting conditions, so that the laser pattern is equally visible in dull and very bright conditions.

3.1.3 Image process warning

Measure description	Road vehicle approaching the LC uses camera and image processor to detect passive LC. Warning provided to the driver via head-up display. This measure could also be used to detect approaching train given adequate sight distances.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Improves LC detection and improves train detection.
Main psychological functions involved	Identification (focus on visual / auditory perception).
Potential negative effects / restrictions	– The measure only applies to those road users who have access to the relevant technology. – Risks of overreliance on this information source when the most important safety measure is for the road user to be attentive and look carefully at this type of LC.
Recommendations for application	– It is important to inform the car drivers that this measure is not failsafe (i.e. there might be LCs and/or railway vehicles, which are not identified by the system or the camera and/or image processor can be out of order). – Road users should be made aware of the functioning of the measure (e.g., by providing this information when the drivers are installing this programme and/or starting to use this programme in their head-up display; announcements in the media to support public awareness and understanding).

3.1.4 Blinking lights drawing driver attention

Illustration	 
Measure description	When a car passes an in-road sensor on approach to the LC, two lights located in the periphery of the level crossing start blinking. The light sources appear in the periphery of the driver's visual field. The salient blinking lights trigger an automatic and effortless visual orientation reaction of the driver towards the peripheral regions of the level crossing that require visual scanning to detect a train (exogenous capture of attention, physiological mechanism).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Improves train detection.
Main psychological functions involved	Detection (focus on visual / auditory perception) and identification (focus on attention and workload).
Potential negative effects / restrictions	– Light emission might disturb residents during night times. Shading equipment can be added to avoid this issue.
Recommendations for application	– Adjust the position of the blinking lights to the respective crossing to optimize the visibility from vehicles with different heights and front vehicle structure. – Maximal usefulness at level crossings with a crossing angle around 90°. – Use light colours that are not used in other traffic areas to convey messages (e.g. white). Avoid red, green, yellow or blue light (licensing problems). – Depending on the location, the system might be solar powered. In dark areas the power supply has to be ensured in a different way. – With a corresponding sensor for detection, the measure will also be useful for pedestrians and cyclists.

3.1.5 Light markings in road to highlight transversal waiting line

Illustration	 
Measure description	Integration of a row of coloured lights into the surface of the road and/or sidewalk, perpendicular to direction of approach. Lights will be activated whenever a rail vehicle (in case of LCs protected with warning lights) or a road vehicle (in case of passive LCs) approaches the LC. Lights aim to generate a "visual barrier", enhancing attention of road users and supporting in stopping in front of the LC (cf. Aigner-Breuss et al., 2013).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Improves train detection and controls the access to LC.
Main psychological functions involved	Detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Potential decrease of readiness to stop at conventionally protected LCs due to shifts in attentional habits. – Effectiveness could vary under different weather and light conditions (e.g. If the user becomes used to guiding their actions based on this visual information, it could have safety consequences in the event of restricted visibility or fault in the lights).
Recommendations for application	– Use in areas without much distraction from or interference with other light or visually salient sources (traffic lights, illuminated or rolling advertisement etc.), e.g. in rural areas.

3.1.6 Speed bumps on approach to LC

Illustration	
Measure description	Installation of well-marked speed bumps within the LC approach zone to reduce road vehicle speed, thus maximising the time available to the driver to process information and make (correct) decision. Layout must prevent driving around bump (cf. Aigner-Breuss et al., 2013).
Road users	Motorized road users.
Prop. effect mechanism	Reduces approach speed of vehicles and improves LC detection.
Psychol. functions	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Enhanced noise pollution, especially in unloaded trucks and tractors (proportion should be checked before implementation). – According to a Finnish study (Seise et al. 2009) roughly half of the people who live near the LC equipped with speed bumps and use it frequently considered speed bumps very unpleasant, while the other half did not see any significant disadvantages. – Due to the potentially poor road user acceptance of this speed calming measure, their attention may not be so directed towards safety signage or safe actions, but toward feeling frustrated or on how to avoid the bumps.
Recom-mendations for application	– It is advisable to conduct a trial of speed bumps before any widespread installation. Speed bumps may be contraindicated when the road surface type and the use of snow removal machinery make them impractical. – Layout must prevent driving around bump. Consider covering the whole width of the road. This way road users cannot avoid the bump, and the measure will implicitly target two-wheelers as well: motorbikes, mopeds, and even cyclists. – Choose distance to prevent distraction directly ahead of LC (Aigner-Breuss et al., 2013) and choose height of bump according to speed reduction needed (Ibid.). – Specific guidelines are needed for the maintenance of speed bumps if installed on gravel roads, which also involves manual work (Seise et al. 2009). – More studies are needed to determine what kinds of LC are best suited to speed bumps, how they should be fastened to different kinds of gravel surfaces, what the proper dimensions of the bumps would be to effectively reduce speeds while being acceptable to road users, and how their maintenance should be organised. (Ibid).

3.1.7 On-road flashing markers

Illustration	
Measure description	Train-activated flashing light beacons on the road (similar to airplane runways) aiming to improve driver behaviour at LCs by indicating the location where the drivers are expected to stop their vehicle. At passive LCs, the lights can be activated 20 seconds prior to the arrival of the train (Larue, Rakotonirainy, & Haworth, 2015).
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LCs and provides up-to-date information about LC status.
Main psychological functions involved	Detection (focus on visual / auditory perception) and identification (focus on attention and workload).
Potential negative effects / restrictions	– Effects of complacency or overtrust could results in case the system fails or, given a certain distribution and familiarity, at passive LCs not yet equipped with the system. – Effect of lights can be attenuated by material covering the road (e.g. snow, leaves, dirt). – Effectiveness could vary under different weather and light conditions (e.g. If the user becomes used to guiding their actions based on this visual information, it could have safety consequences in the event of restricted visibility or fault in the lights).
Recommendations for application	– It is important to inform the car drivers that this measure is not failsafe – Special attention should be put on the maintenance (and snow clearance) of these lights

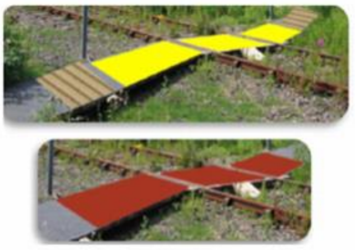
3.1.8 Road swivelling

Illustration	
Measure description	Implementation of a swivelling / bending road course ("gateway") on approach to LCs to evoke speed reduction and enhanced attention in motorized road users (cf. Aigner-Breuss et al 2013).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Reduces approach speed of vehicles and improves LC detection.
Main psychological functions involved	Detection (focus on visual / auditory perception) and identification (focus on attention and workload).
Potential negative effects / restrictions	– Distraction in front of LC. – Drivers may attempt to speed up directly after leaving the gateway (Vaitkus et al, 2017).
Recommendations for application	– Use when adaption of speed is not supported by road / environmental layout (Aigner-Breuss et al., 2013). – Choose distance to prevent distraction (due to steering load) in front of LC and to allow placement of vehicle in 90- angle in front of LC (Ibid.). – Ensure visibility (e.g. by road lighting; Ibid.). – Care should be taken that the angle of the curve on approach does not affect visibility of the level crossing.

3.1.9 LC attention device

Illustration	
Measure description	The LC attention device warns road users about a LC and approaching trains / railway vehicles by yellow blinking LED light. The LC attention device aims to improve the safety of all road users using the LC by improving LC visibility. The device consists of two parts: i) transmitter installed in a train / railway vehicle and ii) attention device (which provides the warning) located near LC. The transmitter installed in a train / railway vehicle sends GNSS based information of its location to the attention device, which warns the road users with a yellow blinking LED light when a train / railway vehicle is sufficiently close to LC.
Road users aimed at	Vulnerable road users and motorized road users.
Prop. effect mechanism	Improves LC detection and improves train detection.
Psychol. functions	Identification (focus on attention and workload).
Potential negative effects / restrictions	– The LC attention device is not failsafe. In case the transmitter in a train / railway vehicle and/or the GNSS is not working (or there is a train / railway vehicle without a transmitter), no warning is provided to road users (and the road users are not aware that the device is not working). In case the transmitter is not in a train / railway vehicle, the transmitter does not work or if there are any other identified problems, the engine drivers should, according to instructions, drive lower speed than in a normal situation (when the system works). (Liikennevirasto, 2015). – It is important that the road users are informed that LC attention devices are not fail-safe and thus the road users should always be careful when crossing the LC. – Based on a survey conducted in Finland (Liikennevirasto 2015) the road users felt that they should be better informed about the functioning of these new LC attention devices before their installation. – Effectiveness might vary under different weather and light conditions due to visibility.
Recom-mendations for application	– The LC attention device is estimated to be ten times cheaper than traditional half barrier solution. The device works with solar energy (no mains power is needed) and no changes to railway infrastructure are needed. (Liikennevirasto 2015). – This is an appropriate solution mainly for LCs with low road vehicle volumes and with no electric power lines nearby (Liikennevirasto 2015). – Some road users proposed that the light warning could be combined with sound (Liikennevirasto 2015).

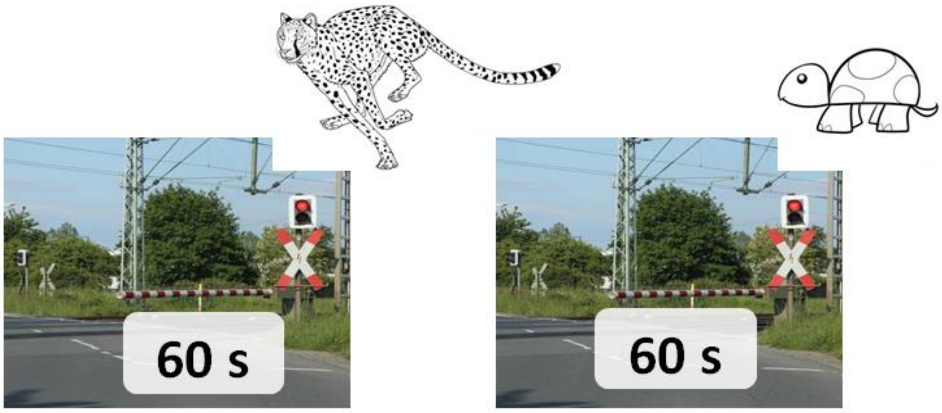
3.1.10 Coloured marking to mark the danger zone

Illustration	
Measure description	This measure is designed to support user decision-making, i.e. where to look for a train, at passive LCs (Turner, 2015). It provides information to road users about where they are at risk of being struck by trains and where they are not. It allows individuals to decide for themselves where to check for trains in line with individual differences in information acquisition and processing. This measure is to be combined with corresponding signage.
Road users aimed at	Vulnerable road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LC and improves possibilities of VRU to cross the LC safely.
Main psychological functions involved	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Potential information overload if used in conjunction with lots of signage. – Care should be taken with the surface material so it is not hazardous to motorcyclists or cyclists in wet conditions. – Usefulness is restricted under snowy conditions.
Recommendations for application	– The road users should be made aware of that they should still carefully look for the trains before crossing the LC. This can be achieved, e.g. by combining the measure with a ← *Look for train* → sign on approach. – Regular maintenance should be organised to retain the effectiveness of this measure (i.e. to maintain the bright colour).

3.2. Measures for level crossings with barriers

This section presents the measures that have been evaluated to be most efficient at influencing safety at level crossings with full and half barriers. The countermeasures identified and described below aim to avert unwanted actions that users undertake at LC of these two types, including the circumvention of closed barriers (climbing over / below; driving around half-barriers), passing the LC after the pre-signalling has begun or while barriers are going down, getting caught between the barriers and getting stuck on the rails.
To decrease or even eliminate the above behaviours, the following countermeasures have been identified:

3.2.1 Adapting the timing of LC closure to the actual speed of the passing train

Illustration	
Measure description	With current systems (closure triggered by train arriving at a certain distance to the LC), slower trains cause longer waiting times at LCs because the safe distance of the trigger spot is calculated for the fastest-moving train. Adapting the closure time to the actual speed of the train allows for regular closure duration of the LC, shortening the absolute waiting time in the case of slower-moving trains.
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Controls the access to LC.
Main psychological functions involved	Decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	− Reliable information on the respective (maximum) train speeds needs to be obtained.
Recommendations for application	− The users should be informed on this change in the timing of barriers' closure, so that they know that the closing time is the absolutely necessary waiting time.

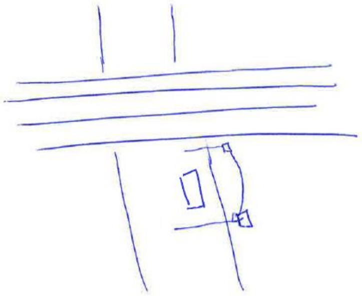
3.2.2 Camera based enforcement (prosecution of violations)

Illustration	
Measure description	Installation of enforcement camera at LC with half-barriers and light protection. Initiation of legal prosecution to deter road users from violations.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LC and controls the access to LC.
Main psychological functions involved	Rule knowledge (focus on knowledge retrieval) and decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– Civilians may protest against this measure. Complaints may be lodged leading to costly procedures. – Potential vandalism against the measure. – Not practicable for pedestrians and cyclists. – Challenging to implement for motorcyclists (number plates only on backside). – Capacities needed for the administrative work associated with the prosecution.
Recommendations for application	– Investigation and consideration of legal bases in the country where the measure will be implemented. – Quick response to violations and high probability of getting caught are likely to enhance effectivity.

3.2.3 Additional display "Two Trains"

Illustration	
Measure description	Installation of additional display to inform the road users that two trains will pass the LC. The aim of this measure is to prevent road users from crossing early, i.e. before red light has gone out / second train has passed.
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Provides up-to-date information about LC status and improves train detection.
Main psychological functions involved	Decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– Visibility could be reduced under certain lighting conditions (e.g. glare); shading equipment or dynamic adjustment of brightness can mitigate this.
Recommendations for application	– The time interval between the two trains should not be too long (cf. measure 1 in this section). – Users should be informed on this change and what this new message means so that they do not disregard it (e.g. through media involvement; additional temporary signage).

3.2.4 Second chance zone

Illustration	
Measure description	Creation of a ‘Second chance zone’ between the tracks and barriers which enables a driver to go through or go back to the safe area if a driver makes a mistake and is trapped between the barriers (i.e. barriers are located further away from LC than in conventional setup).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Improves physical environment of LC.
Main psychological functions involved	Execution (focus on motor execution of action) and detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Can create a misconception to the users in regards to where exactly the safe area is. – The timing of the closing of the barriers needs to be recalculated and recalibrated when barriers are relocated.
Recommendations for application	– Safe areas should be clearly marked.

3.2.5 Sound warning of approaching train

Measure description	Warning sound to indicate that a train is arriving to the LC. The sound warning is only produced when a train is arriving. It could also be effective in passive LC in case additional detection technology could be installed.
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Improves train detection and provides up-to-date information about LC status.
Main psychological functions involved	Detection (focus on visual / auditory perception) and decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– Noise disturbance to the nearby areas, especially if the LC is located close to residential areas, hospitals, schools, etc. – It may not reach all road users (e.g. those in cars with loud music, pedestrians using headphones, hearing impaired).
Recommendations for application	– In LC with barriers, this could be technically coupled with closing signals. Another design option is to include roadside detection and provide the sound warning only when someone is present at the LC. – To be effective for MRU, the sound signal needs to be intense enough to be heard in a closed cabin.

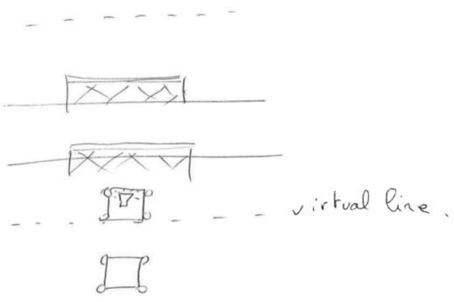
3.2.6 Physical lane separation in front of half barriers

Illustration	 
Measure description	Installation of elements (delineator posts, rods, traffic islands, etc.) to physically separate lanes immediately in front of half-barriers to prevent road users from driving around closed or closing half-barriers (prevention of zig-zagging).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Improves physical environment of LC and controls the access to LC.
Psychological functions	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and execution (focus on motor execution of action).
Pot. negative effects / restrictions	– Possible problems with winter maintenance (i.e. possible challenges in snow clearance).
Recommendations for application	– The elements used should be designed such as not to disrupt normal traffic flow or introduce a new danger.

3.2.7 Increase the length of the first barrier

Measure description	A longer barrier complicates the zig-zagging of vehicles.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Controls the access to LC.
Psychological functions	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and execution (focus on motor execution of action)
Pot. negative effects / restrictions	– Motorists with narrow vehicles (e.g. motorcyclists) could still circumvent the barrier.
Recommendations for application	– To assure that closed-in vehicles still make use of the possibility to get out, a breakability note could be added on the inside of the barriers.

3.2.8 Audible signal while in danger zone

Illustration	
Measure description	Producing a sound message to drivers when they are in the danger zone of the LC (beyond the defined virtual line). Note on applicability: This measure could be effective in passive LC too, on condition the technical infrastructure (e.g. electricity supply) is available or can be established.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LC and controls the access to LC.
Main psychological functions involved	Detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Potential disturbance of nearby areas, especially in the case the LC is located close to residential areas, hospitals, schools, etc. – If used in an urban area the acoustic message could "get lost" amongst other noise.
Recommendations for application	– As an alternative, the sound signal could be given in advance of the danger zone to help drivers anticipate not to drive onto the tracks when slow or stopping vehicles ahead could lead to them needing to stop on the tracks. – The users should be informed of this measure so that they are not startled and hence distracted (trying to understand what is going on) in the case the signal is heard. – Sound intensity could be dynamically adjusted to background noise, such that the warnings are audible in the direct proximity of the LC, but do not disturb residents (Rollins, 2017).

3.2.9 Information countdown to closing the barrier

Measure description	Convey information on seconds until closing.
Road users aimed at	Vulnerable road users and motorized road users.
Proposed effect mechanism	Provides up-to-date information about LC status.
Main psychological functions involved	Rule knowledge (focus on knowledge retrieval) and decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– Some people may “try their luck” and rush across to beat the train putting themselves at risk.
Recommendations for application	– Could use roadside display. – Time could come from LC control.

3.2.10 Complete open / close cycle

Measure description	Currently, if a second train is approaching a LC, the LC barriers may start to open but almost immediately close again. The complete open/close cycle proposed by this measure aims to ensure that the barriers will not start to open if there is insufficient time for a complete cycle of closure. Furthermore, if a second train is approaching, flashing lights should not only stay active, but additional information should be provided for the road users about the second train approaching the LC.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Provides up-to-date information about LC status and controls the access to LC.
Main psychological functions involved	Decision-making (focus on risk-perception, subjective judgment, and motivational factors) and execution (focus on motor execution of action).
Potential negative effects / restrictions	– If having to wait too long it could cause frustration and willingness to take a risk and cross.
Recommendations for application	– Users should be informed about the implementation of this measure. – Longer waiting times could make the user believe that there is something wrong with the barriers and hence consider circumventing them. – This measure could and should be combined with measure 3 - Additional display "Two Trains" described above.

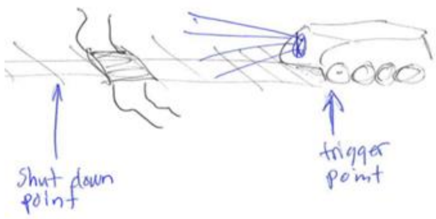
3.3. Measures for all level crossings

This section presents design solutions deemed beneficial to support safe road user behaviour at all kinds of LCs. Some of the measures work by improving LC detection, the first step of information processing that needs to be accomplished regardless of the LC type. Others help road users in activating the right action schemata that fit the behavioural demands of the specific type of LC they are approaching. This support might also involve giving information on the current state of the LC. Measures to enhance train detection by making the train itself more conspicuous are mainly thought to support road users at passive LCs, but can also represent a further line of defence to prevent collisions at active LCs in the case of road users who decide to violate closed barriers in spite of all design efforts to prevent this. Finally, measures to prevent road users from entering the track area when a fluent and timely passage is not warranted (e.g. because of a backlog in traffic beyond the crossing resulting from drivers who want to turn left or a red traffic light), or from getting stuck on the rails in other ways, are reasonable at any kind of LC. The following tables contain the 10 measures that earned the highest ranks in the category of measures applicable at all LC types.

3.3.1 Proximity message - information sharing via connected device (in-vehicle display, satnav, mobile device, etc.)

Illustration	
Measure description	The approach of trains to a LC is detected and information or warnings are provided to road users about the approaching trains. Different technologies can be used for the approach detection, e.g. sensors installed in the tracks upstream the LC (axle counters, radar, ultrasonic sensors or other) or geo-localization of the train and ITS (intelligent transportation system) to transmit information. Likewise, different ways of displaying the information are possible, e.g. using existing or additional in-car displays or mobile devices.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Provides up-to-date information about LC status.
Main psychological functions involved	Rule knowledge (focus on knowledge retrieval) and decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– The display of information and warnings could contribute to driver distraction by directing attention away from the road. Negative effects can be avoided by ergonomic interface design (e.g. audio instead of visual output). In a simulator study (Larue, Rakotonirainy, & Haworth, 2015) a proximity message did not result in significant changes in cognitive load while approaching crossings. – At passive LCs, complacency or over-trust effects could occur if the system fails to give a warning (*miss).* – User trust and use will decrease in case many false alarms are issued.
Recommendations for application	– The messages sent should be adapted to the type of LC in terms of the recommended behaviour (e.g. passive: *drive slow* and *look left and right*, barriers: *please wait*, adding information on prospective time of continuation of the journey if available). – As an alternative to triggering such a system by train proximity, it would also be supportive to provide information based on LC proximity alone if the technical implementation of the train detection appears too challenging. – User should be informed that the system is not fail-proof.

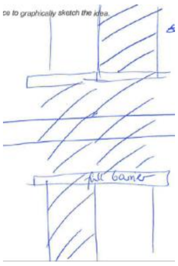
3.3.2 Improve train visibility using lights

Illustration	 
Measure description	Improvement of train detectability using lights. Different implementations are possible, e.g. improving the front lights of trains with LED technology (or by using eye-safe laser on train front). Lights will flash when the train is coming to the LC and the flashing frequency can be adapted to the distance (triggering of lights can be done with GNSS). The train could emit a visible trace beyond its actual dimensions. This could, e.g. be a laser / light beam facing upward.
Road users aimed at	All road users.
Proposed effect mechanism	Improves train detection.
Main psychological functions involved	Detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Stimuli of great visual salience associated with an approaching train could facilitate the diversion of attention from other relevant aspects of the road, especially if they are extraordinarily novel compared to stimuli usually observed in traffic. – In a situation where only a part of all trains are equipped with the measure, the detection of trains that are not equipped could deteriorate (complacency). – Local residents at LC might feel disturbed, depending on light intensity, especially at night.
Recommendations for application	– Though the measure is mainly supposed to help at passive LCs, it can as well be useful at LCs with barriers, preventing road users from violations in the wrong moment. – Activate lights only on approach to LC. – Design to avoid interference with other traffic modes (e.g. not to be confounded with plane position lights, wind wheel markings).

3.3.3 Audible warnings about LC

Measure description	Provision of improved audible warnings for pedestrians to inform them about the approaching LC. The warning can be spoken (e.g. STOP! or "second train coming" where there is a double track) or sounds. Use more than one language where appropriate, e.g. in touristic areas.
Road users aimed at	Vulnerable road users.
Proposed effect mechanism	Improves LC detection.
Main psychological functions involved	Detection (focus on visual / auditory perception) and rule knowledge (focus on knowledge retrieval).
Potential negative effects / restrictions	– Noise disturbance to the nearby areas, especially in the case that the LC is located close to residential areas, hospitals, schools, etc. – Road users not expecting an audible warning could get startled by a sudden onset of sound. – If used in an urban area the acoustic message could "get lost" amongst other noise.
Recommendations for application	– Sound intensity could be dynamically adjusted to background noise, such that the warnings are audible in the direct proximity of the LC but do not disturb residents (Rollins, 2017). – The warning should be very short so that the user has the adequate time to process it, understand it and act accordingly. – Design warning onset to avoid startling road users (e.g. by beginning with a soft gong sound as applied in announcements at airports or railway stations).

3.3.4 Extended "no stop" zone

Illustration	
Measure description	Extended “no stop” zone prevents car drivers from halting on the tracks when caught in heavy traffic.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LC.
Main psychological functions involved	Detection (focus on visual / auditory perception) and rule knowledge (focus on knowledge retrieval).
Potential negative effects / restrictions	– Visibility of road markings can deteriorate due to material covering the LC (e.g. snow, leaves, dirt). – Can create traffic on intersections. – Optimal extra length added on the “no stop” zone not determined yet.
Recommendations for application	– Maintenance for keeping the markings visible should be organized (e.g. snow clearance). – Correct understanding of the marking should be supported by short textual cues (e.g. *no stopping* inscription integrated in the road markings; extra sign *do not stop on the LC* or *only drive onto LC when you can pass*).

3.3.5 Message on smartphone / -watch to warn on approaching train

Measure description	Message to smartphone/-watch to inform road users of an approaching train. Message could interrupt all other applications (such as radio) or transmissions (such as Wifi, Bluetooth) and sound an alarm (and/or jam the connections) when it detects "approaching train".
Road users aimed at	Vulnerable road users.
Proposed effect mechanism	Provides up-to-date information about LC status.
Main psychological functions involved	Identification (focus on attention and workload).
Potential negative effects / restrictions	– The application could create an additional source of distraction in road users who are not already looking at the mobile device. – Potential overreliance on this type of measure could take the road user´s attention away from observing the road and level crossing.
Recommendations for application	– To avoid negative side effects, the technology could contain a use detection and issue a warning only in case the device is currently being handled by the user. – Moreover, the output should optimally not stress visual processing resources (Wickens & McCarley, 2008), but should facilitate a quick orientation of visual attention to the LC (e.g. by arrows, speech output). – Users should be reminded that the system is not fail-safe (e.g. when starting the application).

3.3.6 Coloured pavement markings to mark the danger zone (MRU)

Illustration	
Measure description	Coloured pavement markings that aim to reduce the number of vehicles stopping within a marked envelope, and thus reduce the possibility that a vehicle is on the tracks when a train approaches. This measure should be combined with corresponding signage.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Increases awareness of correct behaviour / dangerousness of LC.
Main psychological functions involved	Detection (focus on visual / auditory perception) and rule knowledge (focus on knowledge retrieval).
Potential negative effects / restrictions	– Effect of colouring can be attenuated by material covering the LC (e.g. snow, leaves, dirt). – Care should be taken with the surface material so it is not hazardous to motorcyclists or cyclists in wet conditions.
Recommendations for application	– Regular maintenance should be organised to retain the effectiveness of this measure (i.e. to maintain the bright colour). – Users should be informed in the case this measure is implemented (e.g. through notification in local media; additional temporary signage).

3.3.7 Satnav intelligence

Measure description	Satnav will show routes avoiding LCs on the preferred option, particularly for professional drivers. It may update in real time to steer drivers away from a LC to avoid the predicted arrival of a train or a known busy train movement. Social intelligence (i.e. influenced by LC closures) is a growing area making use of multiple sources of data, giving perhaps average speed on a route and suggesting a better route in real time. Users could choose to avoid all LCs or just LCs with barriers to avoid waiting times.
Road users aimed at	Motorized road users.
Proposed effect mechanism	Provides up-to-date information about LC status.
Main psychological functions involved	Decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– Effects are limited to those road users who use this type of technology.
Recommendations for application	– User interface should be designed for support of quick comprehension and low distraction potential.

3.3.8 Countdown to train arrival

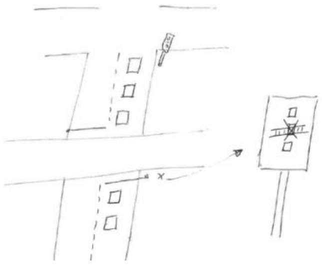
Measure description	Installation of a digital display near LC indicating the time left until the next train arrives to the LC.
Road users aimed at	All road users.
Proposed effect mechanism	Provides up-to-date information about LC status.
Main psychological functions involved	Rule knowledge (focus on knowledge retrieval) and decision-making (focus on risk-perception, subjective judgment, and motivational factors).
Potential negative effects / restrictions	– The system could be misused by road users, instead informing their decision to violate at LCs with barriers. – The system is not fail-safe. – To use the system at passive LCs, additional train detection technology[2] is needed.
Recommendations for application	– At passive LCs, enough time should be available for drivers and riders to consider the information in their decision to stop or to cross. This could be achieved, e.g., by a combination with measures leading to speed reduction and installation at an adequate distance to the LC. – An easier-to-implement variant of a countdown could show the time until the next LC closure (cf. measure 9 in section 3.2).

[2] Note: Several innovative measures proposed here depend on the availability of information about train position. One possibility to provide this information would be to use GPS receivers on board the trains and to transmit the position information to a traffic control centre or directly to the LC. At present, most train systems have no GPS receivers on board or, if so, no service connection (e.g. via GSM) to rail traffic centres. However, there are alternative ways of obtaining an estimate of train position at LCs. For instance, signals from the train proximity sensors that are already used in triggering the LC closing signal could be passed to the LC via V2X communication and used there to estimate, e.g., the arrival time, knowing the distance of the sensor and the average speed of the train. A future possibility would be the use of ITS-G5 communication devices on trains, making GPS information available via CAM messaging.

3.3.9 LED enhanced traffic signs

Measure description	Improving the conspicuity of current retroreflective LC traffic control signs with LED lights (includes STOP, YIELD, crossbuck and DO NOT STOP ON TRACK signs). This measure aims to compete with driver inattention and distractions from ambient lighting and signage.
Road users aimed at	All road users.
Proposed effect mechanism	Improves LC detection.
Main psychological functions involved	Detection (focus on visual / auditory perception).
Potential negative effects / restrictions	– Effectiveness could vary under different weather and light conditions (e.g. will the measure regulate itself to provide sufficient illumination under different lighting conditions, so that the laser pattern is equally visible in dull and very bright conditions?).
Recommendations for application	– LED intensity and colours could by dynamically adapted to the lighting conditions to optimize visibility. – Dependent on traffic volume, the LED could be either always lit or become activated by sensors when road users approach the LC.

3.3.10 Warning sign to avoid blocking back

Illustration	
Measure description	A sign to remind road users to avoid driving onto the LC when they would have to come to a stop (e.g. because of traffic jam).
Road users aimed at	Motorized road users.
Proposed effect mechanism	Controls the access to LC.
Main psychological functions involved	Rule knowledge (focus on knowledge retrieval).
Potential negative effects / restrictions	– When designed inappropriately, it may create additional mental workload. – If the sign uses text and there is no supporting pictogram, the measure may be ineffective for road users who do not speak the local language (e.g. tourists, migrants/refugees).
Recommendations for application	– Usefully to be combined with road markings of the zone to be kept clear. – When using text on the sign, keep it short and provide clear behaviour-related message (e.g. *keep tracks clear*, *do not drive onto tracks in traffic jam*). – An additional pictogram can support the fast perception of the danger and the necessary behaviour and help inform road users who do not speak the local language.

4. DISCUSSION

4.1. Strengths and limitations of the process

The task of designing new human-centred low-cost measures to increase safety at LCs was addressed by a two-stage process: In a first step, a large pool of design ideas was gathered from multiple sources, including a systematic collection of concepts that had already been proposed but are not yet commonly used in railway systems. A further source involved the creative invention of new concepts by human factors, road and rail experts, based on insights about problematic road user behaviour at LCs and the underlying cognitive and motivational processes. In a second step, the ideas collected were assessed according to multiple criteria, including their feasibility, their match with the defined project scope of infrastructural measures and their match with the known profiles of LC accidents and hence their probable prospects for accident risk reduction. The results were ranked on this basis to provide information about their estimated usefulness to increase LC safety on a large scale. The method used in addressing the design task bears strengths and limitations that are discussed in the following.

Overall, the methodology adopted presents a well-balanced approach to defining new human-centred low-cost countermeasures, drawing on a range of information sources and the expertise of stakeholders, both internal and external to the SAFER-LC project. In the first countermeasure design and collection stage, the triangulation of information from different sources – (1) research literature, (2) models of user experience and road user behaviour, and (3) creative input from experts – helped to generate a large and diversified pool of countermeasure ideas. The second stage saw the active involvement of SAFER-LC experts throughout the multiple rating and review loops of the criteria-based ranking and selection of measures. As a result of this approach, views were gathered from a wide range of experts offering different professional and cultural visions. This resulted in some variation in the responses and efforts were made to capture these differences by allowing the experts to provide short comments qualifying their answers. This broad range of expertise and perspective has added richness and validity to the data collected and the resulting selection of measures. Indeed, having the involvement of pilot test leaders in the criteria-based selection process has also helped engage and familiarize partners with the measures and in this way will likely support the future testing and evaluation of these countermeasures in WP4 pilots of the SAFER-LC project.

Given the dynamic and early stage nature of the measures studied it is difficult to carry out an exhaustive review of all new, innovative and low-cost solutions. In this way, in spite of the efforts made in the collection process it is likely that there are additional new, innovative and low-cost LC safety measures, which have been implemented or piloted in some countries or some sections of the railway infrastructure and are not reflected in the current deliverable. The ability to capture these other experiences is limited by the availability of documentation on the proposed measures, especially at an initial or preparatory stage of implementation. For this reason, the current collection of countermeasures represents a snapshot of the state of play at this point in time which will be added to as the project goes on, with any promising new measures encountered during this process to be included in further steps, e.g. in the implementation of the toolbox.

Whilst economic evaluation was not a central objective of the task, it was still required to a certain extent in order to judge whether a proposed solution fell into the envisaged scope of low-cost measures. The assessments on this aspect were based on expert judgement, but not on an explicit economic analysis and comparison of each of the solutions. Furthermore, our definition of low-cost was oriented towards the feasibility and ease of developing and implementing a measure due to low outlay costs (in terms of money, time, logistics etc.). At the same time, the concept of low or high cost could be defined in other ways, e.g. in relation to the impacts achieved by the measure, such that a measure will not be viewed as expensive if it offers a good return on investment in terms of improved safety. However, until the measures have undergone evaluation with respect to their effectiveness and a cost-benefit analysis it is not possible to talk about their cost effectiveness or efficiency.

Another central aspect of assessment was the estimation of each measure’s prospects for accident risk reduction. Such a judgement needs to consider at first the type and frequency of accidents occurring at LCs under various circumstances (e.g. protection type, road users involved, weather conditions, road characteristics, sight distances etc.). Next, the scope and expected safety effects of a given measure need to be compared to this situation in order to estimate the share of accidents and damages that could be prevented with the implementation of the measure. Solving this problem in a computational way would require complete and comparable data not only on the circumstances of LC accidents, but also their consequences, and of course on the safety effects of each countermeasure. Considering the heterogeneous and incomplete database available, a heuristic approach involving expert ratings was chosen to assess the prospects for accident risk reduction. Special attention was paid to warrant a common understanding and sound preparation of the rating task, including good awareness of the most important features of LC accidents in Europe. Still, given the constraints of the data mentioned, some variance and a certain tendency to the middle of the scale could be observed in the ratings. The heuristic nature of the ratings and the implications for the resulting rankings of the measures should be kept in mind when working with the results. Most importantly, it is not a rare case that the exact ranks of two neighbouring measures are based on differences in the second decimal place of the mean effectivity ratings. Thus, the estimated effectivity of measures neighbouring in the table is often similar and not as different as the ranks may suggest.

4.2. Remarks for using the results, implications, and lessons learned

A relatively high number of the selected measures achieved a median score in their mean effectiveness ratings (from about 2.5 to 3.5, implying a moderate expected effect size). This might be partly due to the challenges of rating, but it might also reflect the situation that a lot of the measures listed, and not only the top-ranking ones, indeed have the potential to influence road user behaviour at LCs in a desired way. Therefore, the complete list was included in the Annex, and readers are advised to take note not only of the measures that have been described in more detail in section 3, but also the ones listed in the Annex.

While Annex A contains all measures that survived the selection procedure, the Annexes B to E additionally list all the measures that were excluded from the selection for different reasons (e.g. perceived problems with practicability, high estimated cost or other sort of insufficient match with the defined project scope - cf. section 1.3.2). It should be underlined that the exclusion of measures does not necessarily imply that these measures are deemed inappropriate for the purpose of increasing LC safety. On the contrary, there are measures among the excluded ones that appear highly recommendable from a safety perspective. The most prominent group of these are the ones that were excluded for being *classic upgrades* in railway safety. It cannot be said often enough that the best “level crossing” is one that has been removed and replaced by an under- or overpass (Ellinghaus & Steinbrecher, 2006). Other conventional ways of upgrading LCs like installing half-barriers at a formerly passive LC or equipping a former half-barrier LC with full barriers are also known to be highly effective. Therefore, a strategy for improving LC safety should always consider these means first. However, the idea of the SAFER-LC project was based on the insight that due to economic constraints, classic upgrades are not feasible in all cases, and therefore additional solutions are needed that cause less cost and therefore can be implemented at a larger number of LCs.

Another reason for excluding measures from the selection was a perceived impracticability that could, for instance, result from the expectation of technical, legal or acceptance-related problems. Of course, the classification of a measure as practicable or not depends on a number of preconditions, including the perception of the current status of technological development, a shared cultural understanding of social values and a focus on solutions that can be applied in the majority of cases. Thus, there might be contexts and circumstances in which a measure deemed impracticable in this work could appear practicable. For example, the idea to use a speed limiter in cars that will automatically reduce the driving speed in front of a LC – though it might be effective – was sorted out for being too invasive and suspected to cause acceptability problems when applied to private vehicles. Thinking of constraint use cases, however, the application might appear conceivable, as in the example of using it on trucks in the transport industry. The individual willingness to accept measures like this could also increase with a further spread of automated driving functions in the process of development towards the use of self-driving vehicles.

Some of the measures proposed in the collection phase comprised combinations of single design solutions, for example the *combination of bumps, red light barriers and coloured ground*. Combinations of measures were left out of the presentation in section 3 for stringency, but are included in the table in Annex A. They are just examples of how measures could be combined to aim for a better effect than that achieved by one measure alone. There are more measures in the list that could be usefully combined with others, e.g. a road marking to prevent stopping on the tracks with an associated sign, so this possibility should be considered in the planning of measure implementation. This is important because from a practical viewpoint safety measures are almost never implemented in isolation.

No matter if single or combined, it is understood that the special situation at a given LC should be examined beforehand and the match of the envisaged measures with that situation should be assessed. This includes the involvement of stakeholders to anticipate and avoid potential acceptance issues.

The proposed effects, the potential restrictions and the recommendations for application of the measures that are given in section 3 should be considered in the light of the limited evaluation database. Due to the innovative nature of the solutions considered, there are little or no insights on performance of some of the measures listed, while for others, empirical evidence of their safety effects has been collected in a number of studies. Therefore, the expected safety benefits of the measures and potential challenges related to their implementation and usage are partly based on theoretical considerations, transfer of insights from other domains (e.g. about good warning design to avoid distraction, the need to adapt a signal to the background noise, potential unwanted effects of driver assistance like overreliance or risk compensation) or common sense (e.g. about the expected applicability and effectiveness of solutions under adverse weather conditions). More insights will be gathered in the evaluation phase (cf. 5.1).

In Annex A, the measures are listed in the order of the ranks they achieved in the effectiveness rating. The categories assigned to each measure concerning applicability (full-barrier, half-barrier, passive LC; VRU, MRU), effect mechanism and psychological functions involved could however be used to sort the measures in other ways, e.g. to show all measures applicable for motorized road users at passive LCs, or to look at all measures that can be applied to enhance LC visibility. While this deliverable can only provide a list of the measures in one fixed order, it is envisaged in further steps of the project to make the results available in a form that enables an adaptive sorting and targeted search (cf. 5.2).

The measure illustrations in this report either stem from the expert design workshop, were found in the research literature or were created by project partners. The drawings from the workshop were included here only when they were found to provide added value to the written descriptions, as they were often sketched quickly, sometimes not with high quality. Whilst the creative workshop provided valuable input to the design process, given the limited time of the work session, the depth of description of the measures was somewhat limited. Having the time available, it might have been interesting to consider doing a second phase of creative work with experts to further develop the ideas.

One final conclusion from the working process concerns the importance of a thorough documentation and analysis of LC accidents in Europe. Some progress has been made in this respect (ERA, 2018), but there still are considerable differences in documentation practice across countries in Europe. A sound and detailed database on accident precursors, circumstances, and consequences is a vital precondition for a needs-based further development of safety measures.

5. OUTLOOK

5.1. Empirical tests of LC safety measures

The final list of 89 identified LC safety measures was presented to the SAFER-LC pilot test leaders together with the ranking, classifications and information about the suitability to different test sites. After the introduction of the information, the pilot test leaders were advised to select measures for testing in their test site. The aim was to pilot the measures selected as the top 10 in each of the three categories (see chapter 3). However, the pilot test leaders were also free to choose measures from rank 31 to 89 (Annex A) if they had an interest towards some specific measure(s) and/or the measure was suitable for testing in their test site.

Testing of the selected LC safety measures will be done as part of WP4 in SAFER-LC. Testing will be conducted in different environments including lab tests (simulators and simulations) and field implementations. The testing will be combined with data collection to evaluate the safety effects of each measure and their effectiveness in making the LC infrastructures more self-explaining and forgiving. For the human-centred measures, the evaluation will follow the criteria developed in Task 2.2 and described in the SAFER-LC Deliverable D2.2 (Havârneanu et al. 2018).

5.2. Toolbox of LC safety measures

The most promising measures presented in this deliverable as well as other identified measures (cf. Annex A) will be included in the SAFER-LC toolbox, a practical tool for relevant actors of the LC safety community: road and rail infrastructure managers, train operators, engineers, designers, scientists, decision-makers, policy makers and standardisation bodies rail and road managers.
The toolbox will summarise the most relevant information collected and produced during the project such as safety measures, assessment tools and other practical recommendations. The aims of the SAFER-LC toolbox are to:

- provide an integrated overview of the road and rail safety requirements for the relevant actors within the LC safety community (e.g. road and rail infrastructure managers, train operators, engineers, designers, scientists, decision-makers, policy makers and standardisation bodies);
- provide detailed guidance on the implementation of measures to increase safety at LCs (both human-centred low-cost measures and integrated socio-technical solutions);
- provide a framework for collecting and structuring information in order to feed an accessible and documented database on efficient measures across the road-, rail-, and scientific communities.

These three objectives will help to fill in the existing gaps between (1) research and development, (2) practical implementation of results, and (3) decision-making. The toolbox will provide a systematic but flexible approach, allowing the end-users to adapt it to their specific needs and according to particular national / cultural problems, and to combine different countermeasures in order to reach an optimal effect.

In other words, the SAFER-LC toolbox has both practical and scientific aims. On the one hand it will be a guide to best practice designed to integrate (in a user-friendly and accessible way) all the recommendations, promising interventions, and specifications developed during the project. On the other hand, it will be based on empirical evidence collected from the scientific literature, practical case studies, and from the project lab and field testing results and evaluation.

The selected safety measures will be presented using a standard page structure. This will be developed and elaborated from the one used in this deliverable:

- Measure description
- Road users aimed at
- Proposed effect mechanism
- Main psychological functions involved
- Potential negative effects / restrictions
- Recommendations for application

Moreover, the countermeasures will be cross-classified on several criteria (i.e. keywords) which will facilitate the content search process. The classification keywords will be chosen from the list of classification criteria explained in deliverable D2.2 (Havârneanu et al., 2018). The content and structure of the toolbox is now under development through a systematic process of input integration and will be reviewed by experts both internal and external to the consortium. This deliverable is one main source of input for the toolbox.

To our knowledge, the SAFER-LC toolbox is the first attempt to provide an evidence-based practical tool for relevant actors within the European LC safety community and a structured research framework for technical and human factors scientists concerned with the continuous optimisation of integrated and connected socio-technical safety solutions at LCs. The toolbox will be accessible free of charge at the end of the project, and will continue to be maintained, updated and improved by the International Union of Railways (UIC) after the end of the project for the benefit of the entire road- and railway-safety community.

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7. ANNEX

A. Complete table of LC safety measures included in the selection

B. Table of proposed LC safety measures excluded for practicability issues

C. Table of proposed LC safety measures excluded for insufficient match with project scope or infeasibility of testing in SAFER-LC

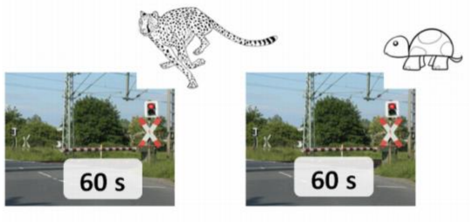
D. Table of proposed LC safety measures excluded for low expert ratings on efficiency or low cost dimension

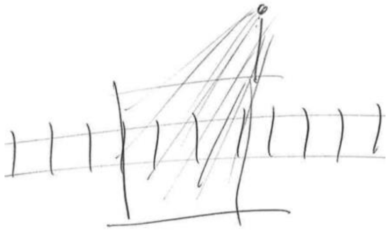
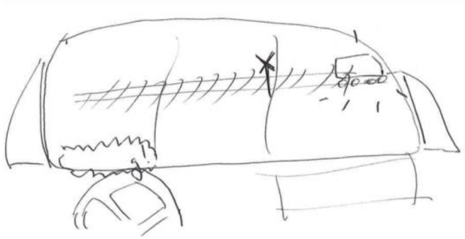
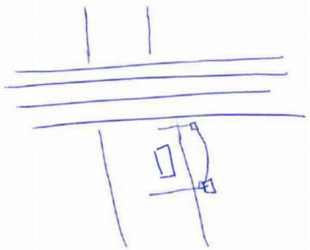
E. Table of proposed LC safety measures excluded for redundancy

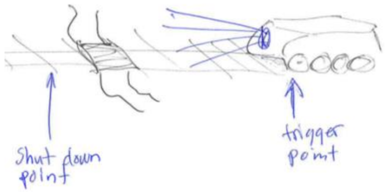
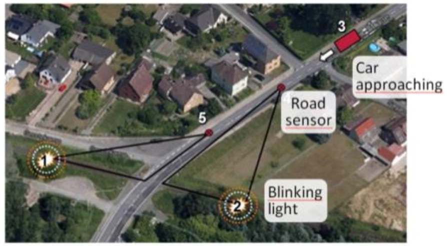
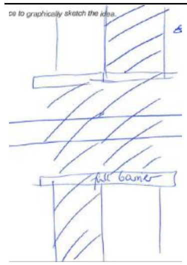
ANNEX

A. Complete table of LC safety measures included in the selection

Note: Letter y *(yes) in colums 5 to 7 denotes applicability of the measure to LCs with full barriers, half-barriers, and passive LC, respectively. Letter* y *in columns 8 and 9 denotes applicability of the measure to address vulnerable and motorized road users (VRU, MRU), respectively.* Effect mechanism *refers to the classification of the proposed effect mechanism according to Silla, Seise & Kallberg (2015; cf. 2.3.2).* Psy. function *refers to the classification of the main psychological functions involved in the proposed effect of the measure (Havârneanu et al., 2018; cf. 2.3.2).* M_{PAR} *and* SD_{PAR} *denote the mean and standard deviation of the* prospects for accident reduction *rating (cf. 2.3.3).*

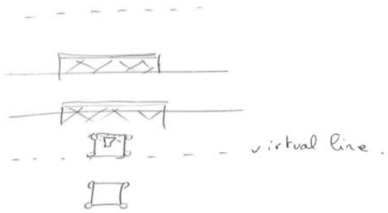
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
1	Proximity message - information sharing via connected device (in-vehicle display, satnav, mobile device, etc.)	The approach of trains to LC is detected and information or warnings are provided to road users about the approaching trains . Different technologies can be used for the approach detection, e.g. sensors installed in the tracks upstream the LC (axle counters, radar, ultrasonic sensors or other) or geolocalization of the train and ITS (intelligent transportation system) to transmit information. Likewise, different ways of displaying the information are possible, e.g. using existing or additional in-car displays or mobile devices. Note on applicability: The messages sent should be adpated to the type of LC in terms of recommended behavior (e.g. passive: drive slow and look left and right, barriers: please wait).		y	y	y		y	Provides up-to-date information about LC status	Rule knowledge, Decision-making	3.78	0.67
2	Adaptation the timing of LC closure to the actual speed of the passing train	With current systems (closure triggered by train arriving at a certain distance to the LC), slower trains cause longer waiting times at LCs because the 'safe' distance of the trigger spot is calculated for the fastest-moving train. Adapting the closure time to the actual speed of the train allows for a regular closure duration of the LC, shortening the absolute waiting time in the case of slower-moving trains.		y	y		y	y	Controls the access to LC	Decision-making	3.78	0.83
3	Camera based enforcement (prosecution of violations)	Installation of enforcement camera at LCs with half-barriers and light protection. Initiation of legal prosecution to deter road users from violations. Note on applicability for VRU: only applies to those with number plates (motorcyclists), impracticable for pedestrians and cyclists.			y		y	y	Increases awareness of correct behavior / dangerousness of LCs	Decision-making	3.67	0.87

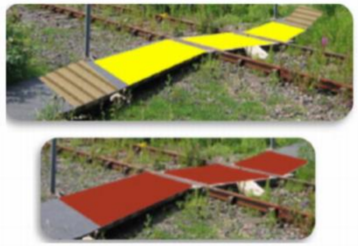
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
4	Additional display "Two Trains"	Installation of additional display to inform the road users that two trains will pass the LCs. The aim of this measure is to prevent road users from crossing early, i.e. before red light has gone out / second train has passed.		y	y		y	y	Provides up-to-date information about LC status	Decision-making	3.44	0.88
5	Active inverted speed bumps	A speed bump that is activated only if an approaching vehicle exceeds a defined speed. During the activation, a hatch (integrated into the road) lowers the pavement surface by a few centimeters, creating an inverted speed bump. (The system is currently being tested on a road with 50km/h speed limit in Sweden). Reportedly produces less noise than a conventional speed bump. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists:				y		y	Reduces approach speed of vehicles	Action execution	3.38	0.74
6	Laser illumination of crossing	LC illumination with solar-powered laser to increase its conspicuity (will also work on top of snow). Low power requirement (could use battery). Can produce pattern like a laser light show. This measure could be activated on approach of train and/or road users.				y	y	y	Improves LC detection	Detection	3.33	0.71
7	Image process warning	Road vehicle approaching the LC uses camera and image processor to detect passive LC. Warning provided to the driver via head-up display. This measure could also be used to detect approaching train given adequate sight distances.				y		y	Improves LC detection	Identification	3.33	0.87
8	Second chance zone	Creation of a 'Second chance zone' between the tracks and barriers which enables a driver to go through or go back to the safe area if a driver makes a mistake and is trapped between the barriers (i.e. barriers are located further away from LC than 'normally').		y				y	Improves physical environment of LC	Detection, Action execution	3.33	0.87

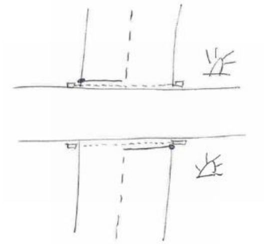
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
9	Improve train visibility using lights	Improvement of train detectability using lights. Different implementations are possible, e.g. improving the front lights of trains with LED technology (or by using eye-safe laser on train front). Lights will flash when the train is coming to the LC and the flashing frequency can be adapted to the distance (triggering of lights can be done with GPS). The train could emit a visible trace beyond its actual dimensions. This could, e.g. be a laser / light beam facing upward.		y	y	y	y	y	Improves train detection	Detection	3.33	1.00
10	Audible warnings about LC	Provision of improved audible warnings for pedestrians to inform them about the approaching LC. The warning can be spoken (e.g. STOP! or "second train coming" where there is a double track) or sounds. Use more than one language where appropriate, e.g. in touristic areas.	none	y	y	y	y		Improves LC detection. Provides up-to-date information about LC status	Detection	3.33	0.71
11	Blinking lights drawing driver attention	When a car passes an in-road sensor on approach to the LC, two lights located in the periphery of the level crossing start blinking. The light sources appear in the periphery of the driver's visual field. The salient blinking lights trigger an automatic and effortless visual orientation reaction of the driver towards the peripheral regions of the level crossing that require visual scanning to detect a train (exogenous capture of attention, physiological mechanism).				y	y	y	Improves train detection	Detection	3.22	0.83
12	Extended "no stop" zone	Extended "no stop" zone prevents car drivers from halting on the tracks when caught in heavy traffic.		y	y	y		y	Increases awareness of correct behavior / dangerousness of LCs. Controls the access to LC	Detection, Rule knowledge	3.22	0.83

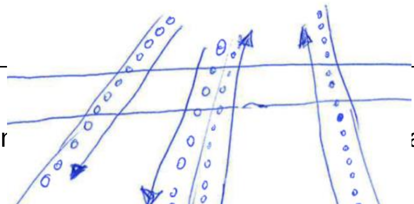
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
13	Message on smartphone / -watch to warn on approaching train	Message to smartphone/-watch to inform road users of an approaching train. Message could interrupt all other applications (such as radio) or transmissions (such as wifi, Bluetooth) and sound an alarm (and/or jam the connections) when it detects "approaching train".	none	y	y	y	y		Provides up-to-date information about LC status. Improves LC detection	Identification	3.13	0.64
14	Light markings in road to highlight transversal waiting line	Integration of a row of colored lights into the surface of the road and/or sidewalk, perpendicular to direction of approach. Lights will be activated whenever a rail vehicle (in case of LC protected with warning lights) or a road user (in case of passive LC) approaches the LC. Lights aims to generate a "visual barrier", enhancing attention of road users and supporting in stopping in front of the LC.	 		y	y	y	y	Improves LC detection	Detection	3.11	0.60
15	Sound warning indicating an approaching train	Warning sound to indicate that a train is arriving to the LC. The sound warning is only produced when a train is arriving. Note on applicability: In LC with barriers, this could be technically coupled to the closing signals. In passive LC it would be effective, too, in case additional detection technology could be installed. Another design option is to include roadside detection and provide the sound warning only when someone is present at the LC. To be effective for MRU, the sound signal needs to be intensive enough to be heard in a closed cabin.	none	y	y		y	y	Improves train detection. Provides up-to-date information about LC status	Detection	3.11	0.78
16	Physical lane separation in front of half barriers	Installation of elements (delineator posts, rods, traffic islands, etc.) to physically separate lanes immediately in front of half-barriers to prevent road users from driving around closed or closing half-barriers (prevention of zig-zagging).			y			y	Improves physical environment of LC. Controls the access to LC	Decision-making, Action execution	3.11	0.93
17	Speed bumps on approach to LC	Installation of well-marked speed bumps within the LC approach zone to reduce road vehicle speed, thus maximising the time available to the driver to process information and make (correct) decision. Layout must prevent driving around bump and leave enough time to allocate attention to the tracks after passing the bump. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists and has consequences for other road users (e.g. cyclists).Design should be fitted to the situation (e.g. number, size and shape of bumps)				y		y	Reduces approach speed of vehicles	Decision-making	3.11	0.78

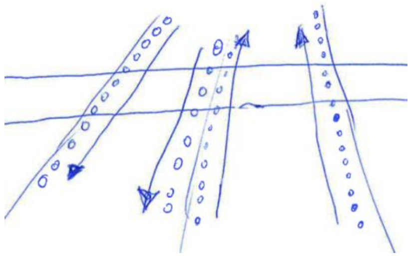
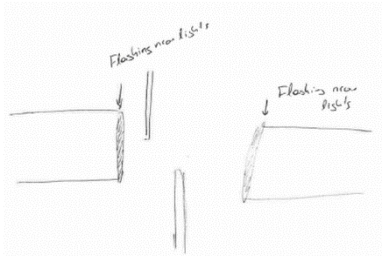
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
18	On-road flashing markers	Train-activated flashing light beacons on the road (similar to airplane runways) aiming to improve driver behaviour at railway crossings by indicating the location where the drivers are expected to stop their vehicle. (Larue, Rakotonirainy, & Haworth, 2015) At passive crossings, the lights can be activated 20 second prior to the arrival of the train. Note on applicability: effective for road users traveling at higher speeds, therefore classified "MRU", but also holds for motorcyclists.				y		y	Increases awareness of correct behavior / dangerousness of LCs. Provides up-to-date information about LC status	Detection	3.11	0.78
19	Colored pavement markings to mark the danger zone (MRUs)	Colored pavement markings that aim to reduce the number of vehicles stopping within a marked envelope, and thus reduce the possibility that a vehicle is on the tracks when a train approaches. This measure should be combined with corresponding signage.		y	y	y	y	y	Increases awareness of correct behavior / dangerousness of LCs	Detection	3.11	0.93
20	Increase the length of the first barrier	A longer barrier complicates the zig-zagging of vehicles. Note on applicability: rather holds for broader vehicles like cars, not so much for VRU as they could still circumvent the barrier. To assure that closed-in vehicles can still get out, a breakability note could be added on the inside of the barriers.	none		y			y	Controls the access to LC	Decision-making, Action execution	3.11	0.93
21	Road swiveling	Implementation of a swiveling / bending road course on approach to LC to evoke speed reduction and enhanced attention in motorized road users. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU; also holds for motorcyclists.				y		y	Reduces approach speed of vehicles	Detection, Identification	3.00	0.71
22	Satnav intelligence	Satnav will show routes avoiding LCs on the preferred option, particularly for professional drivers. It may update in real time to steer drivers away from LCs to avoid the predicted arrival of a train or a known busy train movement. Social intelligence (i.e. influenced by LC closures) is a growing area making use of multiple sources of data, giving perhaps average speed on a route and suggesting a better route in real time. User could choose to avoid all LC or just LC with barriers to avoid waiting	none	y	y	y		y	Provides up-to-date information about LC status	Decision-making	3.00	0.87

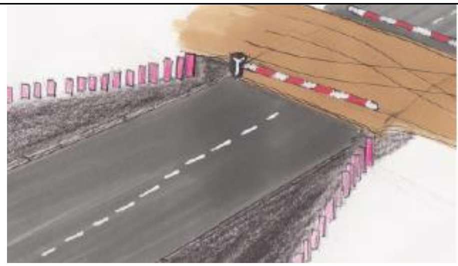
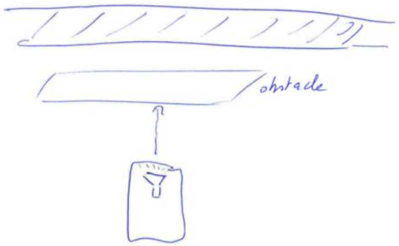
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
		times.										
23	Audible signal while in danger zone	Producing a sound message to drivers when they are in the danger zone of the LC (beyond the defined virtual line). Note on applicability: This measure could be effective in passive LC too, on condition the technical infrastructure (e.g. electricity supply) is available or can be established.		y	y			y	Increases awareness of correct behavior / dangerousness of LCs	Detection	3.00	0.87
24	Combination of bumps, red light barriers and coloured ground	This solution combines road bumps with a varying number of notches (1 notch at 150m, 2 notches at 100m and 3 notches bump at 50m), colored ground with a color gradient from yellow to red according to the distance from the LC, and a red laser barrier to give the effect of a wall to road users when approaching the LC. This solution aims to reduce approach speeds.				y		y	Reduces approach speed of vehicles. Improves LC detection	Detection	3.00	0.76
25	LC attention device	LC attention device warning road users about an LC and approaching trains / railway vehicles by yellow blinking LED light, aiming to improve the LC visibility from nearer and farther distance. The device consists of two parts: i) transmitter installed in a train / railway vehicle and ii) attention device (which provides the warning) located near LC. The transmitter installed in a railway vehicle sends GPS based information of its location to the attention device, which warns the road users with a yellow blinking LED light when a train / railway vehicle is sufficiently close to LC. In case the detection fails or there is a loss of power, the LC reverts to a passive crossing. Note: Other (e.g. simpler) detection technology could be used where necessary as system fails to a safe state.				y	y	y	Improves LC detection	Identification	3.00	0.71

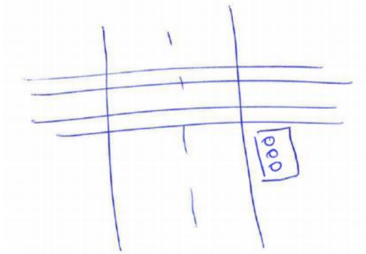
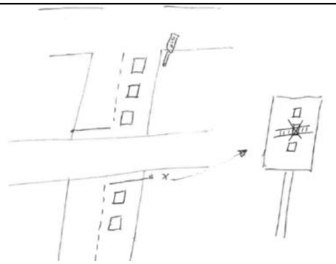
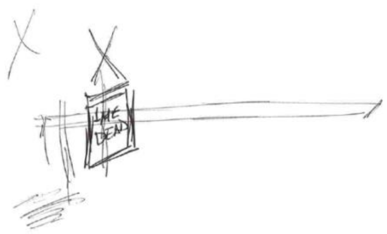
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
26	Countdown to train arrival	Installation of a digital display near LCs indicating the time left until the next train arrives to the LC (i.e. indicating the time until next LC closure).	none	y	y	y	y	y	Provides up-to-date information about LC status	Rule knowledge, Decision-making	3.00	0.53
27	Colored markings to mark the danger zone (VRUs)	This measure is designed to support user decision-making, i.e. where to look for a train, at passive LCs. It provides information to road users about where they are at risk of being struck by trains and where they are not. It allows individuals to decide for themselves where to check for trains in line with individual differences in information acquisition and processing. This measure is to be combined with corresponding signage.				y	y		Increases awareness of correct behavior / dangerousness of LCs. Improves train detection	Decision-making	3.00	0.87
28	Information countdown to closing the barrier	Convey information on seconds until closing. Could use roadside display. Time could come from LC control.	none	y	y		y	y	Provides up-to-date information about LC status	Rule knowledge, Decision-making	3.00	0.76
29	Complete open / close cycle	Currently, if a second train is approaching an LC, the LC barriers may start to open but almost immediately close again. The complete open/close cycle proposed by this measure aims to ensure that the barriers will not start to open if there is insufficient time for a complete cycle of closure. Furthermore, if a second train is approaching, flashing lights should not only stay active, but additional information should be provided for the road users about the second train approaching the LC.	none	y	y			y	Provides up-to-date information about LC status. Controls the access to LC	Decision-making, Action execution	3.00	0.87
30	STOP signs	STOP signs aim to improve the safety of LCs by obliging road users to stop before the tracks, giving them more time to observe an approaching train. However, stopping before LC increases the time to cross the tracks and this might increase the risk of collision.	none			y	y	y	Controls the access to LC	Rule knowledge	3.00	0.87

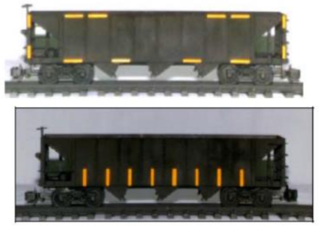
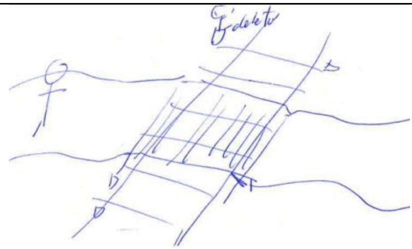
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
31	Reduction of speed limit and introduction of automatic speed enforcement	This combination of measures aims to reduce the approach speed of car drivers when approaching LC. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists.	none			y		y	Reduces approach speed of vehicles	Decision-making	3.00	0.87
32	Simultaneous closing of all barriers	Simultaneous closing of all barriers on both sides of road aims to prevent people and vehicles from zig-zagging	none	y			y	y	Controls the access to LC	Decision-making, Action execution	3.00	0.76
33	Infrared laser and alarms for pedestrians	An infrared laser along the barriers is used to detect VRUs during and after the closure of barriers. An alarm rings if a pedestrian goes through the IR laser. Note on applicability: In LC with barriers, this could be technically coupled to the closing signals. In passive LC it would be effective, too, but additional detection technology would have to be installed.		y	y		y		Provides up-to-date information about LC status	Decision-making	2.89	0.93
34	Portal	Building a portal before an LC to improve its conspicuity. As a secondary benefit, it can be used as a gauge to prevent vehicles too high to safely pass below the overhead lines. Note on applicability: effective for road users approaching the LC at higher speeds, therefore classified MRU, but might also have effect on VRU.				y		y	Improves LC detection	Detection	2.89	0.60
35	Warnings of object on LC tracks	Use of sensors to identify objects on tracks (e.g., a road vehicle blocking the LC). Alerts sent to rail vehicle drivers and infrastructure managers (and road vehicle drivers).		y	y		y	y	Provides up-to-date information about LC status	Rule knowledge	2.89	0.93

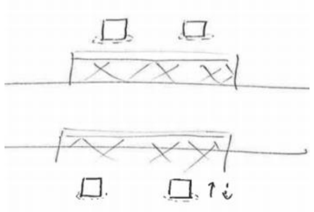
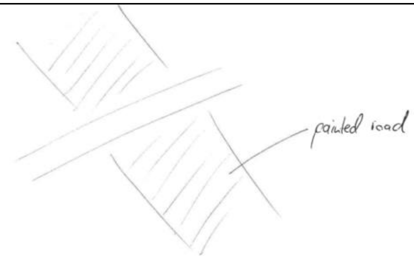
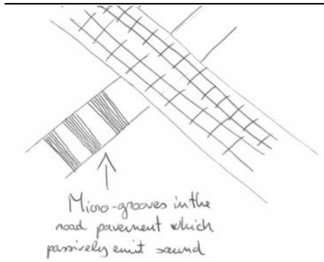
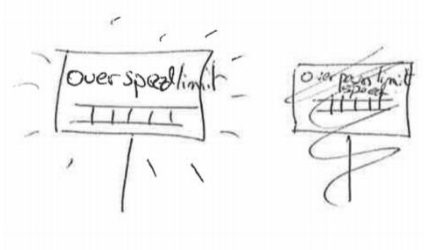
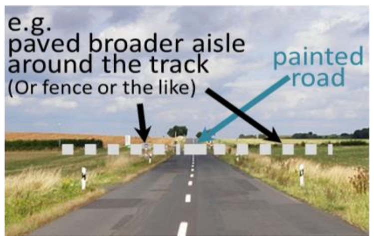


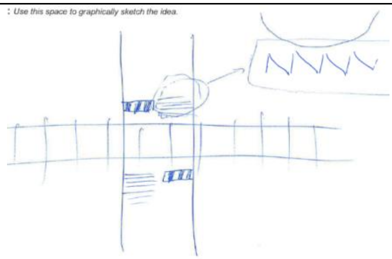
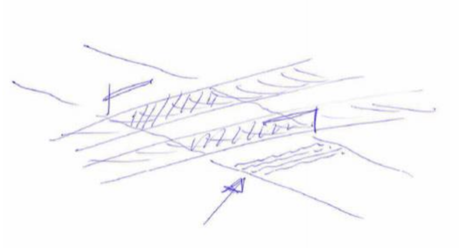
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
36	Marking exclusion area	Marking an exclusion zone at the LC, i.e. danger zone, with red stripes on the crossing section or with LED lights and reflectors. Having LED lines parallel to the road with animated "movement" indicating the preferred moving direction. LED should only be visible on the relevant side of the road. Note on applicability: This measure could be effective in passive LC, too, in case the technical infrastructure (e.g. electricity supply) is available or can be established.		y	y		y	y	Increases awareness of correct behavior / dangerousness of LCs	Detection	2.89	0.93
37	A vehicle-activated strobe light and supplemental sign for passive LCs	Supplementation of LC advance signs with a vehicle-activated flashing yellow light designed to attract attention. This would be combined with an additional sign below which reads “LOOK FOR TRAIN AT CROSSING”. This enhanced sign system should increase driver awareness of the LCs and result in more cautious behaviour.				y		y	Improves LC detection	Detection	2.89	0.78
38	Flashing neon lights	Installation of a bar of flashing neon lights on the road a few steps before the LC, primarily to protect young people paying attention to their phone and not the LC. The light will be an in-road flashing light. The lights will be green when road users are supposed to pass and red when the road users have to wait. This way it is more probable for people looking down on their phone to notice the neon light and stop. Note on applicability: In LC with barriers, this could be technically coupled to the closing signals. In passive LC it would be effective, too, in case additional train detection technology could be installed.		y	y		y		Improves LC detection	Identification	2.89	0.60
39	Pre-signage before the LC	Addition of pre-signage starting approximately 1 km before the LC and repeated several times (e.g. 200 m) to increase visibility of the LC.	none			y	y	y	Improves LC detection	Detection	2.89	1.27
40	LED enhanced traffic signs	Improving the conspicuity of current retroreflective LC traffic control signs with LED lights (includes STOP, YIELD, crossbuck and DO NOT STOP ON TRACK signs). This measure aims to compete with driver inattention and distractions from ambient lighting and signage.	none	y	y	y	y	y	Improves LC detection	Detection	2.89	0.60

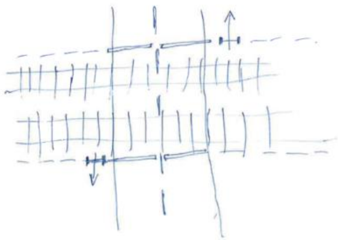
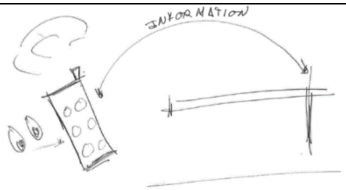
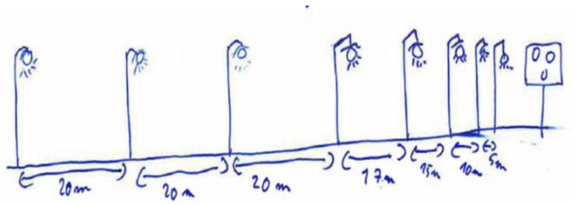
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
41	Flashing/moving lights on barriers/ground	Installation of lights on the barriers to improve the visibility of the LC. Light design should be adjusted to the situation (e.g. steady vs. flashing / moving lights).	none	y	y		y	y	Improves LC detection	Detection	2.89	0.78
42	Tunnel effect stick	Creating a tunnel effect as a driver is approaching an LC on straight roads aiming to reduce driving speeds. This effect can be achieved by installing sticks ranging from white to red in different sizes from 2 meters to the LC to a distance of 10 meters with an angle generating the tunnel effect. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists and possibly cyclists.				y		y	Improves LC detection. Increases awareness of correct behavior / dangerousness of LCs	Detection	2.88	0.83
43	Rings	Installation of two rings going above the road before the LC (one 10 meters in fronts of the LC and another one 150-200 meters to the LC). The lights in the rings start flashing when a train is coming. Note: Other than the simple "portal", this measure is technologically more challenging.				y		y	Improves LC detection	Detection	2.88	0.99
44	Sign to increase search behavior	Installation of signs on approach to LC to increase train search behavior of road users as well as to decrease approach speeds.	none			y	y	y	Improves LC detection	Detection	2.78	0.97
45	Use obstacle warning in car for LC	Use of in-car obstacle warning to identify LCs. ITS detecting barriers on the sides of an LC as obstacles and warning the driver (sound) on approach. The warnings could also be combined with speech message "You are approaching a level crossing".		y	y			y	Improves LC detection	Detection	2.78	1.20

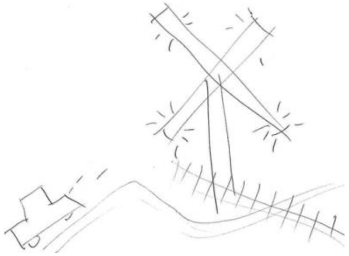
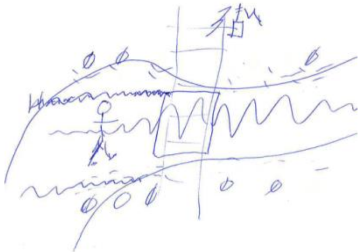
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
46	Traffic light	Use of traffic lights at LCs instead of LC lights, as road users often respect traffic lights more than LC lights. The traffic lights should be coordinated with an announcement of the LC and with ground loops to manage traffic jam and avoid the queuing on the LC. Note on applicability: In LC with barriers, this could be technically coupled to the closing signals. In passive LC it would be effective, too, in case additional detection technology could be installed.		y	y		y	y	Provides up-to-date information about LC status. Controls the access to LC	Decision-making	2.78	0.83
47	Warning sign to avoid blocking back	A sign to remind road users to avoid driving onto the LC when they would have to come to a stop (e.g. because of traffic jam).		y	y	y		y	Controls the access to LC	Rule knowledge	2.78	0.67
48	Improved vegetation clearance	Removal of vegetation near LCs and along the tracks to increase visibility and enable the early detection of LCs and trains. The efficiency of conventional survey procedures could be increased by using web mapping applications (e.g. Google Earth / Bing map / Satellite images) to identify potential problem locations which need immediate action.		y	y	y	y	y	Improves physical environment of LC. Improves train detection	Detection	2.78	0.67
49	Awareness campaign	Awareness campaigns regarding the consequences of not respecting LC rules.		y	y	y	y	y	Increases awareness of correct behavior / dangerousness of LCs	Rule knowledge	2.78	0.67
50	Sound theme bump and flashing post.	Installation of an array of bumps before the LC designed in such way that the sound produced when a car drives across it adds up to a short characteristic sequence of the "Jaws" theme to warn road users of an approaching LC. To increase the effect, the bumps can be coupled with red flashing post.				y		y	Reduces approach speed of vehicles. Improves LC detection	Detection	2.75	0.89

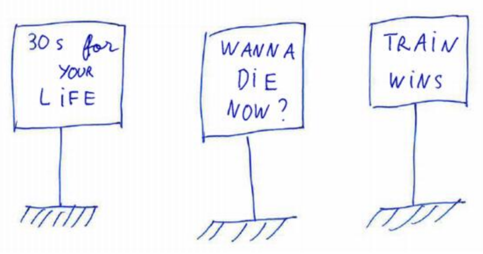
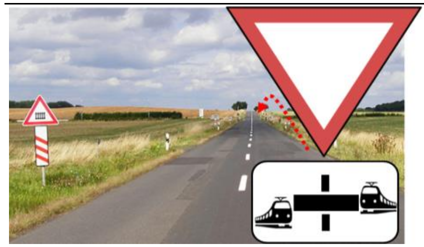
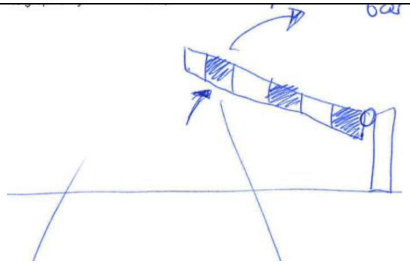
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
												
51	Train LED panel	Train LED panel provides information of an approaching train aiming to encourage pedestrians to wait until the train has passed the LC.				y	y		Provides up-to-date information about LC status	Rule knowledge	2.75	0.46
52	Reduction of speed limit	Reduction of the road's speed limit on LC approach as a way of maximising the time available for the driver to process information and make (correct) decision. Note: will be more effective in combination with camera enforcement.	none			y		y	Reduces approach speed of vehicles	Identification, Action execution	2.75	1.04
53	Designing train outside for higher conspicuity	Design the outside of trains for greater conspicuity, e.g. through retroreflective markings on all train cars and brighter paint schemes on freight cars and carriages. Such measures have the potential to improve driver ability to detect and recognize an approaching train.		y	y	y	y	y	Improves train detection	Detection	2.67	1.00
54	Light display rumple strips for VRUs	Positioning a matrix of "twinkling" LEDs around LCs that increase colour/intensity/frequency towards LC to inform VRUs about the approaching LC.				y	y		Improves LC detection	Detection	2.67	0.71

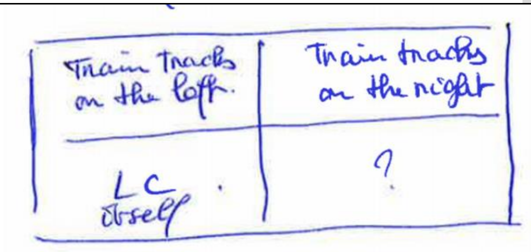
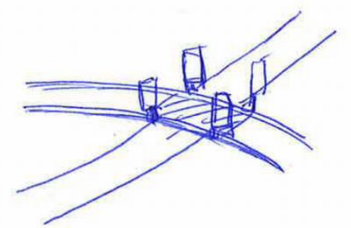
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
55	Higher barriers	Installation of LC barriers directed at VRUs at a greater height than in a normal situation, aiming to prevent violations when the LC is closed. The measure can be combined with hanging bars, grids or chains below the barriers (see measure ID 1_01_1) to prevent pedestrians from crossing below the barriers.		y			y		Controls the access to LC	Decision-making, Action execution	2.67	0.87
56	Paint the road red	The road on approach to the LC painted red to increase visibility of the LC.		y	y	y	y	y	Improves LC detection	Detection	2.67	0.71
57	Noise-producing pavement (rumble strips) on advance to LC	Use of special road pavement (already experimented on highways) which passively produces noise as cars are passing on it. The measure aims to improve detection of LC. Could be combined with speed reduction. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists and has consequences for other road users (e.g. cyclists).Adapt the design to the situation (e.g. number and kind of rumble strips).				y		y	Improves LC detection. Reduces approach speed of vehicles	Identification	2.67	0.87
58	Distribution of speed information	Reminding road users of the prevailing speed limit and providing them with up-to-date information on their current driving speed via a dynamic in-vehicle display (e.g. messages with flashing light). This measure could be combined with enforcement cameras. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists.				y		y	Reduces approach speed of vehicles	Rule knowledge	2.67	1.12
59	Environmental design to enhance the "crossing track" perception	Enhancement of the "crossing track" perception on approach with environmental design, which emphasizes driver perception of rail tracks. This could be done by designing the tracks on the left and right to look more like a crossing street; e.g. having a paved broader aisle round them, or a fence (fence should still allow for looking for a train when road user comes closer). Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU, but also holds for motorcyclists.				y		y	Improves LC detection	Detection	2.63	0.52

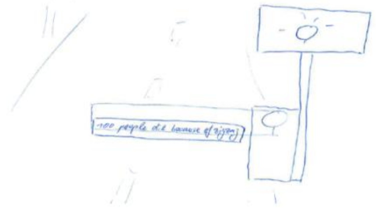
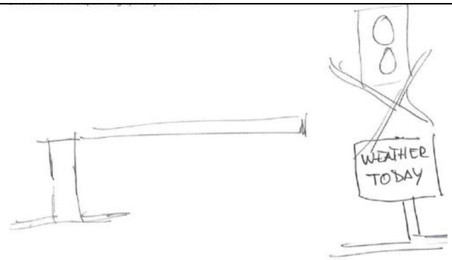
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
60	Ground signaling	different of ground signaling according to the distance of the LC from 200m to 2 meters to the LC, with mini bump to generate a visual and vibration effect				y	y	y	Improves LC detection	Detection	2.63	0.74
61	Attractive signs for children at their height	Explanatory signs of correct LC behaviour for children in accessible language placed at an appropriate height.	none	y	y	y	y		Increases awareness of correct behavior / dangerousness of LCs	Detection	2.56	0.53
62	Rumble strips to prevent zig-zagging	Rumble strips that produce an annoying sound on full width of the adjacent lane to discourage car drivers from zig-zagging at LCs with closed half-barriers.			y			y	Controls the access to LC	Identification, Decision-making	2.56	0.53
63	Anti-slip pavement	Substituting asphalt with permanently dry anti-slipping pavement (≠ wet roads, raining). This measure aims to improve the safety of cyclists and possibly vision impaired people.		y	y	y	y		Improves physical environment of LC	Action execution	2.56	0.88
64	Hanging bars (gate-skirts), grids or chains below the barrier	Installation of hanging bars / grids / chains to full barrier LCs aimed at VRUs to prevent them from crossing below the barrier when the LC is closed. Traditional skirts sometimes still allow violations - skirt design should be sufficiently robust. The measure can be combined with measures aiming to prevent climbing over the barrier.		y			y		Controls the access to LC	Decision-making, Action execution	2.56	0.53

Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
65	Exit door for trapped pedestrians	An LC with full barriers equipped with an exit door on the side that opens from the trackside. If a pedestrian is stuck after the barriers are closed, he or she can exit the area without the need to climb the barriers.		y			y		Improves possibilities of VRU to cross the LC safely	Action execution	2.56	0.53
66	Convey information on barrier breakability to enclosed vehicles (e.g. by sticker)	Installation of stickers inside LC barriers informing drivers of breakable barriers to avoid vehicles getting trapped between the barriers.		y				y	Increases awareness of correct behavior / dangerousness of LCs	Rule knowledge	2.56	0.73
67	App for warning and information about LC approach	An application that warns vulnerable road users on approach to LC to inform them about oncoming LC and give messages according to LC type (e.g. look left and right at passive LC; be patient at active LC). The application should automatically shut down music or other multimedia if currently used.		y	y	y	y		Provides up-to-date information about LC status	Identification, Rule knowledge	2.44	0.88
68	Illusion of increasing speed	Create a visual illusion of increasing driving speed when approaching the LC (e.g. by using lights for the road with decreasing spacing). The measure aims to reduce driving speed. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU; also holds for motorcyclists.				y		y	Reduces approach speed of vehicles	Detection, Decision-making	2.44	1.01
69	Use of timber road surface before LCs	Use of timber road surfaces before LCs to limit vehicle speeds on approach. Timber road surfaces have lower durability compared to concrete surfaces, which could force drivers to drive slower when crossing such LCs. Note on applicability: effective for road users traveling at higher speeds, therefore classified MRU; also holds for motorcyclists.	none			y		y	Reduces approach speed of vehicles	Identification, Action execution	2.44	0.73

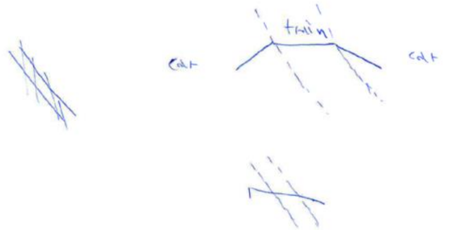
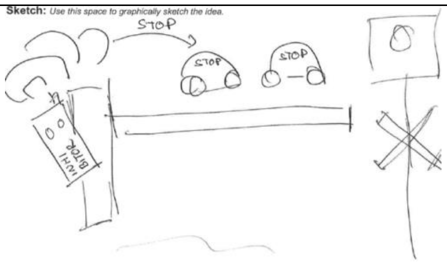
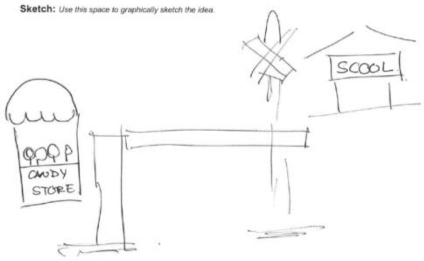
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
70	Super 3M	Development and use of special solar powered film on crossbucks. The film will react to oncoming vehicle lights (headlights or running lights) and a piezo will make the film appear to 'blink' to approaching drivers and thus informing them about the approaching LC.		y	y	y		y	Improves LC detection	Detection	2.44	0.73
71	Audio rumple strips or Surround sound	Use of a matrix of speakers around LC to produce a low volume sound-scope that increases in frequency/volume towards the LC. This measure aims to alert the VRUs to increase their attention when approaching the LC.				y	y		Improves LC detection. Reduces approach speed of vehicles	Detection	2.44	0.88
72	Additional warning sign	Installation of an additional warning sign synchronized with the announcement of LC to improve the visibility of LC in a curved road where the Lc is not easily identified by the road user.	none			y		y	Improves LC detection	Detection	2.44	0.53
73	Rolls on top of full-barriers	Rolls installed on top of full-barriers to discourage pedestrians and bicyclists from climbing over barriers. Should be combined with measure to prevent passing below the barrier (see measure ID 1_01_1) to prevent pedestrians from crossing below the barriers.		y			y		Controls the access to LC	Decision-making, Action execution	2.44	0.73
74	Warning panels	Installation of warning panel to encourage safe behaviour at LCs. Designs can be adopted to the conditions, e.g. poster with shocking picture of car crash; double panel in which one half remains steady, while the second half alternates with safety message or information message, e.g. picture of bullet with message "don't risk your life".	 	y	y	y	y	y	Increases awareness of correct behavior / dangerousness of LCs	Decision-making	2.44	1.13

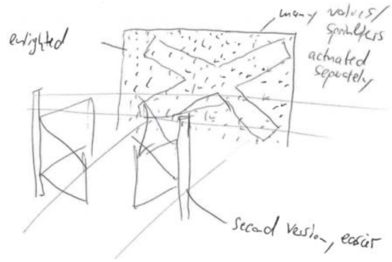
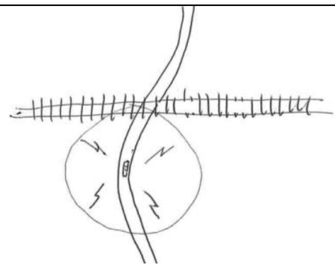
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
75	Include human factors into sight distance models	Use of a model in determining the necessary sight triangle for LC. The model includes elements such as road user observation-reaction time, length of crossing time, and safety margin.	none			y	y	y	Improves train detection	Detection	2.38	0.92
76	Adaptive colours of sign	The improvement of the visibility of LC signs by changing the colour or intensity of the signs depending on time of day (dark, bright) & season (winter, summer) (e.g. like the cup which changes colour when filled with hot/cold beverages).	none	y	y	y	y	y	Improves LC detection	Detection	2.33	1.00
77	Deterrent warnings	Installation of warning panels on the approach to LCs aiming to encourage safe behaviour. The warning panels ('Wanna die now?', 'Train wins!' etc.) light up when a train is approaching the LC.		y	y	y	y	y	Increases awareness of correct behavior / dangerousness of LCs	Detection, Decision-making	2.33	0.71
78	Addition of Give-Way sign	Drivers often fail to perceive a crossing on LC approach, because the road ahead appears uninterrupted. The correct notion and action scheme could be triggered by combining an enhanced Give-Way sign (as it is familiar in the respective country) with the crossbuck, reminding road users of the train's right of way. The additional sign supports the perception of a crossing track of another vehicle.				y	y	y	Reduces approach speed of vehicles	Rule knowledge	2.25	0.71
79	Barriers with freedom to move horizontally	Installation of barriers which can turn horizontally. These could easily be pushed away to the exit side if road users are trapped between the barriers. Must make sure that barriers do not open due to wind etc. Combine with information inside of barriers "When you are stuck just push away the barrier".		y				y	Increases awareness of correct behavior / dangerousness of LCs	Action execution	2.22	0.44

Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
80	Fillers in LC to cover rails	Addition of fillers to LC to prevent vehicles from being stuck at LC with a wheel.	none	y	y	y	y	y	Improves physical environment of LC. Improves possibilities of VRU to cross the LC safely	Action execution	2.22	0.83
81	Display the schedule of the trains at the LC	Active billboards displaying up-to-date schedule of trains for pedestrians. This provides support for pedestrians when deciding on the safe moment to cross the LC.	none	y	y	y	y		Provides up-to-date information about LC status	Identification, Decision-making	2.22	0.97
82	Stream of video images from LC to vehicles	Cameras installed at passive LCs which send images of the LC and the train tracks ahead of the LC in real time to motor vehicle drivers via an embedded telematic system (images can be received e.g. on GPS/multimedia screen). The same images could also be sent to train drivers to a screen in the train cabin.				y		y	Provides up-to-date information about LC status. Improves train detection	Detection, Decision-making	2.11	0.93
83	LC wide mirrors	Use of mirror or system of mirrors to allow road users to detect an approaching train from both directions (same principle as mirrors for parking at parking exits). The size and design of the mirrors should be sufficient to be at the eye-level of all road users.				y	y	y	Improves train detection	Detection	2.11	0.78
84	Wind panel	Wind panel which rotates in line with blowing effects of a train, aiming to generate an effect of the train speed for pedestrians so that they would have a better perception of risk related to crossing of LCs.		y	y	y	y		Increases awareness of correct behavior / dangerousness of LCs	Rule knowledge, Decision-making	2.00	0.53

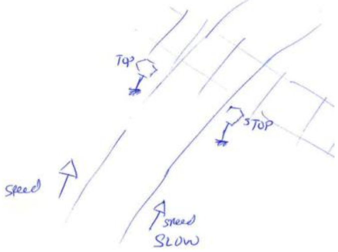
Rank	Measure Name	Description	Sketch	Full-barrier	Half-barrier	Passive	VRU	MRU	Effect mechanism	Psy. function	M_{PAR}	SD_{PAR}
85	Information about risks in barriers	The LC barriers are equipped with displays including digital text for road users (e.g. warnings, jokes, news) to entertain them while waiting for the LC to open. The purpose is to make the waiting time less annoying and thus reduce the risk of violations.		y	y		y	y	Other	Decision-making	2.00	0.50
86	Replacement of STOP signs with Give-Way-signs	Replacement of STOP signs with Give-way signs along low volume roads in rural areas as part of periodic sign maintenance due to poor safety effectiveness associated with STOP signs at LCs.	none			y		y	Improves train detection	Decision-making	1.88	0.83
87	Weather information	Provision of weather information for LC users to entertain them while waiting at the LC to make the waiting time less annoying and thus reduce the risk of violations.		y	y		y	y	Other	Rule knowledge, Decision-making	1.44	0.53
88	Music	Relaxing music played to road users when the train is approaching instead of the usual warning sounds to make the waiting time less annoying and thus reduce the risk of violations.	none	y	y		y		Other	Detection, Decision-making	1.22	0.44
89	Community information post	Placement of an information post of interest to the community at the point of the LC to make the waiting time less annoying and thus reduce the risk of violations.	none	y	y		y		Other	Identification, Decision-making	1.22	0.44

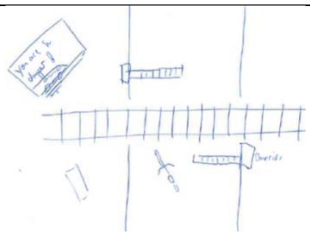
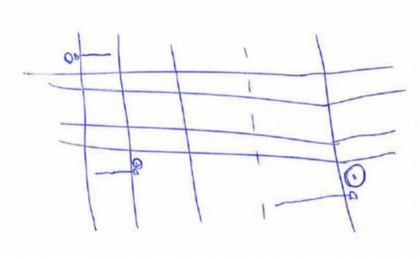
B. Table of proposed LC safety measures excluded for practicability issues

Measure name	Description	Illustration
Virtual Wall Display	A virtual red wall and countdown timer are displayed in front of the LC when a train is passing.	
Spikes on the road	Use of spikes on the road on the opposite lane so people can only go in the right direction (Aim to prevent zig-zagging at LCs with barriers).	none
Limiting driving speeds when approaching LC	The speed limiter (of the car) will automatically adjust the driving speed according to the prevailing speed limit before the LC	none
Small slope to help push away stuck vehicles	Low slope in road design in order to release stuck vehicles.	
Selling stuff / Making waiting nicer	Sell products like coffee, etc. in order to make waiting time more enjoyable when the barriers are closed.	
Car deactivation	Develop a system by which all cars deactivate when the train is arriving - something similar to a telephone inhibition.	
Candy Store	If the LC is near a school put a candy store. Link the LC installation with something everyday and positive. Customize the LC.	

Rain shower as a curtain	Rain shower as a curtain/barrier to increase visibility of LC.	
GPS with an attitude	GPS with an in-vehicle map of passive LCs, which warns the driver on LC approach, shuts off radio & mobile phone during crossing with EMP if necessary (well, ok, not EMP …maybe just small electric shock to driver). Can also warn drivers of approaching train or emergency vehicles with real time map.	
Blocking mobile phone signals at LCs (except of emergency calls)	Use of technologies that can block mobile phone signals (except for emergency calls) at LCs to reduce distracted driving.	None
Removal of LCs	Removal of the most risky LCs by replacing them with under- or overpasses, or by diverting the traffic to other safer LCs nearby.	None

C. Table of proposed LC safety measures excluded for insufficient match with project scope or infeasibility of testing in SAFER-LC

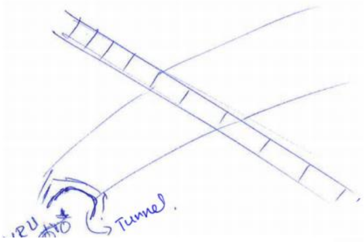
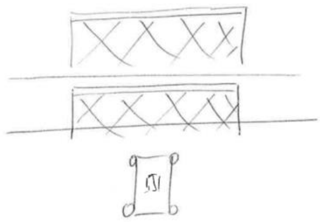
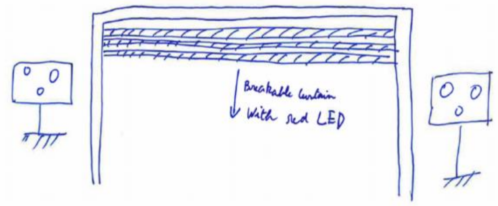
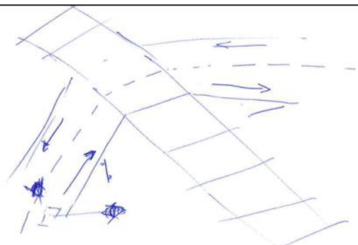
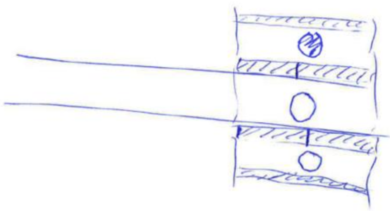
Measure name	Description	Illustration	Remark
Legal measures for motorised users	Legal measures to oblige (motorized) road users to comply with LC measures. STOP at the approach and check both sides of the rail track to make sure that there is no approaching train. Application of strict sanctions on those not following this measure. Place signs to reduce speed to the approach.		Unclear how checking left and right can be reliably controlled. Other measures existent in list for prosecution of violations.
Transforming two-half barriers LXs into four-half-barriers or two long-half-barriers LXs without modifying/moving the train detection means	This measure aims to prevent/minimize barrier bypassing when the LC is closed to road traffic. However, the solution can have drawbacks in congested conditions, as some vehicles may become trapped in the LC zone. Combining this measure with obstacle detection technology may prevent this and enhance safety. An advantage of such a combination is that train detection means can be kept as they are, i.e. the costly and time-consuming relocation of train arrival sensors to a farther location is not necessary. It is also worthwhile to note that the obstacle detection device would only be set to control the closure of exit half-barriers. Therefore, if a vehicle is detected in the LC zone after the closing cycle has started, then the exit barriers remain open until the detected vehicle frees the LC zone. The obstacle detection means can be a very simple and cheap device such as a magnetic loop.		classic upgrade
Low Cost Level Crossing Warning Device	Train activated warning device wherein loop detectors placed between tracks detect trains.		not clearly defined measure
Education programmes	Development of education programmes for different types of LC users, e.g. (1) Old and very old drivers, (2) Novice drivers in driving school (increase exposure to LCs during driver training programmes to develop novice driver schema related to LCs), (3) Truck drivers (to build truck drivers' schema of routes in different states, including crossing both active and non-active states)		not testable in project
Risk assessment processes and risk assessment tools/models	Development and use of risk assessment models / safety assessment tools for railway stakeholders. The number of accidents at LCs is often so small that evaluation of risks based purely on them is unreliable. Risk assessment tools enable the user to a) estimate the current safety of almost all LCs on the state rail network and b) evaluate the safety effects of improvements at any such LC. With the use of average or known costs of LC improvements, the user can even estimate the cost-effectiveness of an improvement or combination of improvements.		not testable in project
Improvement of LC data collection and analysis	Improvement of LC accident reporting (and reporting systems) and databases related to LC environments which enable more efficient use and analysis of collected data.		not testable in project
Telephone number or telephone at the LC	Implementation of telephone or telephone number at LC to enable road users to call using the railway infrastructure in case of danger, obstacles or any issues.		not clearly defined measure
Restricting the access of large vehicles to LC	Large vehicles take more time to cross the LC and thus their access could be prohibited to some LCs.		not clearly defined measure
Frighten people	Make the LC appear more dangerous. E.g. faster barrier closure, sound, make barriers sharp --> damage paint of car	none	not clearly defined measure
Buffer zone	Two sets of barriers on each side of the LC (c. 10 m distance) to avoid vehicles being jammed at LC when the barriers are closed.	none	not low-cost

Measure name	Description	Illustration	Remark
Vulnerable road user pavement warning	A sensor detects different types of VRUs and the image of the user appears on the pavement (in small lights) so they notice together . The image will be accompanied with an audio warning.	none	not clearly defined measure
Train approaching warning to pedestrians	Visual indication that a train is really coming to the crossing and the warning has not failed. A countdown timer or moving light pattern could be used to discourage users to stop for waiting.	none	not clearly defined measure
Convincing sign for cyclists	Warning lights in line of sight of zig-zagging pedestrians.		not clearly defined measure
LC dedicated to pedestrians and other mobilities (segways, cyclists, etc)	As road regulation enables cyclists to occasionally disrespect traffic lights and to not respect the right? of way, it could be effective to have a separate LC with some other device.		clearly defined measure
Ultrasound alarm to scare away animals	Sounds along LC that chase away animals. Only animals should hear and recognise the sounds. E.g., dog pipes.	none	not directed at human road users
Speed radars	Speed radar upstream of the LC.	none	not clearly defined measure
Light with LED	LED light	none	not clearly defined measure
Vigilance wakefulness tape	Vigilance wakefulness tape on sidewalk side without half barrier	none	not clearly defined measure
Three new design concepts of LC that were tested in a simulated scenario (cf. Read et al., 2016)	Concept A: Stronger warnings with community focus - Traffic lights in addition to current RLX flashing lights and boom barriers, Advanced warning signs, In-road studs that light up when warnings are activated, A default closed gate for pedestrians, RLX supervisors / attendants to reinforce warnings and respond to emergencies, Signs displaying 'hold' and 'keep tracks clear' to avoid drivers queuing over the RLX in congested conditions, An emergency lane and 'no standing' zone to provide access of the RLX for queued drivers, Channelized pedestrian fencing, Convenience and amenity for waiting pedestrians such as a shelter, community hub, ticketing machine and café near the waiting area . Concept B: Leverage new technology to display field of safe travel - An in-vehicle display providing auditory and visual cues, based on field of safe travel theory; on approach to the RLX when a train approaching, the display provides an alert tone and a visual train icon appears on the display, A green 'tongue' appears along the road to indicate the safe area of travel ahead, As the vehicle gets closer to the RLX, black curved bars appear (in line with the stop line) to show the limit of the field, When no train approaching, display continues to show a representation of the roadway ahead but shows no indication (i.e. no green tongue is displayed). Concept C: Community focused transit orientated design incorporating shared space principles, A city square / courtyard feel: cafes, meeting areas & community information booths, intended for locations where the RLX is adjacent to a train station,- A 'shared space' area adjacent to the RLX delineated by traffic lights which hold road vehicles back away from the RLX when trains are approaching, A speed reduction to 20km/h within the shared space for both vehicles and trains, Road users expected to give way to more vulnerable road users within the shared space, Replacement of traditional RLX warnings such as boom barriers, flashing lights and auditory bells with RLX supervisors / attendants (i.e. with no dedicated visual or auditory RLX warnings at the crossing)		Combination of many measures. Single solutions are in the list.

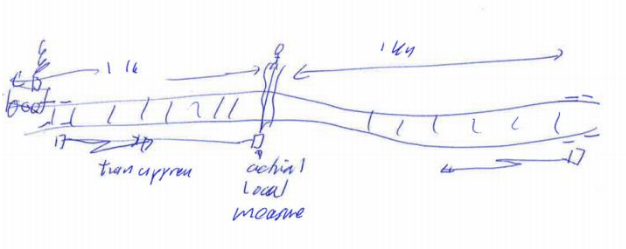
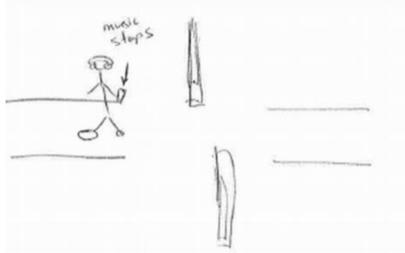
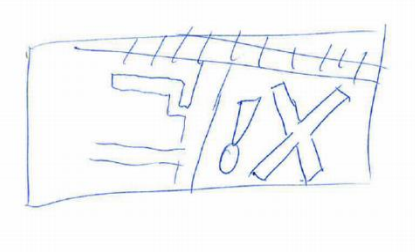
Measure name	Description	Illustration	Remark
Train detection technology. Lower-cost train detection systems	Induction loop detector (detects metal objects moving over an induction loop placed on the railway tracks) or Doppler radar (detects moving objects by bouncing a radar signal from the object and measuring the frequency shift of the signal).	none	not clearly defined measure
Flashing red lights	Aimed to increase compliance of car drivers.	none	classic upgrade
Automatic flashing warning lights	Two types analysed: red flashing lights and white flashing "safe"-signal.	none	classic upgrade
Deterrent sound to prevent Deer-Train Collisions	Deterrent sound with two alarm calls. The first alerts the deer, and the following howling sound deters the deer from the track. To emit this sound from a train, previous deer-train collisions were mapped using a geographical information system (GIS) based on actual collision data, while considering features such as vegetation and landscape topography. This was used to propose an accompanying method to select areas where the sound should be emitted.	none	not directed at human road users
LC Disability Access Toolkit	A toolkit of measures to support disabled pedestrians in safely crossing LC. Proposed solutions are categorized into the seven main areas. (cf. RSSB Project T650)	n	Combination of many measures. Single solutions are in the list.
Jamming communications close to LC	Using communication jammers to prevent people using Bluetooth earphones and other communication devices close to LCs.	none	ethically questionable

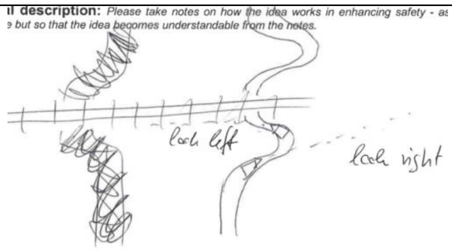
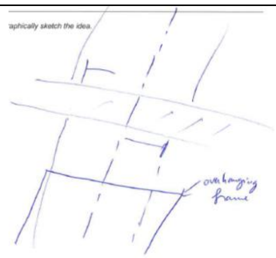
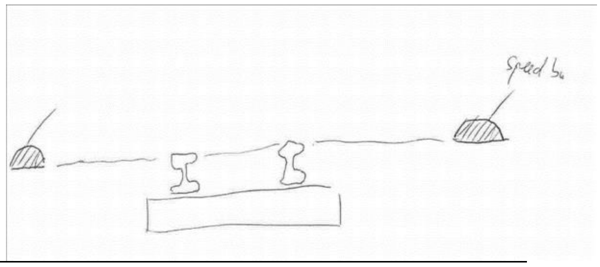
D. Table of proposed LC safety measures excluded for low expert ratings on *efficiency* or *low cost* dimension

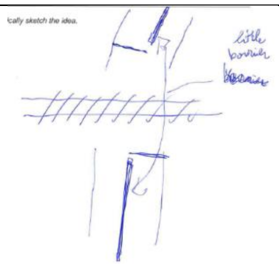
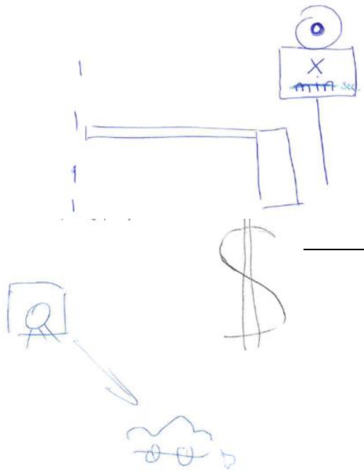
Note: M_{eff} and M_{lc} denote the mean of the How effective? *and* How low-cost? *ratings obtained in the design workshop with road and rail experts (cf. 2.2.3).*

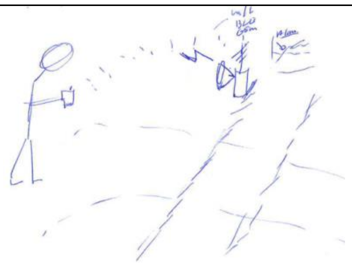
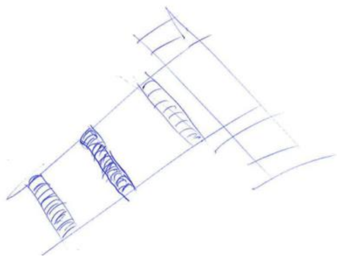
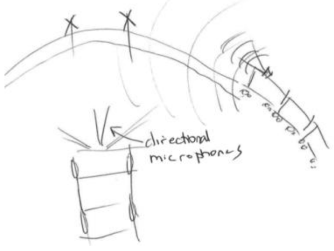
Measure name	Description	Illustration	M_{eff}	M_{LC}
Hearing tests	In addition to 'eye-test' when you get your driving licence also hearing tests could be implemented	none	1.67	4.17
Underpass for VRU (separated grade)	To make underpasses for VRU crossing the rail tracks. By separating grade using underpasses will separate VRU from rail crossings.		4.83	1.00
Very strong barrier	Full physical barrier. The idea is to install a frontal or lateral barrier (very strong: concrete). Concrete blocks. (Confer barriers in Russia)		4.33	1.33
Visual interference	Breakable curtain, like a garage door, with LEDs on it. Gives the impression of a wall --> drivers have to slow		3.86	1.43
Raising LC, crossing at same grade	Raising the LC track from the road so that the approaching vehicles slows at entering to the LC & leaving faster at exiting the LC. That also gives a better view for road vehicle drivers to look for any incoming vehicles		3.00	1.50
Additional barriers before full barriers	full double barriers installed before the LC barriers. The idea is to keep the users as far as possible from the passing train. Additional barrier could also be "virtual barrier".		3.80	1.50

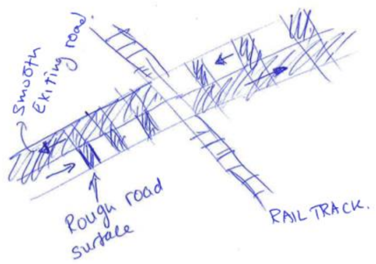
E. Table of proposed LC safety measures excluded for redundancy

Measure name	Description	Illustration
Train approach warning	LC warning device which warns road users of approaching trains based on information collected via sensors installed along the railway line (e.g. 1 km up/down stream of the LC).	
Proximity message - information sharing via connected device (satnav, mobile, etc)	Use of a system which intervenes with people listening to music or paying attention to other multimedia on their phones when approaching LCs either by abruptly shutting down their media or by producing a voice message to warn about the approaching LC.	
Light on barrier	Light on LC barrier to improve LC visibility.	
Requirement by law: information on LCs by GPS	Mandatory inclusion of LCs on navigation software. This ensures that people are informed through their GPS devices that they are approaching an LC.	
Warning light device	Installation of a warning light device on LC traffic signs to enhance road user warnings of an approaching LC. The white light of the warning light device indicates that the device is working and the fast blinking red light warns about the approaching train, or indicates that the system is out of order. The warning light devices are mainly targeted for use on private roads, railway sections with low traffic volumes and motor sled routes where sight distances are not good.	
Vegetation removal	Removal of vegetation near LCs and along the tracks to increase visibility and enable the early detection of LCs and trains.	none
Update train operational schedule in navigation software	The position of train is known by GPS or mobile applications, and warning can be sent to the driver	none
An active signage that reverses back to passive controls in case of a right side failure ("safe failure")	Low cost equipment with reduced safety integrity level (with a design that would fail to a safe state). In case the active LC controls fail to detect whether a train is approaching (detection fails or there is a loss of power), the LC reverts to a passive crossing. If this occurs, a STOP sign appears in front of the flashing lights.	none

Convex mirrors	Use of convex mirrors to help road users to see better sideways when approaching the LC.	none
S-shaped road	Building an S-shaped road before the LC to force drivers to reduce driving speeds and look in both directions at an LC during approach to observe the possible trains. Note: problemativ, because the crossing angle should not be too small or too high. If the road turns first to the right and then to the left, the train might arrive from right while the car is doing the left turn.	
LC indicated in navigation software	To help car/truck driver and warn them	none
Overhanging frame to prevent high vehicles (trucks, etc) from going through a LC when this is forbidden for them	Sometimes, tall vehicle drivers are not aware of the fact that they cannot cross a LC due to the height of the gateway overhead the LC. To prevent this scenario, an overhanging frame can be installed on the road at a safe distance from the road.	
Speed bumps	Force road users to reduce speed. Addition from a redundant mention: Few bumps but not close to LC as that may be a cause for cars being slow (stuck) on/at the LC	
In-vehicle warning system for LCs	Providing warning of approaching train to car drivers at low-density line LCs. No installations needed at the LC itself.	none
Indication of approaching railway vehicle	Identification of approaching trains and railway vehicles via a device installed in the tracks (no need to install anything inside the trains or other railway vehicles). This information will be then transmitted to road users (e.g. to their car displays, mobile phones etc.) to warn them of the approaching train.	none
Better elastic skirts	Traditional skirts often fail, make it more flexible. Prevent people from going underneath	none
Camera recording violations	In case of violation a picture will be taken, person will be identified and fined. (Could also be dummy camera)	none
Avoid opening the LXs if a minimum opening duration is not ensured	This solution can be implemented provided that we have a real time knowledge of trains' location from both sides of the LC	none
Light effect line	Implementation of a white line at the level of the lights to enable the drivers to stop at the correct level	none

Information regarding the arrival of a train from an opposite direction after a train has crossed the LC	because of trains passing from opposite directions in the same LC, the LC must be kept closed after the passing of the first train and an indication to be added that a second train is approachning, this time from the other direction. This way people, mainly pedestrians will be discouraged to pass.	none
Give information: Second train is coming	Display explaining that there will be more than one train	none
Physical barrier (elected "lowest cost")	Implementation of physical barrier in the middle of the road section to prevent crossing the LC with barriers	
Possible second train approaching	On LC with light protection (and with or without half-barriers) - a kind of info that the second or even third train may come, even from the same direction. Any way is ok, from stationary texts on tables to light and / or arrows like Japan.	none
Delay information of the train	The train is geo localized. A light panel to give information of the arrival time. The inconvenient: it can encourage people to force the LC	
Enforcement by automatic cameras (elected "most effective")	Each LC with automatic lights should be equipped with an automatic camera taking pictures of each user who is in the "collision" zone after for example 5 s from the beginning of the flashing. The picture should be sent to the fee-issuing institution. No chance to avoid it. The measure needs: law regulation, equipment	
in/out lane separation	A kind of barrier between road lines in 2 directions protecting against zig-zagging	none

Make train front more visible	Turn on many lights/flashing lights when train is approaching the level crossings. Lights on train front end. Eye-safe laser on train front directed towards LC which is able to light-up the LC. There are lasers with 5 miles range.	none
Traffic light synchronised with the arrival of train	The lights (red-amber-green) should be red few meters (25 m) before the LC when the train is approaching	none
Mobile phone 1 (MPO I)	Young pedestrians walk looking at their mobile phones. --> A device monitors for the e-m transmissions (wifi, oms, bluetooth) and sounds an alarm (and/or jam the connections) when it detects "approaching".	
LC info to mobile phones (VRUs)	In order to target the VRUs using mobile phone while approaching/crossing LC (possibly being distracted). We could send text or sound warning to mobile phones when VRU is at certain distance from LC (no proposal on how this can technically be done) . If VRU is texting he/she would receive whatsapp-type message which will appear to the screen. If VRU is hearing music or phoning he/she would hear overlapping sound warning message: be aware, you are appraoching LC. Aim: improve awareness of approaching LC.	none
Technical solutions using road bumps	Place speed restriction bumps on the approach. Few bumps but not close to LC as that may be a cause for cars being slow (stuck) on/at the LC	
Info on LC status (targeted mainly to VRUs)	Each passive LC should be equipped with similar screens as the bus stops indicating when the next train/railway vehicle is expected to arrive. Or if no train is expected in the near future, the screen could say "No train/railway vehicle expected in the next 5 mins". The question is, can this system be made fail-safe. Aim: The screens providing real time status of LC would draw the attention of LC users (especially VRUs) to would make them to check the status of LC before crossing it.	none
Sound detection based warning	Vehicle or personal (cell phone) app to detect approaching train (horn or even just normal train sounds of engine, wheels). Warning provided (virtually changes passive to active LC). Possible to use in connection with image prosessor or LIDAR detection of upcoming crossing	

Change the road surface texture	Use sticky and rough road texture to make the driver aware that there is something ahead so that to slow the speed. Only on the approaching road lanes. Combine it with speed restriction.	
Rumble strips	Application of structured or milled markings in road surface on approach to LC to enhance attention and reduce speed.	 
traffic lights	Traffic lights coordinated with the announce of the LC and with ground loops to manage traffic jam and avoid the queuing on the LC	none
Improvement of sight distances	Improving the visibility of the train by improving sight distances would be expected to improve driver decision making at passive level crossings by allowing the driver more time to visually scan the scene, process information, and make a decision on approach to a level crossing.	none
Level crossings and information systems	Spain is working on a project using geo-positioning in real time of all road and rail vehicles to provide danger warning notification to drivers and infrastructure managers. The notification is sent to mobile phones as text and audio message and, e.g., for road vehicle drivers, it alerts them on approaching a level crossing.	none
Gate skirts	A LC pedestrian safety device, commonly known as gate skirts, consists of a secondary horizontal hanging gate under the existing pedestrian gate to better block access to the crossings by pedestrians who gain unauthorised entry by going under the down gates in the presence of a stationary or moving train. The gate skirts are designed to prevent pedestrians from violating the LC while the LC warning protection systems are activated.	none
Visual ITS	The visual ITS device was designed to enhance driver behaviour at railway crossings. The device provided real-time messages on the in-vehicle device (Nokia smartphone). The device was positioned within the driving cabin at the usual, center-dashboard location of a GPS. In the "train approaching" scenario, and at active crossing, the device displayed two alternative picture that mimicked the flashing light effect seen at active crossings. For passive crossings, the warning was displayed at the time the crossing would have been activated if the crossing was actively protected. The warning conveyed explanation and action messages to the driver in one symbolic representation, indicating that a train was approaching the crossing and that the driver was expected to stop.	none

Audio ITS	The audio ITS device was designed to enhance driver behaviour at railway crossings. The device was implemented using an existing vehicle manufacturer-installed speakers inside the car to provide verbal warning messages to the driver. In the "train approaching" scenario, a verbal warning was provided while the flashing lights of simulated active crossings were activated For passive crossings, the warning was provided at the time signal would have been activated if the crossing was actively protected. The verbal warning were " Train approaching the crossing ahead" and "Stop at the crossing".	see article
Improvement of the efficiency of vegatation clearance	The efficiency of LC inspections could be improved by i) using web mapping application to identify potential problem locations, ii) by using conventional survey procedures to identify vegetation blockage and delineate trimming boundaries.	none
Enforcement	Stronger law enforcement towards violations at LCs. Photo enforcement to reduce crossing violations by motorists.	none
Message panels	Message with double panel, one half remains constant, the second half is alternating with safety message or information message. For example: *don't risk your life* with picture of bullet	
Increase long-distance train conspicuity in presence of visual barriers	Increase ease of train detection by road users on approach. For example, the train could emit a visible trace beyond its actual dimensions. This could, e.g., be a laser / light beam.