THE ROLE OF HUMAN ERROR IN ACCIDENTS AT GERMAN HALF-BARRIER LEVEL CROSSINGS

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SUMMARY

The work at hand presents the results of an analysis of 51 accidents at German level crossings regarding human error contribution on the part of road traffic users. The results indicate that a half-barrier protection does not provide a strong enough barrier effect to prevent accidents. It is shown that, overall, 41% of all accidents in the sample happened at such half-barrier level crossings, thus making up for the second largest share following light signal system layouts. Accidents at full-barrier protected level crossings and level crossings without technical protection in the sample are negligible. The findings from the investigation of human error types leading to accidents at half-barrier level crossings are of particular interest. Using the GIDAS framework for human error categorisation in the automotive domain, they reveal that 73% of errors occur in the planning stage of human information processing. Violations of rules like deliberately bypassing closed barriers are most prevalent. Countermeasures to minimise the occurrence of such accidents at half-barrier level crossings are discussed.

INTRODUCTION

Despite the fact that accidents at level crossings only account for a fairly small share of all road traffic accidents, they are of particular relevance because of their severe consequences for property and persons. Unlike road traffic users, train drivers need not stop at level crossings. They have to trust in the roadside protection systems to ensure clear tracks upon train approach as their ability to react to hazards and to prevent collisions is limited. Due to the large mass of the train combined with fairly high speeds and low frictional resistance of steel tire and rail, braking distances are rather long. Consequently, 94% of all collisions between road users and rail vehicles in Germany originate from misconduct on the part of a road user (1).

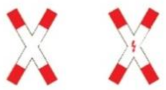
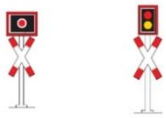
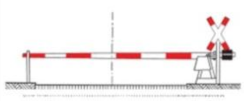
Especially accidents at level crossings without barrier protection often lead to the public calling for the setup of barriers in order to improve safety. A considerable amount of collisions, however, still occurs at level crossings with half-barrier protection systems. Since errors of train drivers and operators or technical failures in such accidents are scarce, a deeper understanding of the contributing errors of road users at such seemingly advanced level crossing protection layouts was sought in this work, using a systematic approach of error categorisation.

First the most common protection setups are described, in order to provide an understanding of the specific features of German level crossing layouts. In the second section, an overview of error classification methods based on psychological models of human information processing is presented and a description of the GIDAS (German In-Depth Accident Study) approach selected for this analysis is given (2). A broad variety of documents regarding level crossing accidents is then reviewed and categorised according to the selected framework in the third part of this work and statistical analysis of the distribution of human error types at different level crossing setups is conducted. Based on the identified critical steps in information processing, conclusions about issues in interaction design and options for improvement of the current layout at German level crossings are derived and discussed from a human centered perspective in the last section.

PROTECTION AT GERMAN LEVEL CROSSINGS

Trains differ from road traffic users regarding specific characteristics which require strict rules for the shared space at level crossings. In particular, trains are track-bound, with long braking distances due to high mass and speed together with low frictional resistance and run according to fixed timetables. Rail vehicles therefore always have the right of way over road vehicles at German level crossings (3). Different signs and technical layouts (Table 1) are applied as means of protection to indicate this priority.

Table 1: Protective elements at German level crossings (drawings adapted from Giesa& Bald, 2003 (4))

Distance in front of the level crossing	Signs and technical elements	Description
240m		Either sign 151 (left), announcing a level crossing without barriers or sign 150, announcing a level crossing with barriers is implemented. In future only sign 151 will be used for both.
240m		Sign 153, depicting 240m distance to the level crossing. Sign 150 or sign 151 is always installed above it. Always on both sides of the road.
160m		Sign 159, depicting 160m left to the level crossing. Always on both sides of the road.
80m		Sign 162, depicting 80m left to the level crossing. Always on both sides of the road.
Immediately in front of the level crossing		Sign 201, St. Andrew's Cross, signaling the priority of the railway traffic.
Immediately in front of the level crossing		Flashing red light signal (not built anymore) and yellow-red light signal. When a train is approaching it first shows yellow and then red.
Immediately in front of the level crossing		Half-barrier, ranging over the half width of the street, combined with yellow-red light signal. On both sides of the rail.
Immediately in front of the level crossing		Full-barriers, ranging over the full width of the road. Sometimes combined with light signal.

In Germany, all level crossings are announced by three successive rectangular white signs on both sides of the road. Depending on distance to the level crossing upon approach, these signs display either a triple (240m), double (160m) or single (80m) diagonal red bar.

At the furthest distance of 240m in front of the level crossing a triangular warning sign, depicting either a train or a barrier icon, is added. The St. Andrew's cross is mounted on both sides of the road right in front of the railway track. It signifies priority of rail traffic at every level crossing.

The application of additional protective technology depends on regulations regarding the specific criticality of the respective level crossing (Table 2). Road traffic density, number of tracks and road/ track type (e.g. highway, urban road, rural road/ main track, secondary track) and railside speed limit, among others, are criteria that influence the protective layout at level crossings [(3), (5)].

Table 2: Level crossing protection, depending on the criticality of road and railway

Criticality of the level crossing	Common protection
High	Technical; full-barrier level crossing with an automatic level crossing free detection
Medium to high	Technical; light signalling system or light signalling system with a half-barrier
Low	Without technical system; Signs

If criticality is rated medium to high for rail as well as for street parameters (e.g. a public road traffic density of 100 – 2500 motor vehicles and a speed limit up to 160 km/h on the track), level crossings can be protected using a light signal system with or without half-barriers (3). Level crossings with an even higher criticality have to be protected with full-barriers and an automatic level crossing clear detection. Level crossings with a lower criticality both for rail and road do not have to be equipped with technical protection systems. These types of level crossings are announced solely by signs, as described in Table 1. In addition, an unobstructed view of the tracks by the road traffic users has to be ensured to enable them to check whether a train is approaching (3). Additionally, train drivers have to blow the whistle at a predefined distance upon approach of such level crossings to provide for a supplementary acoustic warning to road traffic users [(6), (7)].

Out of the 22201 level crossings in Germany, the biggest share of 10059 in total is not equipped with any technical protection systems. Neither light signals nor barriers are installed, meaning the crossing railway is announced solely by signs.

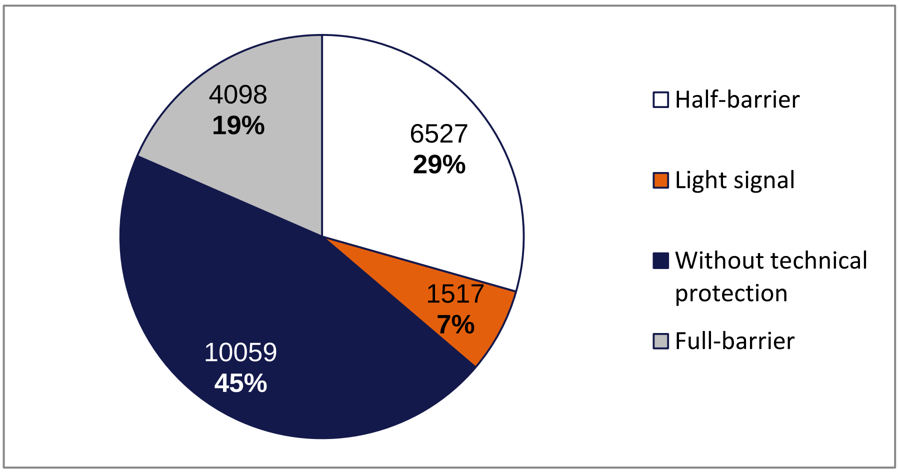


Figure 1: Protection systems at German level crossings (8)

The second largest share of German level crossings consists of half-barrier level crossings. Overall, 6527 level crossings are equipped with this type of barrier system. It is usually also furnished with light signals or flashing lights.

The highest protection level, consisting of a full-barrier with or without additional light signals and an automatic level crossing clear detection, is fitted at 4098 German level crossings. Level crossings with light signals but without additional barriers account for the smallest share of all level crossings in Germany. A total of 1527 level crossings are equipped with red- and- yellow light signals or red flashing lights (8).

CLASSIFICATION OF HUMAN ERROR

A reliable categorisation framework is required in order to reach a dependable insight into the underlying mechanisms of human error in level crossing accidents.

Numerous experts have developed approaches to describe the nature of human error from a cognitive psychology perspective for different applications.

Most approaches share the description of human error in terms of failure in a specific step within a sequence of information processing steps. Identifying the critical step in information processing can help to gather insights into the weaknesses of a system design. If errors can frequently be assigned to one certain step within the process, this indicates an unfitting system design regarding the adequate support of the user. Two of the most recognized contributions in the field of human error are Reason’s generic error modelling system (9) and Rasmussen’s model of internal human malfunction (10).

In his taxonomy, Reason defines three basic error types which occur at different stages of task completion. These error types are slips, lapses and mistakes. Slips are errors that occur at the stage of task execution, when a plan that is actually correct is misapplied. Lapses are errors resulting from omissions of necessary actions. They occur in an intermediate state of information processing and result most often from insufficient retrieval of important information from memory or lack of attention. While slips emerge when a correct plan is applied incorrectly, mistakes comprise errors that result from plans that are inherently faulty in the respective situation. Mistakes occur at the planning stage of information processing. Another type or rather class of error is described by Reason as violations. Such human errors differ from the other three categories in the sense that violations manifest themselves through deliberately committing faulty actions.

Similar to Reason’s classification, Rasmussen’s model of internal human malfunction is based on the assumption of distinct stages of human information processing, each of which can lead to the emergence of specific errors. In his categorisation, he differentiates seven types of human errors that enable the rater to identify the critical step of information processing which in turn leads to the occurrence of an error (Table 3).

Table 3: Error taxonomy from the model of internal human malfunction

Error taxonomy from the model of internal human malfunction		
Error description		**Error type**
Was the operator able to intervene in order to prevent the accident?	*Yes →*	Structural error
No ↓		
Did the operator detect important information in the environment?	*Yes →*	Information error
No ↓		
Did the operator correctly diagnose the state of the system based on the information?	*Yes →*	Diagnostic error
No ↓		
Did the operator choose a goal that was reasonable under the given circumstances?	*Yes →*	Goal setting error
No ↓		
Did the operator choose a strategy that would achieve the intended goal state?	*Yes →*	Strategy selection error
No ↓		
Did the operator execute procedures consistent with the strategy selected?	*Yes →*	Procedure error
No ↓		
Did the operator execute procedures as intended?	*Yes →*	Action error

Since Rasmussen's model was not originally developed for error analysis in the automotive domain, but for accident analysis in industrial operations, Graab, Donner, Chiellino and Hoppe (2008) reviewed its applicability for human error categorisation in road traffic accidents (2). According to findings from their German in Depth Accident Study (GIDAS), strategy selection errors and action errors as described by Rasmussen rarely occur in the automotive context. A subdivision into five meaningful error categories resulted to be sufficient for describing the causes of all potential roadside accidents.

Maintaining the sequential procedure of human information processing, the GIDAS categories are accordingly labelled information access (German: "Informationszugang"), information admission ("Informationsaufnahme"), information evaluation ("Informationsverarbeitung"), planning ("Zielsetzung") and operation ("Handlung").

Table 4: GIDAS error categorisation

Error category	Description of influence	Indicator
Information access	Relevant information cannot be perceived	E.g. glare, parking vehicles that cover signs, foggy weather
Information admission	Interfering information and influences in and outside the car	E.g. crying children, fatigue, focus on other car
Information evaluation	Information interpreted in a wrong way	E.g. lack of experience, underestimation of speed or distance
Planning	Violations of rules, wrong decisions	E.g. bypassing active barriers
Operation	Wrong actions taken	E.g. confusing controls

In order to categorise the errors in more detail, each can be assigned general influences and specific indicators that comprise the cause of human error.

Since it is the purpose of this work to identify contributing human factors in level crossing accidents, and the major share (94%) of them is caused by road traffic users (8), the GIDAS categorisation was deemed to provide the most suitable approach. It offers the necessary depth and detail for the analysis of error causation, is specifically tailored to the application in road traffic accident analysis and spares superfluous fragmentations.

METHODS

The sources reviewed to generate the analysed accident sample consist of official accident reports of the Eisenbahnbundesamt (EBA - German federal railway authority), police reports and newspaper articles. Reviewed material was restricted to level crossing accidents that happened in Germany between the years 2000 and 2012 in order to ensure comparability regarding laws and layouts, which differ between neighbouring European countries.

To be included in the analysis, all descriptions had to be documented in enough detail to be unambiguously assigned to one of the five error categories of the GIDAS classification (information access, information admission, information evaluation, planning or operation) by two independent experts. A total number of n=51 from initially 126 level crossing accident descriptions could thus be analysed in this work. 75 reports had to be excluded because of insufficient detail of description. The remaining 51 accidents were clustered by type of safety layout (without technical protection: n=4, light signal: n=25, half-barrier: n=21, full-barrier: n=1).

RESULTS

Looking at the level crossing accident sample clustered by protection layout showed that 21 of 51 analysed accidents in Germany happened at half-barrier equipped level crossings. A slightly larger share of accidents in the sample occurred at level crossings that are equipped with light signal protection. Accidents at level crossings without technical protection (4) as well as accidents at level crossing with a full-barrier (1) were scarce (Figure 2).

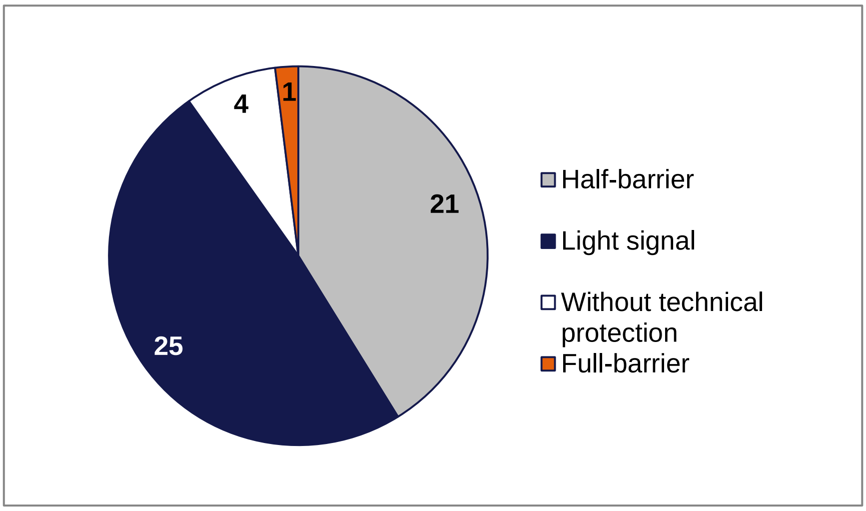


Figure 2: Distribution of level crossing accidents in the sample over the different safety systems

Regarding the underlying human error according to the GIDAS error categories (information access, information admission, information evaluation, planning and operation), a chi-square test of the equality of frequency distribution was carried out. It revealed that the general frequency distribution of the human error categories over all 51 events was unequal in a highly significant fashion (X^2=31,45; df=4; p<0,0001). Overall, most accidents (78%) could be assigned to one of the two error types of information admission or planning (Figure 3).

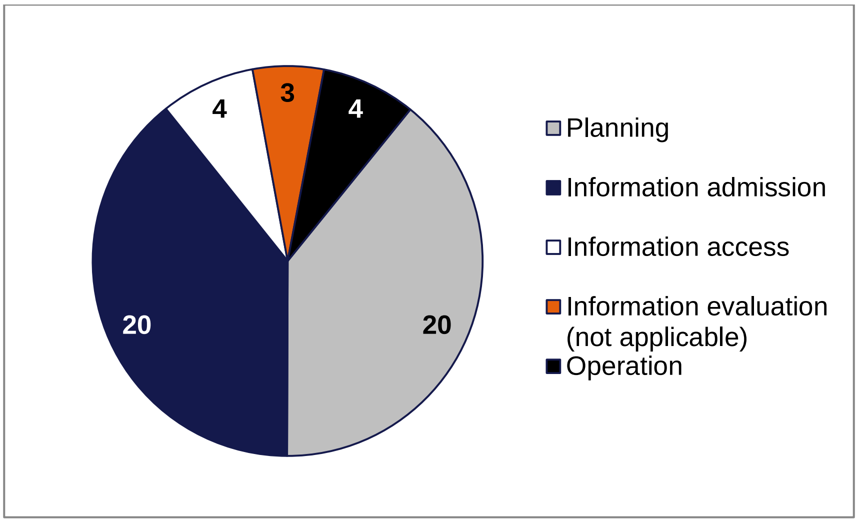


Figure 3: Distribution of the types of human error leading to accidents in the sample

Assuming that the presence of a barrier protection system on a level crossing is a deciding factor in the type of human error committed by the road traffic user, level crossing protection layouts were separated into "barrier level crossings" (half and full) and "non-barrier level crossings" (light signals without technical protection) for a more detailed investigation for each of two classes. Comparing the distribution of assigned error types at barrier level crossings and non-barrier level crossings revealed statistically significant differences (X^2=20,42; df=4; p<0,001; Figure 4).

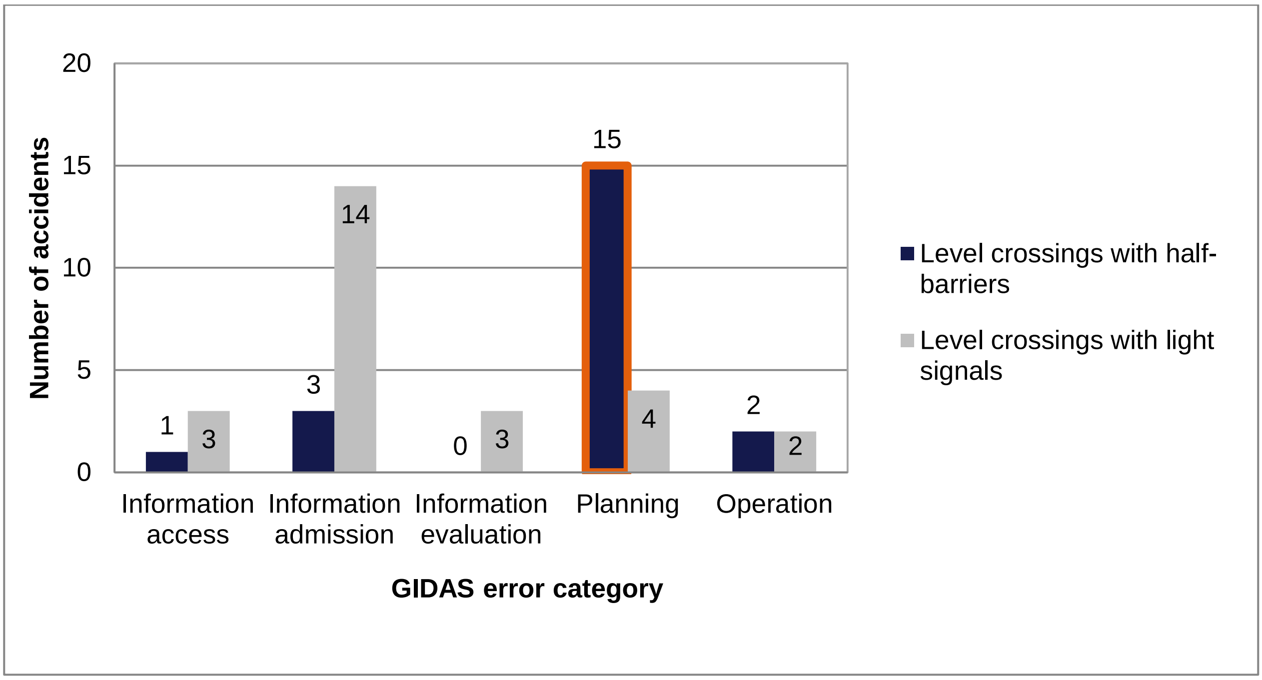


Figure 4: Types of human error in accidents at level crossings with and without half-barriers

At level crossings with light signals 13 out of 25 accidents were assigned to the GIDAS category information admission. Errors of this type outweighed all other error types, resulting in a significantly unequal distribution of error types ($X^2=16,4$; df=4; p=0,003).

At level crossings with barrier protection systems, by contrast, accidents could primarily be assigned to the category of planning according to GIDAS. In a total of 15 out of 21 cases errors were found at this stage, which led to a highly significant unequal distribution of assigned error types ($X^2=24,5$; df=3; p<0,0001). Considering influences and indicators, it appeared that planning errors at barrier-protected level crossings were predominantly comprised of acts of deliberate bypassing of closed half-barriers.

DISCUSSION

When examining the distribution of accidents according to type of protection system at German level crossings, it becomes apparent that a remarkably large share occurs at level crossings with light signals as well as at half-barrier layouts.

Half-barrier protection as a safety layout for level crossings of medium to high criticality shows considerable effects when comparing the general share of installation in Germany to the share of accidents in the sample. Almost one-third of German level crossings (29,4%) are equipped with this protection system type (Figure 1), which appears to convey a more noticeable warning than the often overlooked light signal systems. However, with 41,2% of accidents in the analysed sample taking place at these crossings, it seems that the benefit towards accident prevention is only marginal.

It is also striking that while results do not suggest that half-barriers prevent accidents much more effectively than light signal systems, they seem to affect the underlying types of errors that lead to accidents.

As the findings from the GIDAS error categorisation distribution indicate, errors on the part of the road user undergo a clear shift from not noticing the displayed warnings to deliberately violating traffic rules (Figure 4). In these cases, drivers appear to make a conscious decision to drive around closed half-barriers.

This suggests that risks perceived by drivers committing such planning errors might not match the actual high risks associated with the action of bypassing the barriers.

Risk can be described as the product of probability of occurrence and severity of consequences for an event (11). Planning errors, that lead to accidents at half-barrier level crossings could either result from an underestimation of the probability for the event “train approaching” or inadequate expectations regarding the severity of possible consequences from bypassing barriers, or even both. Disadvantageous risk-perceptions could be further reinforced by erroneous learning effects due to prolonged barrier closing times. If road users repeatedly experience a long time interval passing between the barriers closing and the train actually arriving at the level crossing, the perceived probability of a collision in case of bypassing might decrease while the perceived benefit of saving time through driving around the barrier might grow at the same time.

Future development of safety measures at half-barrier level crossings should be aligned with the findings that planning represents the prevalent type of human error as shown in this work. Three different approaches to enhance safety based on the described insights are thus proposed to prevent accidents at half-barrier level crossings.

First, following a psychological approach in order to modify risk perception of road users especially at half-barrier level crossings is suggested.

Additional perceivable evidence of a train actually approaching while people are waiting in front of a level crossing with half-barrier protection should be provided. The introduction of acoustic signalling by the train drivers as it usually only has to be done at level crossings without technical protection systems (6) could be a possible and easy to implement means to enhance such evidence. In case of two trains passing during one closing interval, a digital display announcing the second oncoming train after the first one has passed could also be useful. This might counteract the possible misperception of road traffic users that it is safe to bypass the still closed half-barriers after one train has passed.

Besides a more adequate perception of the probability of a train approaching, providing a viable notion of the severity of consequences is believed to increase the road user's subjectively perceived risk to a more suitable level. The willingness to take the risk of violating traffic rules and bypass half-barriers should thereby be decreased. Measures to enhance people's awareness of the life-threatening consequences of being hit by a train seem essential to achieve this.

Warning campaigns are obvious measures to improve risk perception. These campaigns should be focused on the area surrounding the level crossings. Billboards (e.g. depicting cars after collisions with trains) could be placed upon approach to the level crossing in some distance. It is crucial for such installations to be easily perceivable without interfering with the recognition of level crossing related traffic signs. A minimum distance of 240m from the level crossing (distance of the first crossing indicator; Table 5) is suggested.

Another influential factor on rule violations at level crossings is impatience on the part of the road user. As Seehafer (1997) describes, exhibition of impatient behaviour (e.g. starting up the engine again) linearly increases with the time spent waiting in front of a half-barrier (12). If an additional time buffer is found to prolong the time from barrier closure to train arrival at half-barrier level crossings this effect has to be considered.

It appears useful to critically question the idea of a "safety buffer" through extended closing times as it might lead to an even more dangerous increase in readiness of bypassing.

The second suggested approach to reducing planning errors at half-barrier level crossings thus targets drivers' impatience while waiting. Waiting is a large part of everyday life, waiting in line at the supermarket, waiting for the next bus, waiting for the rain to stop and so on. Waiting is generally perceived as rather boring and a waste of time by most people.

This notion is intensified, when there is no indication for how long it will take and there is no distraction available, as it usually is the case with waiting at level crossings. The main idea here is providing alternative activities while waiting in front of a closed half-barrier. Drivers should be given the opportunity to pass time in an attractive or useful fashion. Very simple setups like a trashcan placed besides the road that could invite people to a useful activity by getting rid of garbage in the car. The layout of such installation could also try to target sportsmanship by inviting drivers and passengers to compete in "scoring baskets".

Another way to provide pastimes could be via QR-codes at level crossings. These black and white square patterns can be read by smartphones and lead users to a web page. Content referred to at level crossings could be mini games that drivers can play while waiting. An additional incentive like high score lists or competitive modes with other drivers in could further enhance the appeal of waiting. Such games might also have an educational character, informing about safety issues at level crossings.

These first two approaches described are merely virtual attempts to reduce the probability of planning errors from a psychological perspective, by raising risk awareness and offering alternative activities while waiting.

Without physical measures a road traffic user who wants to bypass a closed half-barrier is still able to do so. To ensure prevention of level crossing accidents that result from planning errors and violations in particular, the impeding character of the half-barrier protection needs to be increased.

The third approach discussed here, therefore suggests the implementation and improvement of physical barrier protection systems.

Full-barrier level crossings appear as a comparatively safe means to prevent level crossing accidents. With an equipped share of 18,5% among German level crossings (Figure 1), only one single accident was found in the sample occurring here (Figure 2). The conclusive explanation for this seems to be the mere physical barrier between road user and track. Obviously, full-barriers span the entire width of the level crossing and can not be bypassed easily. From a safety perspective, physical barriers that simply can not be evaded by road traffic users should be implemented more often. However, furnishing all level crossings in Germany with full-barrier protection systems is unfeasible, because it is both complex and expensive for the reasons of the high safety integrity level that has to be met and the operational processes and regulations that have to be regarded. Future research on level crossing safety should therefore be concerned with the development of innovative protection concepts and inexpensive alternative solutions to the commonly used full-barrier layouts with automatic level crossing clear detection.

A good example for such concepts can be found at Russian level crossings. Here, platforms are being pulled up from street level, creating a barrier from outside and an off-ramp from inside the level crossing (Figure 6).

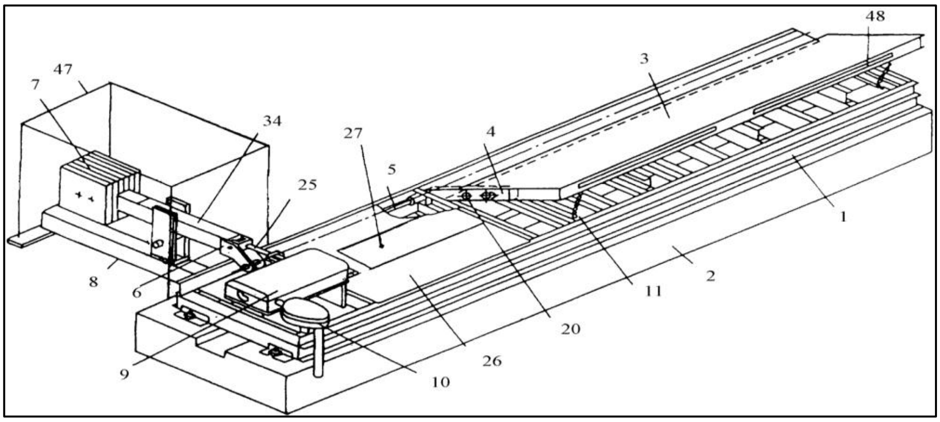


Figure 5: Russian level crossing protection system (13)

This solution has a great advantage over full-barrier setups, as road traffic users can not get locked in on the level crossing. Such a ramp system could be added to a half-barrier level crossing to lock it across the entire width of the road without compromising the ability of clearing the crossing after closure.

CONCLUSION

When comparing half-barrier protection systems to level crossings with light signals, the accident analysis conducted in this work reveals that half-barriers merely influence the cause of accidents but apparently do not prevent them more effectively. Instead of overlooking them, as road users sometimes do with light signals, closed half-barriers are deliberately bypassed. To reduce the amount of accidents at half-barrier level crossings in the future, three approaches are presented. The most promising solution seems to be the improvement of physical barriers, which renders deliberate bypassing difficult to impossible. Additionally, psychological approaches towards enhancing subjective risk perception and offering alternative activities to pass time while waiting should be taken into consideration to promote safe behaviour.

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