SAFER-LC: Level Crossing Design Meets Traffic Psychology

Jan Grippenkoven, Annika Dreßler
Institute of Transportation Systems
German Aerospace Center e.V. (DLR)
Lilienthalplatz 7
38108 Braunschweig
jan.grippenkoven@dlr.de; annika.dressler@dlr.de

Abstract

Human inattentiveness or risk-taking can easily compromise the safety offered by warning signs and approved safety systems in rail and road traffic. For this reason, level crossings remain one of the major vulnerable spots within the railway system. The degree of safety at level crossings does not solely depend on the level of reliability of technical safety systems. Since the safety standard of technical systems at level crossings is extremely high, the most variable factor and most critical point in the context of the level crossing is road user behavior. Within the joint European research project SAFER-LC, human factors were therefore identified as an important starting point to find and develop effective measures that can enhance safety at level crossings.
A huge variety of safety measures has been proposed in the past. Some measures focus on improving the visibility of trains and infrastructural elements, some appeal to road users' understanding of the situation through informative signs or warnings, others use structural changes in the road surface to induce speed reduction. This article provides an overview of road-user-centered measures proposed in the literature to enhance the safety of traverse at level crossings. A descriptive model of three fundamental steps in human information processing – perception of the level crossing, activation of relevant knowledge and formation of behavioral intention – serves as a framework to systemize and categorize road-user-centered safety measures from the literature. The overview offers a psychological perspective on measures that could be implemented by rail and road infrastructure managers to enhance safety at level crossings.

Keywords: level crossing; human factors; rail safety; road safety; accident prevention.

Human information processing during level crossing approach

Within the railway system, that follows the highest safety standards, level crossings are one of the most vulnerable spots. The reason for this vulnerability is the shared responsibility for safety between rail operators on the one hand and road traffic participants that have to know and obey the traffic rules on the other hand. The official ERA statistic lists 573 significant level crossing accidents in the EU for 2012, resulting in 237 fatalities and 336 serious injuries [1]. Still, these are only the official numbers that are usually reported by the largest national railway providers. The huge amount of private railways with their level crossings and the respective accidents are often not included. Therefore it can be assumed that the real numbers of accidents exceeds the official numbers.

Level crossings can be regarded as a sociotechnical system (cf. [2], [3], [4], [5]) that consists of technical elements in the traffic infrastructure facing different kinds of traffic participants that represent the social component of the system. The safety and resilience of this system depends on the reliable function of the technical component on the one hand and the careful and traffic-rule-abiding behavior of the road traffic participant on the other hand. During the analysis of level crossing accident reports, it is striking that the responsibility for accidents usually has to be assigned to the road traffic participants involved. In this context the rather abstract phrase "human error" is often used to describe the cause of the accident [6], [7], [8]. This might be enough to classify the accident from a juridical point of view, yet it is not sufficient from an analytical standpoint. Sometimes details are provided, for example when it is asserted in reports that a "driver disobeyed the rail traffic's right of way", or when a bicyclist "overlooked an approaching train" or a careless driver "deliberately drove around closed half barriers" [9], [10]. Still, in order to find new solutions to effectively reduce the number of accidents, these descriptions are not satisfactory. Nevertheless, formulations like "overlooking", "disobeying" or "deliberate violation" can serve as a starting point to form hypotheses about the nature of human errors that played a role in an accident. These hypotheses subsequently serve as a basis for a process that begins with a deeper human factors analysis and ends with the design of human-centered safety measures.

Taking into account the special situation of approaching a level crossing, there are several psychological models describing human information processing that appear suitable to describe circumstances that can lead to accidents at level crossings (e.g. [11]). Building on the model of information processing, initially proposed by Wickens and Hollands

[11], Grippenkoven and Dietsch [12] describe a sequence of five cognitive steps that have to be passed through successfully in order to cross a railroad in a safe and appropriate way: Road traffic participants must (1) detect at least parts of the safety layout of a level crossing (e.g. signs), (2) identify correctly the kind of level crossing that these parts of the safety layout belong to, (3) retrieve schemas and scripts connected to passing the level crossing from long-term memory, (4) form an appropriate action intention, matching the current situation at the level crossing, and (5) translate the intention into a correctly executed action. For a handy structure to guide the conception of countermeasures, these steps can be grouped together into three basic phases:

1. Perceiving the level crossing,
2. Retrieving relevant knowledge from long-term memory,
3. Choosing and executing appropriate actions.

In each of these phases, specific errors can arise that might ultimately result in an accident between the road traffic participant and a train. The subdivision of errors according to the stage in information processing involved leads to a useful categorization of level crossing accidents that helps to propose adequate countermeasures based on the underlying need for support. If for example in a set of level crossing accidents the origin of the majority of events can be assigned to errors within stage 1, *perception*, this might lead to fundamentally different proposals with regard to safety measures compared to another set, where the majority of accidents can be assigned to stage 2, *knowledge retrieval*.

Human errors during level crossing approach

Based on the mentioned phases of information processing relevant during the approach towards level crossings, a description of typical errors on each single stage will be given in the following sections. Starting with typical problems with regard to the detection of a level crossing, each link in the chain of information processing will be addressed.

Perceiving a level crossing: detection and identification

For successful completion of the first step of information processing, *detection*, the most important precondition is that infrastructural elements of the level crossing are objectively perceivable and not obscured by any obstacles. Additionally, at passive level crossings, road users do not only have to identify the crossing itself, but must also be able to gather information to judge if a train is coming or not in order to choose their appropriate behavior. If elements of the level crossing protection or approaching trains are not visible early enough, road users have no chance to adapt their behavior to the current situation. Occlusions at level crossings can for example result from overgrowing vegetation or vehicles parked in the triangle of sight. Especially at passively protected level crossings, occlusion has to be considered as a serious problem, since the road traffic participant must be enabled to perceive the approaching train early. Nevertheless, at actively protected level crossings it is important as well that the states of light signals and barriers are perceivable early enough.

If the precondition of objective perceptibility is met, the actual probability of detection of the relevant target stimuli such as the rail vehicle, the level crossing signage or traffic lights, depends largely on how well these target stimuli visually differ from their surrounding environment [13], [14]. The better an approaching rail vehicle can be discriminated against its surrounding, for example due to its color, its lighting or acoustic signals, the lower the probability that it will not be detected by the road user. For example, a rusty freight train in front of a brownish front of an industrial building at dusk is way harder to detect than a red-gleaming train with modern headlights under daylight conditions. Besides these characteristics of the visual array, the individual eye-sight of a road traffic participant will be a determining factor for the perception of the level crossing and approaching rail vehicles.

In addition to the visibility of rail tracks, traffic lights and barriers, the audibility of acoustic signals of rail vehicles is a second factor that is supposed to support road traffic participants to take note of the approaching danger at the level crossing. However, acoustic signals from rail vehicles are not always easy to perceive, especially for drivers in closed vehicles. In a study [15], 75 accidents at level crossings in the USA were analyzed in terms of the audibility of the train's acoustic warning signals at the location where the accident took place. In 27 cases, the researchers concluded that the horn of the train was not to be heard well enough inside a motor vehicle. Given the improved acoustic insulation methods of modern cars to effectively shield the driver's cabin from environmental noise as well as the fact that a lot of drivers listen to music while driving, the risk of missing the acoustic signal of railway vehicles during an approach towards a level crossing has to be seriously taken into account.

A peculiarity of road user's errors in the early steps in information processing is that they are usually unintentional omissions [16]. Failures in the detection of relevant features at level crossings cannot be considered to occur deliberately, since the information that a driver misses will never be subject of deeper mental processing.

Retrieval of knowledge about level crossings from long term memory

After the first step in information processing has been successfully completed and active and / or passive elements of the level crossing have been detected, these sensory impressions must be processed further by the road traffic participant. Schemas and scripts with regard to the traverse of the level crossings have to be activated in order to retrieve the appropriate rules and actions from long term memory that match the kind of level crossing as well as its current status. An actively protected level crossing with light signals, for example, requires a different kind of visual scanning behavior from the user than a passive level crossing. Based on the recognition of the type and current status of the level crossing, an action intention can be formed quickly in order to pass the level crossing safely as a next step. The action schema or script typically incorporates not only one single action, but a procedural sequence of steps that need to be followed and activated at the right moment during the approach. An example for a driver approaching a passive level crossing who has already noticed the first countdown marker with the warning sign and has determined the kind of level crossing (passive) and thus the required action sequence, could be: *decelerate → look left and determine if train is approaching (no) → look right and determine if train is approaching (no) → pass*. When the sequential activation of the single steps is disturbed by distractions, unintentional omission errors (lapses) can occur, i.e. steps from the script can unintentionally be left out (cf. [11]). Such an omission can be either the consequence of an external distraction, for example of a conversation between other passengers in the vehicle, or result from an internal distraction. Drivers might be distracted internally for example by their current emotional state and thoughts when they are thinking about a complex issue while driving a vehicle.

However, successful retrieval of level crossing related schemas and scripts depends primarily on whether the correct pieces of knowledge are actually stored in LC users' long-term memory and generally retrievable. If road traffic participants do not have sufficient knowledge about level crossings and the required behavior, the schemas and scripts they will be able to retrieve are of limited use. Previous findings support the assumption that deficient understanding of signage and red flashing lights at the level crossing plays a major role as a cause of misconduct [17] [18]. A nationwide German survey [19] revealed considerable uncertainty and misconceptions about the correct, i.e. legally prescribed, behavior required by various elements of LC infrastructure. For instance, St. Andrew's Cross at passive level crossings in Germany requires road users to give the right of way to rail vehicles, but it does not oblige a road user to stop if no train is approaching. About one third of 1241 surveyed drivers were unsure about the necessity to stop. Though this misconception might be interpreted as being in favor of safety, it shows that the respective rule is not clearly represented in long-term memory and not readily available. Moreover, the same survey showed many other shortcomings in road users' rule knowledge that undoubtedly challenge safety. As an example, participants had to judge the correctness of the (incorrect) statement "A flashing red light at the level crossing is just a warning. Only when a steady red light appears, you have to stop!" (translated from German). Only 57% of respondents were able to correctly judge this statement as being false. 4% of respondents replied to the statement that they did not know whether this statement was true or not. 39% incorrectly agreed with the statement and confirmed the statement that a red flashing light was only a warning. While this survey reveals a general lack of understanding with regard to the theoretical knowledge, studies that examined driver behavior at level crossings in real traffic point to the same direction [12] [20]. Moreover, they show that the lack of road users' knowledge about level crossings is also expressed in actual misconduct. Using an eye-tracking system, Grippenkoven & Dietsch [12] investigated the natural gaze behavior of 24 motorists in a real-world driving context that included the traverse of a passive level crossing. Despite the fact that the scanning patterns of all participants comprised visual fixations on parts of the level crossing signage during approach, two thirds of the participants subsequently did not derive the correct script from their long term memory to check the peripheral regions of the level crossing for a potentially approaching rail vehicle.

As the survey of Ellinghaus & Steinbrecher [19] suggests, knowledge deficiencies are not limited to passive level crossings. In another study of Grippenkoven, Gimm, Stamer, Naumann & Schnieder [20], a camera-based traffic observation at an actively protected level crossing with a flashing red light system revealed that the misconceptions related to this kind of protection shown by Ellinghaus & Steinbrecher [19] can be observed in road traffic participant's actual behavior as well. Within 286 red light phases, 46 critical red light violations by road users were detected [20]. In the cited study, red-light violations were only counted if they occurred at least three seconds after the activation of the flashing red light or later, since those could not be attributed to a limited amount of time to break in front of the crossing. Overall, many road users appear to lack fundamental schemas about the meaning of level crossing signage as well as scripts about the appropriate sequence of actions during the approach towards a level crossing. This can be considered problematic, since the existence and retrievability of those schemas and scripts are an important precondition to form adequate intentions with regard to the necessary actions at a level crossing, like watching out for an approaching train, reducing the speed, or stopping when facing any kind of red light. The issue of forming an in/correct action intention and subsequently translating it into a motor sequence is addressed in the following section.

Behaving correctly: action intention and execution

After the retrieval of schemas and scripts, an intention to behave in a certain way can be formed as the next step in information processing. This behavioral intention plays an important role in the context of level crossings. Its formation depends, on the one hand, on the results of the preceding information processing. If, for instance, a road users' schemas of the required actions are faulty, this will probably bring about a correspondingly wrong intention (e.g. "I believe that red flashing lights are just a warning and do not oblige me to stop" → "I will pass."). The resulting maladaptive behavior represents a *mistake* according to Reason's error taxonomy [21]. On the other hand, the choices of road traffic participants during this phase are strongly influenced by motivational aspects, that do not always favor the execution of adequate behavior in the next step, but might as well lead to deliberate violations of traffic rules [22], [21]. While the misconducts due to detection problems or poor knowledge about level crossings described earlier can often be classified as unintentional, errors in the stage of forming a behavioral intention are more likely to be deliberate in nature or to be the result of previous learning experiences in the absence of negative consequences.

Learned misbehavior can easily arise if a road traffic participant regularly uses a particular level crossing that is rarely used on the rail side [23]. This may cause the road user to develop a tendency to behave carelessly, incorrectly overgeneralizing that no train will appear at this crossing. Accordingly, Sanders and Wertheim [24] postulate that the extent of visual search behavior that road users engage in at a level crossing is negatively correlated with the frequency of their use of this level crossing. The more frequently road users encounter the level crossing without having to give the right of way to a rail vehicle, the less frequently they will check whether a rail vehicle is approaching. If road traffic participants only use a specific level crossing that is barely frequented by rail vehicles their maladaptive approaching patterns, like not slowing down or not turning the head, might have no consequences. An enhanced danger might arise if these road traffic participants approach another level crossing that is frequented more often by trains and transfer their maladaptive behavior to this context assuming that there will be no train approaching either. Furthermore, the learned misbehavior can also be particularly dangerous if a familiar railroad crossing is used at an untypical time of the day. If a certain level crossing is normally used by a resident at certain times of the day, for example on the way to work and back, fatal misassumptions and misbehaviors might be developed, that become dangerous when the level crossing is used outside the usual time frame. An Australian investigation found that 73 out of 85 drivers involved in a railroad crossing accident were residents that are familiar with the level crossing [25]. However, this cannot unequivocally clarify the role of maladaptive learning in accident causation, since residents are not only more prone to develop a learned misbehavior with regard to a certain level crossing, but can also be assumed to use a local level crossing more often compared to nonresidents. The increased number of traverses increases the statistical probability of encountering a train at the level crossing.

Besides the learned misconduct that leads to violations that are not perceived as such but that rather become a routine, deliberate violations also occur quite frequently in the context of active level crossings [9]. While in the case of a violation of a red light at a level crossing, at least in some cases a misunderstanding of road users can be assumed, this assumption is not justified with regard to violations at level crossings with half barriers. A barrier is a physical object that blocks a road user's trajectory over the rails. The perception of the barrier is a necessary precondition for bypassing it. Bypassing therefore can be categorized as a motivated, deliberate violation. Impatience as a consequence of long closing durations of barriers is usually assumed to be motivating road traffic participants to commit a violation, as well as an inappropriate risk-taking of drivers that overestimate their own abilities and underestimate the risk of mortality as the consequence of a collision with a rail vehicle [23]. Previous learning experiences might play an important role in the emergence of the motivation to illegally bypass a half barrier at a level crossing. Depending on the level crossing, road users can encounter waiting times of several minutes before a train appears. Based on many encounters with closed barriers at a certain level crossing, the time interval between the closure of the barriers and the arrival of the train might be learned to be the standard interval by a road user. Certain road users might consider this standard interval as the time frame they can use to illegally bypass the crossing. In particular, at railway lines on which irregular trains might operate at different speeds, a violation based on the assumption of a standard time interval between closure and arrival can be highly dangerous. Typically, closing times of barriers at level crossings are projected for the fasted rail vehicle that operates on the line. A sensor at some distance to the level crossing detects the approaching rail vehicle and triggers the closure of barriers early enough to give road traffic participants potentially situated in the danger zone between the barriers time enough to get out before the train arrives. When the closure of the barrier is projected for the fastest vehicle based on a rail side sensor, the time of closure before a train arrives increases proportionally for slower trains. Thus, at level crossings that are used by trains that operate at different speeds, the time of closure is variable and unpredictable for the road user [23]. A standard time interval of closure should therefore not be assumed. Likewise, some road traffic participants appear to hold the misconception that during a level crossing closure phase only a single train passes a level crossing [22]. This might result in the misconception of road users that a technical defect of the level crossing occurred, in case the barriers do not open immediately after a train has passed the crossing. Such a misconception may increase the readiness to bypass a level crossing. From the perspective of a railway expert, such misconceptions might be hard to understand, however most road traffic participants have no mental model of the way the railway system functions and are therefore susceptible to fallacies that affect their own safety.

Finally, the intended action to negotiate the level crossing has to be executed correctly. Errors in the process of execution can be classified as unintentional. It may happen that an appropriate action – with respect to the type of level crossing and its current status – is chosen, but its motor execution is faulty or timed inappropriately (category of *slips* in Reason's taxonomy, [21]). Stalling the engine of a motorized vehicle in the danger zone of the level crossing is an example of an error at the level of action execution. Another example is a poor timing combined with a faulty projection when entering the danger zone as a driver in a group of vehicles and having to stop on the rails. Especially drivers of longer vehicles such as buses or trucks face an increased risk of getting blocked back in a group of vehicles and have to be extra cautious and check if there is sufficient room for their vehicle on the opposite side of the level crossing. Besides long vehicles, certain level crossings infrastructures are more likely to create blocking situations. Especially when a level crossing is located in a curve or just behind a junction that vehicles approach from a road that is build parallel to the rail tracks it is sometimes difficult to see what is behind the level crossing. This issue is difficult with regard to perception as well as the timing of the traverse. Regarding especially non-motorized traffic participants, a bad maintenance state of a level crossing can increase the difficulty of passing a level crossing. Bicyclists, wheelchair users or people using a walking frame face difficulties when the area between the rails is not at the same level with the street that can hinder crossing or even lead to a fall.

Human Centered measures to enhance level crossing safety

Based on the errors and violations described in the previous sections and the understanding that certain human errors especially occur within certain stages of information processing, it is possible to derive specific countermeasures or assistance systems to increase the safety for road users of a level crossing. Table 1 provides an impression of some of the existing measures proposed by international practitioners and researchers in the field of level crossing safety. For readers who are interested in more detailed insights in specific measures, the references to the original sources are provided. The approaches presented in table 1 are not meant to substitute proven level crossing safety technology, but rather as supplementary modifications to enhance safety by taking into account the particularities of human behavior discussed above.

Table 1 - Human-centered approaches to increase the safety of behavior at level crossings

Stage in road users' information processing	Approaches to reduce the likelihood of misconduct of road users
Perception	• Measures to enhance visibility of rail vehicles (by vehicle design and design of layout/environment) [16] [26] • Measures to enhance visibility of advance warning signs, e.g. by equipping them with pulsing lights [27] • Measures to induce early speed reduction on road side to enhance time available for detecting a rail vehicle, e.g. bumps or rumblestrips [28] [29] • Measures to enhance attention paid to level crossings by road users, e.g. coloured or patterned road markings, LED-light-button markings integrated into road surface in front of level crossings [28] • Measures to elicit automatic allocation of attention to the parts of the track that need to be scanned to detect an oncoming train, e.g. PeriLight [30]
Retrieval of knowledge	• Avoidance of all external sources of distraction on approach to level crossings, e.g. of billboards • Introduction of dynamical feedback systems on approach to LC, e.g. variable traffic signs with situation-specific warnings [31] • Use of "Stop" sign at appropriate part of passive level crossings, due to its clearer behavioral implication compared to St. Andrew's cross [19] [32] [33] • Replacement of red flashing lights by yellow-red or green-yellow-red traffic lights, due to higher familiarity from road traffic context [34] [23] [20] [17] • Campaigns to raise consciousness on safe behavior at LC, enhancement of traffic education in school, strengthening of LC content in driver education [35] [36] [37]

Action intention and execution	• Giving explicit warnings at active LC when more than one train will pass during one closure [28] • Strengthening of law enforcement, e.g. by traffic cameras, raising penalties for violations [38] • Special installations like higher barriers or loosely installed rolls on top of barriers to discourage pedestrians to climb over barriers [39] • Complementary warnings in special situations, e.g. where road is running parallel to tracks in advance to LC, e.g. by variable traffic signs [31] • Impediment of driving around closed half barriers, e.g. by traffic islands between lanes, posts, rods [28] • Installation of hanging bars / grids / chains to boom to prevent pedestrians from crossing below the boom when closed [28]

Summary

Level crossing safety is a topic that should be addressed as well from a technological as from a human factors perspective in order to find effective human-centered measures to improve safety. Therefore the ongoing project SAFER-LC (Safer level crossing by integrating and optimizing road-rail infrastructure management and design) aims to improve level crossing safety by identifying and evaluating innovative solutions and tools for the design of future level crossings with regard to the road- and rail infrastructure as well as advanced driver assistance systems. Many of the approaches presented in the previous section could be as well suitable as cost-effective measures to increase the safety of level crossings. Dynamic feedback systems alongside the approaching road, additional lane markings, measures to slow down the road traffic or systems like PeriLight that capture the attention of road users represent systems that might enhance safety at level crossings, yet ought not to be understood synonymously to proven technical level crossing safety systems like barriers or light signals. They should be regarded as additional systems which could increase the safety of road users' behavior by taking into account their potential errors. In order to make level crossings more self-explaining, forgiving and safe, it appears reasonable to focus more strongly on road traffic participants with their particular perception, motivation and behavior to find both, effective and affordable solutions to minimize the number of accidents.

Acknowledgement

SAFER-LC project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723205.

References

[1] European Railway Agency (2014). *Railway Safety Performance in the European Union.* Valenciennes: European Railway Agency.

[2] Read, G. J., Salmon, P. M., & Lenné, M. G. (2013). Sounding the warning bells: The need for a systems approach to understanding behavior at rail level crossings. *Applied Ergonomics, 44*(5): 764–774.

[3] Salmon, P. M., Lenné, M. G., Read, G. J., Mulvihill, C. M., Cornelissen, M., Walker, G. H., ... (2016). More than meets the eye: Using cognitive work analysis to identify design requirements for future rail level crossing systems. *Applied Ergonomics, 53:* 312–322.

[4] Salmon, P. M., Lenné, M. G., Read, G. J., Mulvihill, C. M., Cornelissen, M., Young, K. L., ... (2015). Beyond the Crossing: A Cognitive Work Analysis of Rail Level Crossing Systems. *Procedia Manufacturing, 3:* 2921–2928.

[5] Read, G. J., Salmon, P. M., Lenné, M. G., & Stanton, N. A. (2016). Walking the line: Understanding pedestrian behavior and risk at rail level crossings with cognitive work analysis. *Applied Ergonomics, 53:* 209–227.

[6] Salmon, P. M., Read, G. J., Stanton, N. A., & Lenné, M. G. (2013). The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis & Prevention, 50:* 1278–1288.

[7] Laapotti, S. (2016). Comparison of fatal motor vehicle accidents at passive and active railway level crossings in Finland. *IATSS Research, 40*(1): 1–6.

[8] Larue, G. S., Rakotonirainy, A., & Haworth, N. L. (2015). A simulator evaluation of effects of assistive technologies on driver cognitive load at railway-level crossings. *Journal of Transportation Safety & Security, 8*(sup1): 56–69.

[9] TÜV SÜD Industrie Service GmbH im Auftrag der DB Netz AG (2015). *Bahnübergänge im Spiegel der Statistik - Bahnübergangsstatistik 2015*. Version für Dritte. Berlin: DB Netz AG.

[10] Wörth: Radfahrer stirbt auf Bahnübergang (2017). *Main-Echo, 9 November*. Retrieved from http://www.main-echo.de/regional/blaulicht/art12299,5208569

[11] Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2012). *Engineering psychology and human performance* (Fourth edition.). New York: Pearson Education.

[12] Grippenkoven, J., & Dietsch, S. (2015). Gaze direction and driving behavior of drivers at level crossings. *Journal of Transportation Safety & Security, 8*(sup1): 4–18.

[13] Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

[14] Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Reviews Neuroscience, 5*(6): 495–501.

[15] NTSB (1986). Passenger/commuter train and motor vehicle collisions at grade crossings. Safety Study NTSB/SS-86/04, Washington, DC: National Transportation Safety Board

[16] Carroll, A. A., Multer, J., & Markos, S. H. (1995). *Safety of Highway-Railroad Grade Crossings: Use of Auxiliary External Alerting Devices to lmprove Locomotive Conspicuity*. Report DOT-VNTSC-FRA-95-10. Washington, DC: U.S. Department of Transportation.

[17] Lenné, M. G., Rudin-Brown, C. M., Navarro, J., Edquist, J., Trotter, M., & Tomasevic, N. (2011). Driver behavior at rail level crossings: Responses to flashing lights, traffic signals and stop signs in simulated rural driving. *Applied Ergonomics, 42*(4): 548–554.

[18] Manz, H., & Slovak, R. (2008). SELCAT (Safer European Level Crossing Appraisal and Technology): Dissemination Campaign for Car Drivers (D9). European Commission.

[19] Ellinghaus, D., & Steinbrecher, J. (2006). *Das Kreuz mit dem Andreaskreuz. Eine Untersuchung über Konflikte an Bahnübergängen*. Hannover: Continental AG.

[20] Grippenkoven, J., Gimm, K., Stamer, M., Naumann, A., & Schnieder, L. (2015). Fehlverhalten von Verkehrsteilnehmern an Bahnübergängen mit Blinklichtsicherung. *Signal+Draht, 107*(12): 23–27.

[21] Reason, J. (1990). *Human error*. New York: Cambridge University Press.

[22] Grippenkoven, J. (2017). Wahrnehmung und Verhalten am Bahnübergang. *Deine Bahn*, 2: 10–15.

[23] Seehafer, W. (1997). Verkehrsgerechte Sicherung von Bahnübergängen. In *Eisenbahningenieurkalender '97*, Hamburg, Tetzlaff Verlag (pp. 109-134).

[24] Sanders, A. F., & Wertheim, A. H. (1973). The relation between physical stimulus properties and the effect of foreperiod duration on reaction time. *Quarterly Journal of Experimental Psychology, 25*(2): 201–206.

[25] Wigglesworth, E. C. (2001). A human factors commentary on innovations at railroad-highway grade crossings in Australia. *Journal of Safety Research*, (32): 309–321.

[26] Schöne, E. (2013). *Ein risikobasiertes Verfahren zur Sicherheitsbeurteilung von Bahnübergängen. Dissertation. Dresden:* TU Dresden.

[27] Noyce, D. A. & Fambro, D. B. (1998). Enhanced traffic control devices at passive highway-railroad grade crossings. In *78th Annual Meeting of the Transportation Research Board.* Washington, D.C.

[28] Aigner-Breuss, E., Aleksa, M., Braun, E., Machata, K., Knowles, D., Runda, K., ... (2013). *MANEUVER: Ein Handbuch für PraktikerInnen und EntscheidungsträgerInnen*. Wien: Bundesministerium für Verkehr, Innovation und Technologie.

[29] Tey, L.-S., Wallis, G., Cloete, S., & Ferreira, L. (2013). Modelling driver behavior towards innovative warning devices at railway level crossings. *Accident; analysis and prevention, 51:* 104–111.

[30] Grippenkoven, J. (2016). PeriLight – effektive Blicklenkung am Bahnübergang. *EI - Der Eisenbahningenieur*, 1: 48–51.

[31] Rösiger, T. (2008). Evaluation dynamischer Rückmeldungen am Bahnübergang. Saarbrücken: VDM.

[32] Schöne, E., & Buder, J. (2011). Einsatz von Stoppschildern an nicht-technisch gesicherten Bahnübergängen. *EI - Der Eisenbahningenieur, 3:* 25–29.