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Human-centered measures to enhance safety at level crossings

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Abstract

Road user behavior plays a major role in accidents at level crossings. Therefore, measures to improve safety at level crossings should be developed with a human factors perspective. Moreover, they should be affordable and applicable to a large number of crossings to achieve tangible safety effects. We report on work to collect and design human-centered low-cost measures to enhance the safety of level crossings that was part of the European project SAFER-LC. First, a pool of design ideas was collected from the research literature, models of road user behavior, and a design workshop with road and rail experts. Second, the measures collected were filtered, categorized and ranked in a three-step process including a classification of their application context and an assessment of their prospects to reduce accident risk. The resulting set comprises 89 measures and will be further developed into a web-based toolbox for road and rail safety practitioners.

Keywords: human factors, road users, errors, violations, rail safety, cost-effective

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1. Introduction

In 2017, a total of 467 accidents occurred on European level crossings according to the statistics of the European Union Agency for Railways (2019). Level crossings (LCs) are defined as any level intersection between a road or passage and a railway open to public or private users. This excludes passages between platforms within stations and passages over tracks for the sole use of employees (EU Parliament and Council, 2016). Fatalities in LC accidents represented 29% of railway accident fatalities in 2016, making LC accidents the second most frequent type of fatal accident in the European railway system (European Union Agency for Railways, 2018). The consequences of collisions of railway vehicles with road vehicles or vulnerable road users are extraordinarily severe, due to the heavy weight and the long stopping distance of railway vehicles even at low speeds (DB Netze, 2017; Operation Lifesaver, 2019). In addition to the economic impact of fatalities and injuries, LC accidents cause significant costs due to material damage, damage to the environment, and primary and secondary delays due to interruptions of rail operations (European Union Agency for Railways, 2017).

The European project SAFER-LC – Safer level crossing by integrating and optimizing road-rail infrastructure management and design – takes a multi-perspective approach on improving road and rail safety by minimizing the risk of LC accidents, focusing on both technical solutions and human processes (http://safer-lc.eu/). The human factors work within the project aims to analyze and consider the needs of different road users to propose ways to make LCs more self-explaining and forgiving. The current paper introduces the process and results of activities to establish and pre-evaluate a set of new human-centered low-cost measures to enhance LC safety.

1.1. The need for human-centered low-cost measures in LC safety

Unsafe behavior of road users – unintentional or intentional – is the major cause of LC accidents (DB Netze, 2017; Grippenkoven, 2017; Grippenkoven & Dietsch, 2015). For example, Laapotti (2016) found out in her analysis of fatal LC accidents in Finland between 1991 and 2011 that an observation error on the part of the motor vehicle driver was the immediate risk factor in more than 70% of accidents at passive LCs and in 31% of all accidents at active LCs. Other common risk factors were anticipation or evaluation errors and other human risk factors. The latter refer, e.g., to the deliberate disregard of danger, which was more common at active LCs.

The most effective approach to increase safety at intersections of road and rail is to remove LCs or to replace them by over- or underpasses. Many countries have adopted policies of avoiding the construction of new LCs; however, there is still the possibility of exceptions where the traffic situation calls for a road-intersection and the effort of grade separation can be validly argued to be excessive (e.g. Deutscher Bundestag, 1990; Dutch Safety Board, 2019; Ley 38/2015 del sector ferroviario; Office of Rail and Road, 2018). Moreover, due to the high number of existing LCs in Europe, and world-wide, and high conversion costs (European Union Agency for Railways, 2019; UNECE, 2016), LCs will prospectively remain a part of the road and rail system for a long time and require other ways of protection. The problem of high cost also impedes a comprehensive upgrade of existing LCs with established safety solutions such as automatic barriers. Beyond that, even though automatic barriers might reduce the risk of road users committing unintentional errors at LCs, the problem of violations and specific errors (e.g. getting stuck on the rails) still leads to a considerable number of accidents (Dutch Safety Board, 2019; Grippenkoven, Giesemann & Dietsch, 2012).

These problems highlight the need to take a human-centered approach that considers perception and attention as well as judgment and motivation of LC users, and to develop effective low-cost safety measures that can be applied to a high number of LCs. Low-cost measures were defined as measures that cost less than a conventional upgrade when applied to a large number of LCs. Moreover, the identification of measures to improve LC safety was directed at innovative measures that are not commonly used at present to protect LCs in European countries.

1.2. Demands and challenges to road users at LCs

Our human factors analysis focused on the action of crossing a LC and the demands and challenges it puts on the road user, to find out how road-users can best be supported by different measures to cross the LC safely. From an information-processing perspective, the crossing action can be divided into five steps that road users need to complete for the purpose of a safe traverse (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 (5) to properly execute the intended action.

The nature of unsafe road user behavior at LCs is heavily influenced by the type of protection applied. The type of protection is the primary determinant of the behavioral demands imposed upon road users in the intermediate phases of information processing after LC detection and identification. The most basic difference in behavioral demands is brought about by the presence or absence of active controls and barriers at the LC. Closed barriers represent a clear and strong cue to road users that they should stop in front of the crossing. In contrast, at 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 active visual search and potential detection after detecting the crossing itself (Larue, Watling, Black, & Wood, 2019). Therefore, the focus of problematic behavior at passive LCs is an insufficient preparation of the traversing action in terms of obtaining information and enabling a stop in time if necessary (Grippenkoven & Dreßler, 2018). This task is easier to accomplish with active signals and barriers at active LCs. In contrast, the main challenge for road users at active LCs is the extrinsic imposition of waiting time that comes into conflict with the individual's mobility goals and hence has the potential to provoke violations and risk-taking behavior (Larue, Blackman & Freeman, 2019).

While the demands and challenges road users face at passive vs. active LCs differ in some important respects, there are also similarities. These similarities relate mostly to the early phase of detecting and identifying the LC itself, and the late stage of motor planning and execution of the action of crossing the LC. With respect to the former, measures that enhance the conspicuity of the LC and elements informing about its nature will be beneficial for any type of LC. With respect to the latter, the problem of getting stuck on the rails because of poor anticipatory action planning (e.g. due to traffic tailback or an overestimation of the achievable speed in light of an imminent closure; Cale, Gellert, Katz, & Sommer, 2013; Pelz, 2011) needs to be tackled at all types of LCs, although this can be especially risky at LCs equipped with barriers. Finally, even though the relevant action knowledge (schemas and scripts) that needs to be activated in the intermediate phase is very different across LC types, common measures could be used to support its activation. For example, an additional sign or an in-vehicle information system could convey hints on the correct behavior in both cases – either to slow down and look left and right for a train at passive LCs, or to watch the status of active controls and obey the signals at active LCs with barriers.

The specific demands and challenges that road users face when approaching and crossing the different kinds of LCs were the starting point of the development and organization of human-centered low-cost safety measures in this work. Three basic LC types were included in the development process: active LCs with full barriers, active LCs with half-barriers (including other types of active protection that can be circumvented with relative ease) and passive LCs. During the work, for the purpose of documentation, all measures that could be applied to all LC types were grouped together. The same was done for full- and half-barrier LCs, as just under half of the measures identified for either of these types could also be applied to the other one. Therefore, the results were structured under three application categories: (1) passive LCs, (2) active LCs with barriers and (3) all LCs.

2. Methods in the identification of measures

The identification of LC safety measures comprised two main phases (see Fig. 1): a *collection* of a large pool of design ideas from multiple sources, followed by a *selection* of measures, based on multiple criteria.

2.1. Collection of LC safety measures

In the collection phase, a pool of design ideas was gathered from three main sources (Fig. 1, top):

- A comprehensive review of international studies, reports and experiences in the field of human factors applied to LC safety
- The study and discussion of human factors and psychological models to support the understanding and prediction of road user behavior at LCs
- A design workshop conducted with road and rail experts, resulting in the conception of innovative measures to make level crossings safer by positively influencing road user behavior.

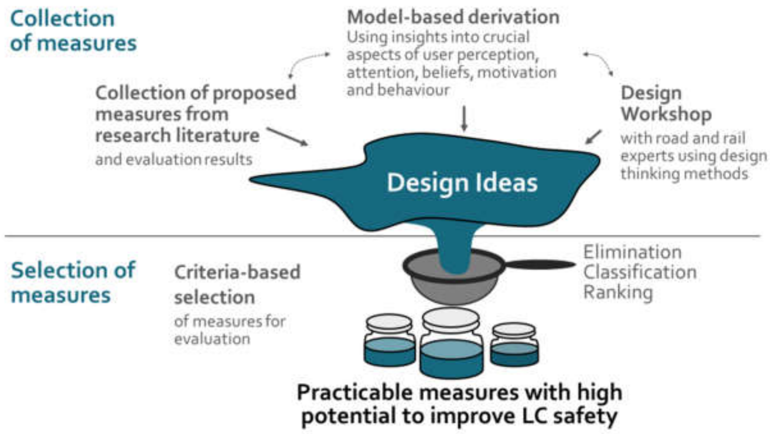

Fig. 1 Approach in the definition of new human-centered low-cost countermeasures

In the literature review, 125 documents were examined for LC safety measures and all information contained on a given measure was captured using a standard template (cf. SAFER-LC Consortium 2018). To build up the literature database, all SAFER-LC partners identified and contributed documents with a focus on human factors at level crossings including user requirements; incorporation of the user perspective in safety systems and measures; accident and incident contributors; perception and acceptance of risk; errors, lapses and violations; and vulnerable users. No limits were set to the geographic scope or type of literature to be included or publication date. The documents were collected from online scientific databases and web tools (e.g. RSSB Spark web tool), ResearchGate, websites of related research projects and cited references listed in the bibliography of other publications. The development and collection of measures was also informed by the analysis of theoretical models of road user behavior at LCs (cf. Havârneanu et al. 2018), identified from related research, publications and analytical tools in road and railway safety, traffic and transport psychology, and human factors. Approaches and models considered included Sociotechnical Systems Theory (Read, Salmon & Lenné, 2013; Trist, 1981), Cognitive Work Analysis (Vicente, 1999), the Generic Error Modelling system (Reason, 1990), the Model of Human Information Processing at LCs (Grippenkoven, 2017), the SEEV model (Wickens et al., 2015), Zero-risk theory (Summala 1988) and Protection Motivation Theory (Maddux & Rogers, 1983), amongst others.

The last input to the pool of ideas was a design workshop held with 38 road and rail systems experts from 11 European countries and the USA. The experts worked together in six groups, each tasked with finding creative solutions to one of three LC scenarios: *LCs with full barriers*; *LCs with half-barriers and/or light protection*; and *passive LCs*. In this brainstorming, participants were asked to consider typical examples of unsafe road user behavior at the LC type and the needs of different vulnerable road users (VRU) and motorized road users (MRU). The ideas, documented on a template, were rated for perceived effectiveness, cost and innovation (1 - not at all to 5 – most).

The design and collection activities described resulted in a pool of potential countermeasures to enhance LC safety with 185 entries altogether. The pool contained a broad variety of measures in terms of scope, innovation, effect mechanism, technology use, target group, and other dimensions. As it was an explicit objective to include new ideas on LC safety, the entries also differed in the degree of elaboration, development and evaluation. Therefore, information on evidence of effectivity could be identified only for part of the measures. The similarity between a number of the entries called for a redundancy check. Therefore, the aim of the following phase was to review, sort and rank the measures, to identify those recommended for further empirical testing.

2.2. Selection process

Three steps were undertaken in the criteria-based selection of measures. First, the collection was reviewed in order to eliminate redundancy and exclude measures that did not match the defined scope. Second, all remaining measures were classified in terms of their application context and effect mechanisms. Third, the measures were assessed on their prospects for reducing accident risk and their need to be further researched.

The elimination of redundant mentions was based on an individual review by the human factors experts within SAFER-LC, followed by a joint discussion. The same procedure was followed to identify measures that were outside the project scope, with reasons including lack of innovation (e.g. classic upgrade), not being directed at human road users, or not being clearly defined. A further aspect considered was the feasibility to test the measure within the project. At the time of the inquiry, 7 different sites with a large spectrum of possibilities were projected for tests in SAFER-LC (cf. SAFER-LC Consortium, 2017). Measures that could not in principle be tested empirically at any site were eliminated. Furthermore, ten experts from SAFER-LC assessed the practicability of each of the proposed solutions based on legality, social acceptability, ethics or other dimensions affecting practicability. A measure was eliminated from the list when assessed as impracticable by half or more of the evaluators. Finally, measures from the design workshop that had received extremely low mean expert ratings in effectivity or low cost (i.e. rating <=2 on a scale from 1 to 5) were eliminated. After these review steps, 89 potential LC safety measures remained in the pool.

The second processing step involved a consistent categorization of the measures, in terms of their applicability to different LC and road user types and the mechanism behind the intended effect on road user behavior. A dichotomous categorization (yes / no) was used to indicate each measure's applicability to *full-barrier*, *half-barrier*[†] and / or *passive* LCs and its suitability for MRU and VRU, respectively. The intended effect mechanism was classified using an adapted version of the categories defined by Silla, Seise & Kallberg (2015): *improves train detection, improves LC detection, controls access to / supports egress from LC, reduces approach speed of vehicles, increases awareness of correct behavior / consequences of violation, makes waiting time more tolerable, improves physical environment of LC*, *provides up-to-date information about LC status*, *supports LC safety actions, improves possibilities of VRU to cross the LC safely*, and o*ther*. The main psychological function involved in the intended effect was assessed using the model of human information processing at LCs (Grippenkoven, 2017; Grippenkoven & Dietsch, 2015; Havârneanu et al., 2018), i.e. *detection*, *identification, activation of rule knowledge*, *decision-making* and *execution*.

The third processing step was to rank the measures in terms of their prospects to increase LC safety. To this end, nine human factors experts individually assessed to what extent each measure would reduce the risk of LC accidents, using a 5-point Likert scale from *not at all* to *very strongly*. All contributors were instructed to consider the accident statistics for European LCs and compare the patterns observed there to the given scope (LC type, road user type) and assumed effect of the measure in question. Given the innovative nature of the measures, the research evidence demonstrating effectiveness is often limited. Therefore a second assessment was collected concerning the extent to which further research was needed to evaluate the measure´s effects. The experts were asked to base their judgement on the evidence collected in the literature research and their previous experience and to indicate their response on the Likert scale as described above. From the nine ratings of the prospects for accident risk reduction (PAR) and the need for more research (NMR), the mean value was calculated for each measure on both dimensions. The list of measures was then sorted in descending order by, first, the mean PAR rating and, second, the mean NMR rating. A rank variable was created based on the resulting order. The result was a list of 89 LC safety measures in which the measure rated with the highest prospects for accident risk reduction ranked first, while measures with lower prospects for risk reduction appeared in a later position. If two measures scored equally on this criterion, the one with the higher need for research ranked higher than the other.

3. Results

Overall, 36 measures were identified for use at passive LCs, 29 for LCs with barriers, and 24 for use at all kinds of LCs (see Fig. 2a). In each of the three LC categories, there are at least 10 measures that can be universally applied to address all types of road users. Measures that are specifically designed for either MRUs or VRUs are about equally frequent, except in the passive LC category, where a particularly large number of measures were identified for MRUs. In the following, we summarize the characteristics of the measures identified per LC type, including the psychological function involved in the measure´s effect (see Fig. 2b), and present a sample of five measures for each LC type to illustrate the results. A complete list can be found in Dreßler et al. (2018).

[†] Other active LC protection systems that allow rather easy circumvention (e.g. protection by blinking red lights only) were also included in this category.

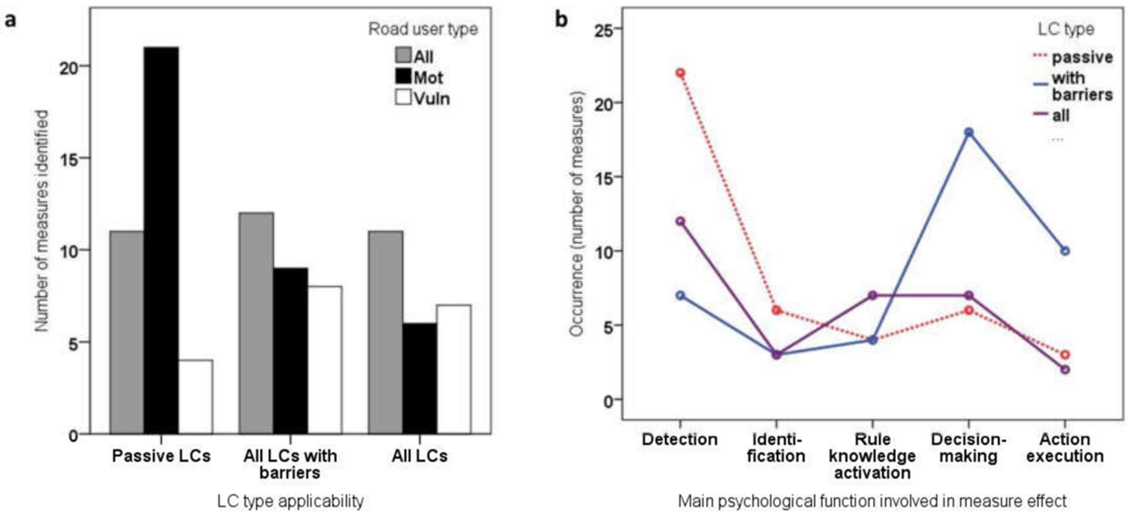

Fig. 2 (a) Frequencies of measures identified for the defined LC and road user categories; (b) Frequencies of main psychological function involved in measure effects by LC type. Note: For each measure, between one and two main psychological functions were identified

3.1. Measures for passive LCs

Table 1. Measures for passive LCs (sample). *RU* - road user category (*Mot*–motorized, *Vul*–vulnerable), *Rk* – measure rank.

Measure name and description	RU	Psychol. Function	Effect Mechanism	Rk
Active inverted speed bumps. Only in case an approaching vehicle exceeds a defined speed, a hatch (integrated into the road) lowers the pavement surface by a few centimeters. Reportedly produces less noise than a conventional speed bump.	Mot	Action execution	Reduces approach speed of vehicles	5
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. This measure could be activated on approach of train and/or road users.	All	Detection	Improves LC detection	6
Blinking lights drawing driver attention. When a road user passes an in-road sensor on approach to the LC, two lights located at the tracks start blinking in the left and right periphery of the road user's visual field. They trigger an automatic and effortless visual orientation reaction towards the regions of the level crossing that require visual scanning to detect a train.	All	Detection	Improves train detection	11
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 road user approaches the LC. Lights aims to generate a "visual barrier", enhancing attention of road users and supporting them in stopping in front of the LC.	All	Detection	Improves LC detection	15
Speed bumps on approach to LC. Use of well-marked speed bumps within the LC approach zone to reduce road vehicle speed, thus maximizing the time available to the driver to process information and make a correct decision. Layout must prevent driving around bump and leave enough time to allocate attention to the tracks after passing the bump.	Mot	Decision-making	Reduces approach speed of vehicles	18

Table 1 shows a sample of the overall 36 measures collected for passive LCs. The ten best ranked measures were: *Active inverted speed bumps, laser illumination of the crossing, in-car warning based on image processing, 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 swiveling, LC attention device,* and *colored marking of the danger zone*. The majority of measures (n=22) supported the psychological function of *detection* to make road user behavior safer (see Fig. 2b). The three most frequent effect mechanisms contributing to this support are the *improvement of LC detection* (n=15[‡]), the *reduction of approach speed* (n=5),

[‡] Up to two categories could be assigned to each measure both in terms of main psychological function involved and effect mechanism. Therefore, the frequencies do not necessarily add up to the same number.

and the *improvement of train detection (n*=4). A number of measures involve the use of lights. For these, a proposal to ensure effectiveness under different weather and natural light conditions is to allow for adjustment in light intensity. Moreover, light measures need to be designed so as not to distract other road users or become a nuisance to residents – which can be achieved by taking into consideration the needs of third parties during the design phase and using, e.g., appropriate shades to direct the light in the desired direction only.

3.2. Measures for LCs with barriers

Table 2. Measures for LCs with barriers (sample).

Measure Name and description	RU	Psychol. Function	Effect Mechanism	Rk
Adapting the timing of LC closure to the actual speed of the passing train. With current systems, triggered by a 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. Closure timing adaption allows for a regular closure duration of the LC, shortening the absolute waiting time in the case of slower-moving trains.	All	Decision-making	Makes waiting time more tolerable	2
Camera based enforcement (prosecution of violations). Use of enforcement camera at LCs with half-barriers and light protection. Initiation of legal prosecution to deter road users from violations. For VRU, only applies to those with number plates (motorcyclists); impracticable for pedestrians and cyclists.	All	Decision-making	Increases awareness of correct behavior/ consequences of violation	3
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.	All	Decision-making	Provides up-to-date information about LC status	4
Second chance zone. Creation of a 'Second chance zone' (i.e. longer distance) 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.	Mot	Detection, Action execution	Improves physical environment of LC	8
Sound warning indicating an approaching train. Sound is only produced when a train is arriving (could be technically coupled to the closing signals in active LC; for passive LC, additional detection technology is needed). Alternative design: use roadside detection and provide warning only with road user present. Signal needs to be intensive enough to be heard in a closed cabin.	All	Detection	Improves train detection. Provides up-to-date information about LC status	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).	Mot	Decision-making, Action execution	Controls access to/ supports egress from LC	17

Concerning LCs with automatic full or half-barriers, the ten best ranked measures were: *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.* The psychological function addressed by most of the measures is *decision-making* (*n=18*), followed by *action execution* (*n*=10; see Fig. 2b). The attempt to influence the decision process is often made by *controlling the access to/ egress from the LC* (*n*=9) or by *providing up-to-date information on LC status* (*n*=5), while the targeting of action execution is typically associated with *controlling the access to/ egress from the LC (n*=7). Some measures aim to motivate road users to make a compliant decision by introducing additional negative consequences of violations (e.g. camera-based enforcement, see Table 2), others aim to alleviate negative consequences associated with the desired behavior – waiting – e.g. by introducing short and reliable closure times. Another class of measures aims at allowing road users caught between the barriers to escape the danger zone (e.g. second-chance zone).

3.3. Measures for all LCs

Regarding the measures to enhance safety at all types of LCs, the ten best ranked ones were: *proximity message via connected device, improving train visibility using lights, audible warnings about LC, extended "no stop" zone, message on smart device to warn on approaching train (VRU), colored pavement markings to mark the* *danger zone (MRU), routing avoiding LCs by satnav intelligence, countdown to train arrival, LED enhanced traffic signs* and *warning sign to avoid blocking back.* Some detailed examples are given in Table 3. Many measures aim at enhancing the *detection* process (*n*=12). A considerable number is also directed at supporting the *activation of rule knowledge* (*n*=7) and *decision-making* (*n*=7; see Fig. 2b). Support of detection often involves *improving LC detection* (*n*=5), *improving train detection (n*=3), and *increasing the awareness of correct behavior/ consequences of violations (n*=4). The support of rule knowledge activation and decision-making is mostly achieved by *increasing the awareness of correct behavior/ consequences of violations (n=3* each) and *providing up-to-date information about the LC status (n=3* for rule knowledge, *n=4* for decision-making). A number of the measures proposed involve the use of digital devices to convey information or warnings to the LC user. In such applications, emphasis should be put on ergonomic design of the interfaces and messages, to support users in perceiving relevant environment information and not distract them. This could be achieved, for instance, by formulating short and clear-cut messages on the right thing to do, and prefer audio over visual messages where possible. A number of measures also involve the use of information on the current train position. As such information is not always easily available, a viable alternative would be to use LC proximity or LC closure time information.

Table 3. Measures for all LCs (sample).

Measure Name and Description	RU	Psychol. Function	Effect Mechanism	Rk
Proximity message - information sharing via connected device. The approach of trains to LC is detected and messages are provided to road users. Different options for detection (e.g. sensors in the tracks upstream the LC; geo-localization of train) and information display (e.g. in-car displays, mobile devices). Messages should be adapted to LC type (e.g. passive: *drive slow, look left and right and give way to the train*, barriers: *please wait*).	Mot	Rule knowledge, Decision-making	Provides up-to-date information about LC status	1
Improve train visibility using lights. Different implementations are possible, e.g. improving the front lights of trains with LED technology or eye-safe laser. Lights will flash when the train is coming to the LC; flashing frequency can be adapted to the distance. The train could also emit a visible trace beyond its actual dimensions, e.g. by a laser / light beam facing upward.	All	Detection	Improves train detection	9
Audible warnings about LC. Provision of improved audible warnings for pedestrians to inform them about the LC ahead. 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.	Vul	Detection	Improves LC detection. Provides up-to-date information about LC status	10
Extended "no stop" zone. An extended "no stop" zone prevents car drivers from halting on the tracks when caught in heavy traffic.	Mot	Detection, Rule knowledge	Controls access to/ supports egress from LC	12
Colored pavement markings to mark the danger zone (road). 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.	Mot	Detection	Increases awareness of correct behavior/ consequences of violation	20

4. Conclusion and Outlook

4.1. Empirical testing and exploitation for practice

Using a multi-step procedure of collection and review, we identified a set of 89 human-centered low-cost measures to support safe road user behavior at LCs. The measures were organized for basic application contexts, including LC and road user types, and for the ways in which their effects are achieved. Moreover, a pre-evaluation concerning the prospective effectiveness of the measures was completed. Due to the innovative nature of some of the measures, empirical data on effectiveness was not available in all cases. Therefore, the evaluation was based on existing research results, where available, and expert assessment, including consideration of models of road user behavior and transfer of insights from other domains, where test results were scarce. To continue and enrich the evaluation process with data on the effectiveness of measures to support adaptive road user behavior, empirical tests will be completed in the further course of the SAFER-LC project. The evaluation will follow a human factors methodological framework (Havârneanu et al., 2018) and include tests in driving simulators and protected areas as well as field tests at LCs (cf. SAFER-LC Consortium, 2017).

To make the results available to practitioners in LC safety, a web-based toolbox will be created. It will comprise an extensive list of safety measures, including the human-centered low-cost measures. The toolbox will enable browsing and searching the data according to specific problems and application contexts. For this purpose, the classification of the measures will be further detailed through keywords, and empirical findings on effectivity will be added. For each measure, the toolbox will also include a consideration of potential negative effects and restrictions as well as recommendations for application to provide a valuable source of information and inspiration to LC safety stakeholders such as road and rail infrastructure managers, train operators, engineers, designers, scientists, policy makers and standardization bodies.

4.2. Remarks and implications for LC safety

Our widespread search for human-centered low-cost measures to increase LC safety included the identification of proposed measures in an extensive literature review as well as the use of creative methods to develop ideas for improvement and new solutions. Nevertheless, it is likely that there are additional LC safety measures that have been conceived, piloted or implemented somewhere in Europe or the world and have not been reflected in the process. The ability to give a complete record is limited due to the availability of documentation, especially of measures at an initial or preparatory stage of development, and of course due to the continuous innovation process. Therefore, the current collection represents a snapshot of human-centered low-cost measures at this point in time. It will be further enriched as the project continues, serving as valuable starting point for LC safety stakeholders to use and expand. This will become possible through the online SAFER-LC toolbox which will be easy to update and which will facilitate the collection of feedback and new inputs from end-users.

In the process of selection, a range of measures was excluded for different reasons, such as perceived problems with practicability, high estimated cost or other kinds of insufficient match with the defined scope. Therefore, e.g., all “classic upgrades” – raising the level of protection by established means like adding automatic barriers or building an overpass – were not further processed in the collection because they represent well-known options to address LC safety, while they usually entail high costs. The SAFER-LC project was based on the insight that classic upgrades are not economically feasible in all cases, and therefore additional solutions are needed that cause less cost and can be implemented at a larger number of LCs. Still we advise that any strategy for improving LC safety should consider the means of classic upgrades.

Any implementation of measures should involve the prior examination of the special situation at the LC to assess the match of the envisaged measures with that situation. This includes the involvement of stakeholders to anticipate and avoid potential acceptance issues. LC infrastructure planners should also consider if an enhanced effect could be achieved by a combination of measures. The overall set of countermeasures includes some combinations of design solutions, but these are just some examples of how measures can be combined.

Finally, we would like to highlight yet again the importance of a thorough documentation and analysis of LC accidents. Some progress has been made in this respect (cf. ERA, 2017), but there are still considerable differences in documentation practice across countries. However, a profound description of accident precursors, circumstances, and consequences is of invaluable help not only in identifying the most effective starting points to increase LC safety, but also in improving the evaluation of safety measures in terms of benefits and costs.

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