Safety at level crossings

Compact accident research

Unfallforschung der Versicherer

GDV

CONTENTS

Preliminary remarks

Level crossings are found at the intersections of two very different transport systems. According to the official statistics, up to 40 percent of all accidents involving injuries in rail transport occur at level crossings.

The new study of the UDV (German Insurers Accident Research) entitled "Sicherheit an Bahnübergängen" (Safety at level crossings) shows that most accidents occur at level crossings with half barriers or at level crossings without technical protection equipment. Most accidents involving fatalities or serious injuries are recorded at level crossings with technical protection equipment. The kinds of behaviors that are critical in leading to accidents can be subdivided into the following categories: willfulness, problems clearing the level crossing, carelessness and lack of visibility or restricted visibility or recognizability. Individual level crossings can be rated for risk on the basis of points ratings for critical parameters. A distinction should be drawn here between motorized and non-motorized road users. The most effective measures for improving road safety include structural demarcation of the lanes by means of traffic islands or road dividers, the installation of red-light monitoring systems and the installation of obstacle detection systems to monitor the danger zone.

Further findings of the study can be obtained from the research report entitled "Sicherheit an Bahnübergängen" [Safety at level crossings] (www.udv.de/bahnuebergang).

Background and procedure

Level crossings are a particular kind of intersection where two transport systems with different attributes and safety philosophies cross each other. Level crossing accidents account for less than 0.03 percent (878 accidents involving injuries) of the total number of accidents on the roads but more than 1 percent (55) of the fatalities. These accidents are thus disproportionately severe (German Federal Statistical Office, 2012a). As far as rail transport is concerned, level crossings feature prominently in the accident statistics: Between 30 and 40 percent of all rail accidents involving injuries occur at level crossings (German Federal Statistical Office, 2012b).

The causes of accidents at level crossings and the factors influencing them have scarcely been researched at all up to now in Germany. According to the rail operators, 95 percent of these accidents are caused by errors on the part of road users. On the roads, as well, 95 percent of accidents are caused by road users' errors. In order to ascertain the effect of infrastructural deficiencies on accidents, as is usual in such cases, the UDV commissioned a scientific study to answer the following questions, in particular:

- What factors affect the accident risk at level crossings, and to what extent?
- What measures can be taken to reduce this risk?
- Can a model be created in order to assess and compare the safety of level crossings?

The selected procedure consisted of a detailed analysis of the accidents that had occurred in Germany as well as an extensive international search for effective measures to combat accidents at level crossings. On this basis, quantitative and qualitative risk models were developed, suitable measures were identified, and a procedure was developed for rating safety at level crossings. The various steps involved are described in the detailed research report (UDV 2017).

Infrastructure and accidents

The study covered the German federal states of Baden-Württemberg, Rhineland-Palatinate and Saxony. The rail infrastructure data was obtained from the route databases of DB Netz (2014) and the Schweers + Wall Rail Atlas, rail traffic volume was obtained from the German Federal Statistical Office. The infrastructure data for classified roads was provided by the responsible departments of the federal states concerned. For level crossings on non-classified roads, the required data was obtained manually from aerial photographs using geoinformation system software. The accidents were analyzed based on the data of the German federal rail accident investigation body (EUB), the accidents recorded by the police and accident data from the claim files of selected insurance companies.

There were 5,258 level crossings in the area covered by the study that were in compliance with the ordinance on the construction and operation of railways (EBO). These made up 21 percent of all level crossings in Germany. Only just under 60 percent of all the level crossings in the area covered by the study were in the Deutsche Bahn (DB) network and around 40 percent were part of other operators' networks. Only those level crossings that were part of Deutsche Bahn's network were included in the study.

Data quality

The infrastructure data of Deutsche Bahn (DB) includes information on location coordinates, the type of protection offered at the level crossing, the type of road or road classification and the status of the line. The following statuses are possible: "in operation", "closed" and "removed". This allowed the data to be filtered so as to include in the study sample only level crossings on lines that were in operation. To ensure that a line on which there were accidents during the study period had not been shut down in the meantime, this information was checked against the information in the German Federal Railway Authority (EBA) database indicating the lines that have been closed in recent years.

Tabel 1: Level crossings complying with the ordinance on the construction and operation of railways (EBO) and percentage of all level crossings in DB's network (Source: Federal Statistical Office, 2010; DB infrastructure database)

Federal state	Level crossings in the study area			
	All level crossings		DB's network	
	[-]	[%]	[-]	[%]
Baden-Württemberg	2,488	47.3	1,254	50.4
Rhinland-Palatinate	1,221	23.2	874	71.6
Saxony	1,549	29.5	971	62.7
Total	**5,258**	**100.0**	**3,099**	**58.9**

The initial analysis of the aerial photographs revealed that some level crossings were no longer visible or could not be found at the specified coordinates, although they were still included in Deutsche Bahn's infrastructure database. Level crossings were generally excluded after the initial analysis of the aerial photographs for the following reasons:

- Elimination of a level crossing due to rerouting of a section of road or rail track
- Replacement of a level crossing with a grade-separated solution
- Removal of the level crossing without a replacement (often happens with farm or forest tracks)

In a second step, 533 level crossings were excluded from further study because they were in one of the following categories:

- Particular types of protection (barriers where a call to a rail employee is required, user-operated private gates, etc.)
- Industrial siding
- Identical location/duplicated data
- No road parameters obtainable
- Flagged for closure or closed
- Siding
- Not DB (route number > 9000)
- Non-existent
- Internal traffic only
- Private road (not open to public traffic)
- Passengers' crossing point/access to station

Accident data was essentially available from two different sources: the German federal rail accident investigation body (EUB) and the police records of road accidents (in the form of geo-referenced accident data loaded into the EUSka software). The first thing to do therefore was to check whether there were any differences in terms of the accidents recorded. All the relevant 3,099 level crossings in the DB network in the area covered by the study were used for this. Both in the EUSka database and at the EUB, the rail accident investigation body, an accident is recorded as an accident with fatalities if one of the people involved in the accident dies within 30 days of the accident. The definition of an accident with serious injuries deviates from this. In the EUSKa database an accident is considered to be an accident with serious injuries as soon as one of those involved in the accident is admitted to hospital as an inpatient. On the other hand, the German federal rail accident investigation body (EUB) doesn't record the accident as an accident with serious injuries until an individual has been an inpatient for at least 15 days.

When the same periods were compared in the two databases, differences were found in the total number of recorded accidents (figure 1). A considerable number of accidents recorded in the EUB database do not appear in the EUSKa database. Consequently, only the EUB records were used for the subsequent accident analyses and modeling. This ultimately resulted in a total study sample of 2,566 level crossings, at which 226 accidents involving injuries and damage to property were recorded by the EUB in the period

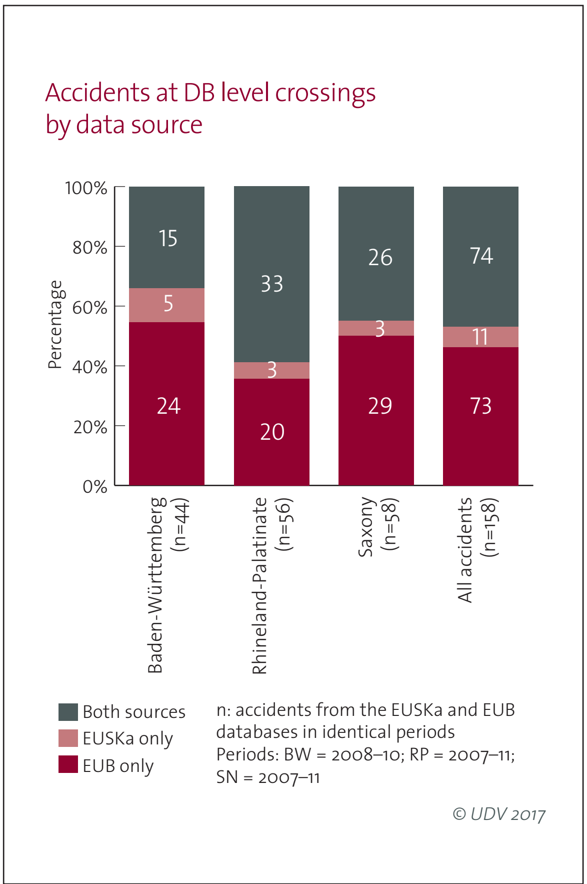


Figure 1: Comparison of the contents of the EUSKa and EUB data sources

from 2005 to 2011. At 1,902 (around 75 percent) of these level crossings, it was not possible to obtain road traffic volumes from the databases directly. At 11 level crossings there was no data available for the load classes of the rail traffic.

However, the traffic volume is a fundamental input variable for the creation of the accident model. The original study sample thus had to be adjusted accordingly. The level crossings for which both the road and rail traffic volume was known were included in the study initially. In addition, it was possible to estimate the road traffic volume for level crossings without technical protection equipment because the ordinance on the construction and operation of railways (EBO section 11, paragraph 7) stipulates a fixed upper limit for the daily traffic volume (DTV). The road traffic volume at the 514 level crossings without technical protection was thus estimated accordingly.

In the end, there were 1,169 level crossings available for the study (the study sample), at which the German federal rail accident investigation body (EUB) recorded 110 accidents involving injuries and property damage in the period from 2005 to 2011. 27 people were killed, 24 suffered serious injuries, and 102 suffered minor injuries.

Selected results of the accident analyses

The following findings of the **accident analyses** apply to the study sample.

At 95 of the 1,169 level crossings, at least one accident occurred during the period studied (table 2). The protection of level crossings is categorized in the ordinance on the construction and operation of railways (EBO) as follows:

- Non-technical protection (adequate fields of view and/or whistle signals)
- Flashing lights or light signals alone
- Flashing lights or light signals with half barriers
- Flashing lights or light signals with full barriers
- Full barriers alone
- Control by a rail employee

Flashing lights (including in the combinations above) are no longer approved for new level crossings and are only found in existing level crossings.

Table 2: Level crossings with and without accidents by type of protection

Level crossings	Types of protection								
	Full barriers			Half barriers		Traffic light signals only	Flashing lights	Without technical protection equipment	All types of protection
	With traffic light signals	Full barrier only	With flashing lights	With traffic light signals	With flashing lights				
Without accidents	88	39	6	234	156	9	12	530	1,074
With accidents	2	1	0	27	18	2	6	39	95
All level crossings studied	90	40	6	261	174	11	18	569	1,169

Around half of the level crossings in the study sample (569) were without technical protection equipment. The most frequently used form of technical protection consists of half barriers with light signals, followed by half barriers with flashing lights. These two types of protection (grouped together as half barriers) account for around 37 percent of the level crossings in the area covered by the study. A total of 45 accidents occurred at these level crossings. Only 136 level crossings in the study sample (11.6 percent) had full barriers.

Categories of people involved in the accidents

The rail accident investigation body (EUB) divides the casualties into three groups: train passengers, train drivers and road users. The fatalities were exclusively road users, as were two-thirds of the seriously injured (figure 2). Overall, around the same number of people inside and outside the train were injured, although the occupants of the train generally only sustained minor injuries.

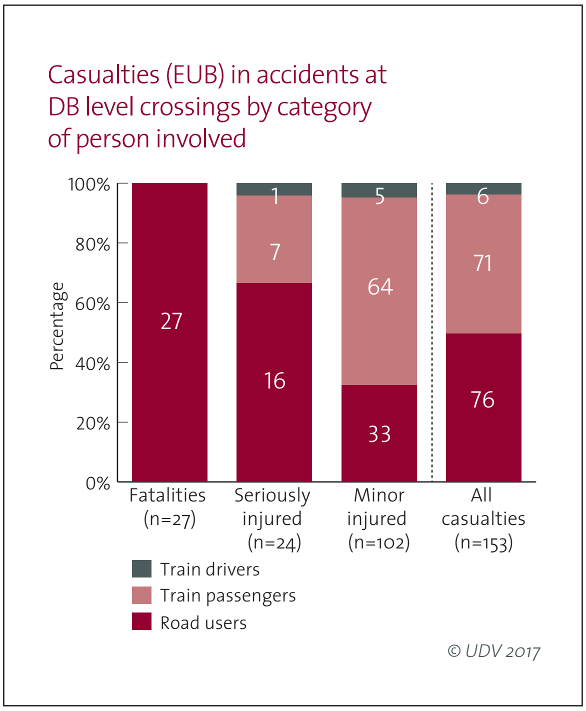


Figure 2: Categories of people involved in accidents (in accordance with the EUB) at DB level crossings in the study sample

Accident causes

According to the EUB database, the key accident causes were the disregarding or circumventing of technical protection equipment (in 53 percent of the cases) and failure to observe the priority of the train (38 percent). 17 of the total of 25 accidents involving fatalities occurred when road users disregarded or circumvented technical protection equipment.

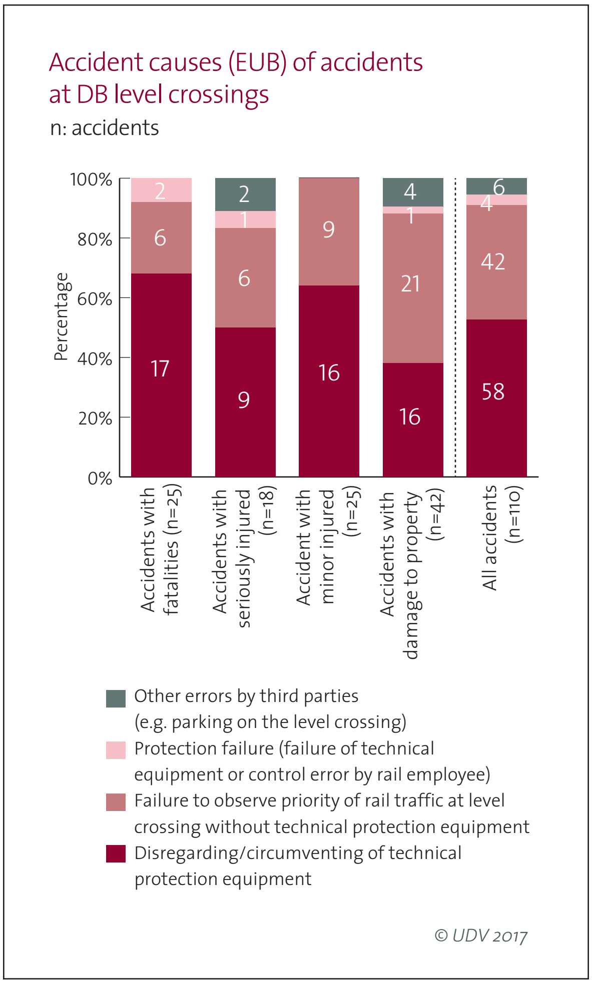


Figure 3: Accident causes (EUB) of the accidents at DB level crossings in the study sample

Location on main and branch lines

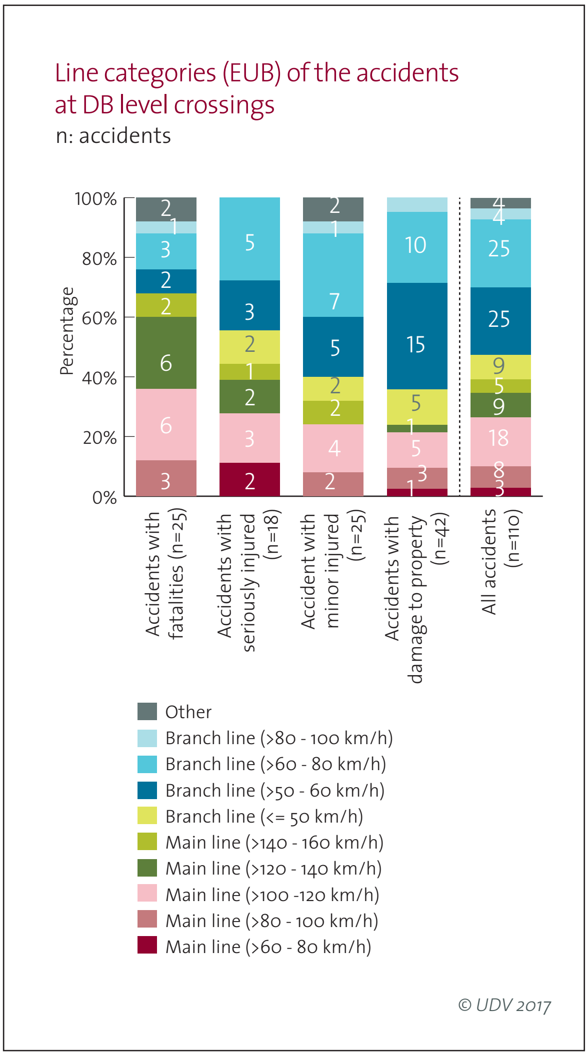


Figure 4: Line categories (EUB) of the accidents at DB level crossings in the study sample

The rail network is divided up into main and branch lines. Main lines generally form the backbone of the network. Branch lines complement them and improve links to areas not covered by the main lines. The ordinance on the construction and operation of railways stipulates their essential operating characteristics. For example, EBO section 40 stipulates maximum speeds of 80 km/h on branch lines (or 100 km/h in technical conditions that are the same as for main lines), and section 11 stipulates that level crossings without technical protection equipment are permissible only on branch lines. The EUB also differentiates lines by the speed ranges permitted on them. "Other" lines are those that are not part of a route (e.g. industrial or other sidings).

Accidents involving serious injuries occur predominantly at level crossings on main lines. One reason for this are the higher train speeds and the greater numbers of trains on main lines as opposed to branch lines. 39 percent of all accidents occurred on main lines.

Type of protection

46 of the total of 110 relevant accidents involving injuries and damage to property (around 42 percent) occurred at level crossings without technical protection equipment. Around the same number of accidents (47) occurred at level crossings with half barriers, followed by 14 accidents at crossings with flashing lights (without barriers).

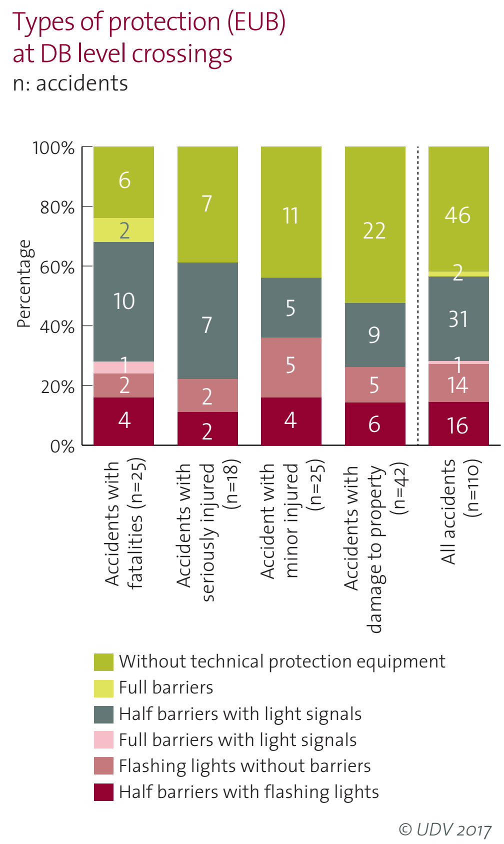


Figure 5: Types of protection (EUB) at DB level crossings in the study sample where accidents occurred

Road classes

The road classes at the level crossings studied are subdivided in the database into federal highways, state highways, district highways, other non-classified urban or district roads with general vehicular traffic, other roads such as agricultural or forest tracks with vehicular traffic, and footpaths and cycle paths. Around a third of all recorded accidents (35 percent) occurred on classified roads.

Additional findings from the total study sample

The most common type of protection in the total study sample was “half barriers with light signals” (35 percent). Level crossings without technical protection equipment accounted for 22 percent of the total. Around 62 percent of all the recorded accidents involved injuries, and in over one in three of these accidents, at least one person was killed or seriously injured. 69 percent of the accidents were caused by road users disregarding or circumventing technical protection equipment, and 21 percent of them were the result of a failure to observe the priority of trains at level crossings without technical protection equipment. Around 54 percent of the accidents involving injuries and damage to property were recorded on main lines.

Most accidents (78 percent) occurred at level crossings with technical protection equipment: 2 percent with full barriers, 47 percent with half barriers and 29 percent with flashing lights or traffic light signals. Accidents on classified roads accounted for 25 percent of the total.

Results of the modeling

Following a certain amount of data cleansing, 1,040 level crossings were used to create the quantitative model for calculating accidents at level crossings. The EUB recorded 103 accidents involving injuries and damage to property at these level crossings in the period from 2005 to 2011. A total of eight submodels were created for level crossings with technical protection equipment and those without. Initially, distinctions were drawn between submodels for accidents involving injuries and damage to property A(I,D), accidents with injuries only A(I) and accidents with damage to property only A(D). In addition, there was a distinction between submodels for level crossings with general vehicular traffic and level crossings on footpaths and cycle paths.

Table 3: Overview of the submodels and underlying study sample

Submodel	Level crossings (LCs) with technical protection equipment			Level crossings without technical protection equipment (<=2,500 motor vehicles a day)				
	Total n = 473			Total n = 567			with motor vehicles[1] n = 370	without motor vehicles[2] n = 197
	A(I,D)	A(I)	A(D)	A(I,D)	A(I)	A(D)	A(I,D)	A(I,D)
No. [A/7a]	59	42	17	44	23	21	34	10
Mean [A/(LC*7a)]	0.12	0.09	0.04	0.08	0.04	0.04	0.09	0.05

1) Level crossings on roads with general vehicular traffic (<=2,500 motor vehicles a day)
2) Level crossings on footpaths and cycle paths (without vehicular traffic)

Six of the submodels were discarded due, above all, to very low numbers of accidents, poor estimates of the coefficients for the explanatory variables and a high probability of error: it was not possible to generalize from them.

One model each was created for level crossings with technical protection equipment and for those without. The results show that the accident risk of level crossings with flashing lights or traffic light signals is greater than for level crossings with a half barrier by a factor of 9.5 and for those with a full barrier by a factor of 49. The accident risk at level crossings with technical protection equipment on lines with a maximum speed of 160 km/h is greater by a factor of 3.2 than on lines with a maximum speed of 100 km/h. The type of protection, curvature of the road and maximum speed of the trains were identified as key parameters affecting the numbers of accidents at level crossings with technical protection equipment.

The accident risk is greater by a factor of 1.6 at level crossings without technical protection equipment on roads with general vehicular traffic compared to those on footpaths and cycle paths. The road class (footpath/cycle path or road with general vehicular traffic), road surface and distance to the next intersection are key factors affecting the accidents that occur at these level crossings.

When these models are used, it should be borne in mind that the very low numbers of accidents at the level crossings studied mean that the calculated number of accidents at each level crossing may turn out to be an overestimate or underestimate.

Qualitative model

The qualitative model allows the general risk of a single level crossing to be assessed using different parameters. A distinction is drawn between non-motorized and motorized road users. In the case of the latter, the zones where the risks arise are the decision-making zone and the clearance zone. The procedure is based on extensive studies of the literature, qualified estimates and complementary empirical studies. The influencing factors are the rail traffic volume, the speed of the trains, the type of protection, the time for which the barriers are closed before the train arrives, the road traffic volume, the road traffic situation, the visibility on the road and the risk in the clearance zone. The aim of the qualitative model is to classify the risk and effectiveness of the measures that can be carried out to reduce the numbers of accidents. This was done by assigning points to the influencing factors. The points assigned to the individual parameters were added to obtain totals for non-motorized and motorized road users and obtain a measure of the risk at the level crossing. It was calculated what the minimum and maximum points totals could be.

The visibility for motorized road users was generally rated as very poor because fields of view are not explicitly kept clear for active level crossings and therefore it can be assumed that visibility will be obstructed by vegetation and Building (points rating: 5). On the other hand, the visibility for pedestrians and cyclists can generally be rated as moderately good (points rating: 3) because they have a view of the rail line immediately before entering the danger zone even when fields of view are not explicitly kept clear. Conditions are thus generally more favorable for them than for drivers.

Table 4: Risk rating of a level crossing

Points totals for road users		Low risk	Medium risk	High risk
Non-motorized		6 to 13	14 to 22	23 to 27
Motorized	Decision-making zone	7 to 15	16 to 24	25 to 34
	Clearance zone	1	2	3 to 4

A full barrier largely eliminates both unintentional and intentional inappropriate actions and can thus be described as the most effective type of protection. This type of protection was thus used as the benchmark for rating other types of protection. This is how the limit values of 22 points for non-motorized road users and 24 points for motorized road users were obtained. These points ratings are the upper limit for a rating of medium risk. These points ratings could be used to obtain risk ratings for a level crossing for both non-motorized and motorized road users. These consist of three risk levels (table 4).

If the level crossing is rated as:

- Low risk, there is no immediate need for action.
- Medium risk, this is acceptable, but a comprehensive local review should be carried out to ascertain whether risk-reducing measures are necessary.
- High risk, this indicates that appropriate measures should be taken to reduce the risk.

When identifying the measures to be taken, it is important that the two groups of road users are considered separately. In addition, measures taken to manage the risk in the decision-making zone must not be considered to compensate for the risk in the clearance zone and vice versa.

Detailed analysis of insurers' accident documentation

108 claim files were used for the detailed analysis. Around two-thirds of these accidents (71) involved injuries (table 5). 20 road users were killed, 31 people suffered serious injuries, and 128 suffered minor injuries. Most of those with minor injuries (74) were occupants of trains, while most who sustained serious injuries (22) were road users. Around half of these accidents occurred at technically protected level crossings with half barriers or with flashing lights/traffic light signals only.

In most of the accidents, a car without a trailer collided with a train. The relatively high number of trucks with trailers involved is particularly striking. No cyclists or pedestrians were involved.

In many of the claim files examined, the costs for the damages were calculated by means of an expert valuation. In the great majority of cases, a distinction was drawn between the costs on the rail side and the costs for the road user. The average total cost for damage to property of each accident at a level crossing with half barriers was around 218,800 euros. That is almost twice as high as for damage to property at level crossings without technical protection equipment (table 6). The ratio of the costs for damages incurred on the rail side and by road users was

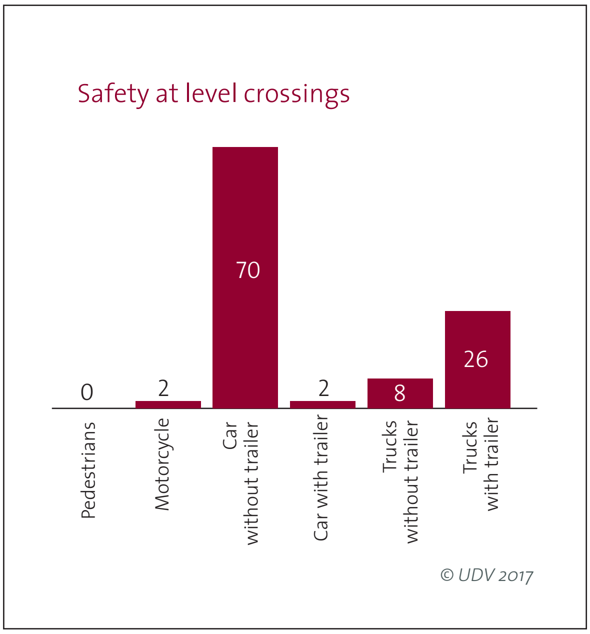
Table 5: Accidents and casualties by type of protection

Accident occurrence		Accidents and accident consequences by type of protection of the level crossings studied				
		All types of protection	Full barrier	Half barrier	Flashing lights or traffic light signals	Non-technical protection
Number of accidents involving injuries	**All accidents**	71	2	22	22	24
	Accidents involving fatalities	14	0	5	6	3
	Accidents involving serious injuries	21	0	6	7	8
	Accident involving minor injuries	36	2	11	9	13
Number of casualties	**Train passengers**	179	4	88	38	49
	Rail employees	29	2	12	4	11
	Fatalities	0	0	0	0	0
	Seriously injured	4	0	1	0	3
	Minor injured	25	2	11	4	8
	Train passengers	79	1	54	8	16
	Fatalities	0	0	0	0	0
	Seriously injured	5	0	1	0	4
	Minor injured	74	1	53	8	12
	Road users	71	1	22	26	22
	Fatalities	20	0	8	9	3
	Seriously injured	22	0	6	9	7
	Minor injured	29	1	8	8	12
Accidents involving damage to property only		37	1	9	4	19
Total number of accidents		**108**	**3**	**31**	**26**	**43**

Table 6: Costs of rail damages and damages for road users by type of protection

Accident costs (calculated damages based on expert valuation in the insurer's files)*		Costs of damages by type of protection of the level crossings studied				
		All types of protection	**Full barrier**	**Half barrier**	**Flashing lights or traffic light signals**	**Non-technical protection**
Rail	Total costs of damage to property (€)	12,636,207	381,200	5,730,000	2,427,307	4,068,500
	Number of files with cost estimate	92	1	28	22	41
	Costs of damage per accident (€)	137,350	381,200	204,643	110,332	99,232
Road users	Total costs of damage to property (€)	2,305,250	80,000	615,500	792,500	744,950
	Number of files with cost estimate	88	1	28	20	39
	Costs of damage per accident (€)	26,196	80,000	21,982	39,625	19,101
Total costs	Total costs of damage to property (€)	14,941,457	530,200	6,345,500	3,219,807	4,813,450
	Number of files with cost estimate	96	2	29	24	41
	Costs of damage per accident (€)	**155,640**	**265,100**	**218,810**	**134,159**	**117,401**

* Calculated costs were not available in all files



particularly striking. The ratio was highest for level crossings with half barriers. The costs of rail damages there were greater than those for road users by a factor of around 9.3. On average, the costs of rail damages were five times those of road users.

Figure 6: Train collision opponent

Detailed analysis of insurer's accident documentation

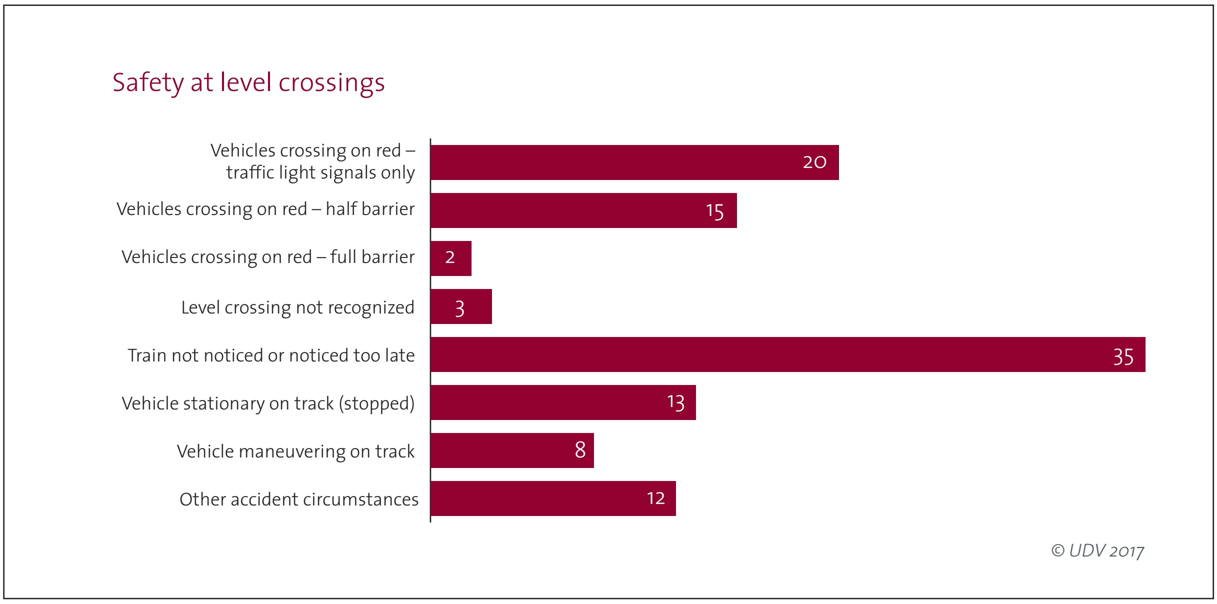
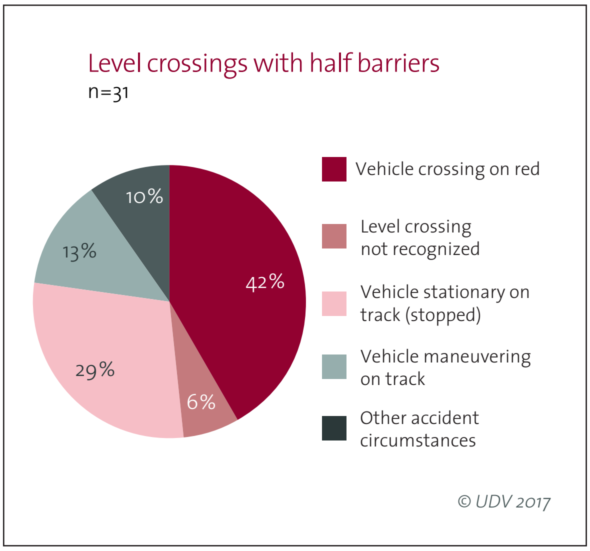


Figure 7: Accident circumstances from the claim files

It was possible to reconstruct the accident circumstances from the information in the claim files in many cases (figure 7). In most cases the accidents were caused by red-light violations at level crossings with technical protection equipment (figures 8 and 9). At level crossings without technical protection, in the great majority of cases the train was not noticed or only noticed too late (figure 10).



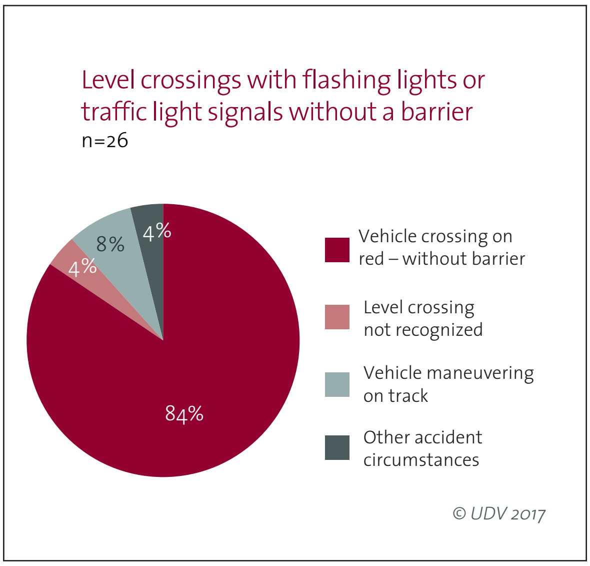


Figure 9: Accident circumstances at level crossings with flashing lights or traffic light signals

◄ *Figure 8: Accident circumstances at level crossings with half barriers*

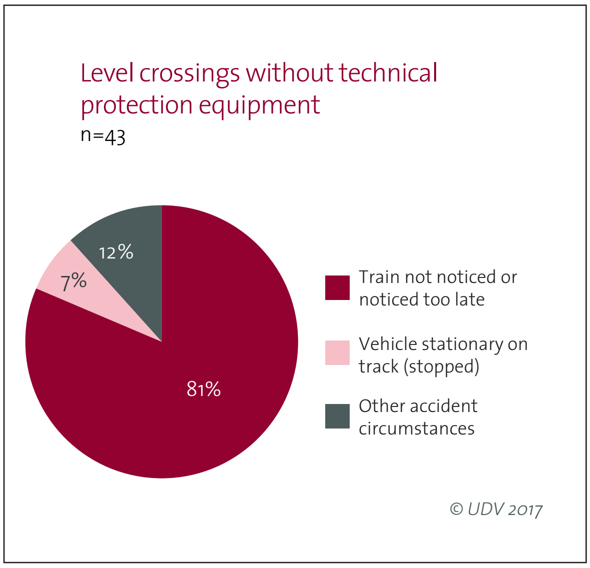


Figure 10: Accident circumstances at level crossings without technical protection equipment

Based on the accident circumstances, the following typical behaviors and influencing parameters were identified as contributing to the accidents.

Willfulness

Some drivers willfully drove around the closed barrier or crossed the track in violation of a red light. Red-light violations were found to be most common at level crossings with half barriers or with flashing lights or traffic light signals only. In one claim file, for example, a car was described as driving past a line of waiting vehicles and then around the closed barrier before being hit by a train.

Clearance problems

These problems occurred predominantly at level crossings with half barriers and level crossings without technical protection equipment. Trucks with trailers standing in the track area before the half barrier came down were particularly common in these cases. This often occurred because they were maneuvering on the track, maneuvering after a wrong turn or due to their tractrix curve, a traffic jam or the driver underestimating the vehicle's length when crossing the tracks.

Carelessness

This was a factor, above all, at level crossings without technical protection equipment. Car and truck drivers noticed the level crossing but failed to give priority to trains. The following reasons were given in some cases for the failure to give priority to the train: The train was noticed too late, the vehicle braked and came to a stop too late, or the warning signal was not heard. At level crossings with half barriers, the accidents most often involved vehicles that were in the track area before the barrier came down due to a loss of control by the driver or a failure to notice the level crossing. They were then hit by the train.

View and recognizability

Some of these cases involved drivers who, due to an unfavorable road design (small bend radius, narrow road, poor visibility ahead), had to wait in the track area and were hit by the train. In some cases, the driver had not seen a red light (e.g. due to the glare of the sun), and the side of the vehicle was hit by the train.

Effective measures

A large number of measures were rated that can contribute to risk management or reduction at level crossings. A distinction was drawn between measures that take effect in the decision-making zone before the level crossing and those that take effect in the clearance zone after it. The investment costs and operating costs were taken into account as far as possible in the ratings. The measures outlined below represent solutions that would significantly reduce the frequently encountered behaviors that led to accidents at the level crossings studied. They have already proved to be effective both in Germany and elsewhere.

Structural demarcation of the lanes by means of traffic islands or road dividers

This results in a sharp reduction (70-90 percent) in the number of drivers driving around the half barriers, makes drivers more attentive and improves road safety in the decision-making zone.

Red-light monitoring by means of surveillance cameras

This results in a substantial reduction of intentional red-light violations at level crossings with technical protection equipment, particularly at those that only have flashing lights or traffic light signals (no barriers). This substantially reduces the number of drivers driving around the half barriers by up to 80 percent. It thus improves road safety in the decision-making zone.

Obstacle detection systems

These systems do not allow trains to proceed unless the level crossing's danger zone is clear. Collisions with stationary vehicles (e.g. as a result of tailbacks, loss of control by the driver and uncompleted maneuvering) in the clearance zone are almost totally eliminated (SELCAT, 2008). The approved technologies for this now have a significantly higher level of safety, and the number of technical malfunctions is negligible.

Summary and recommendations

1,169 level crossings with fully available infrastructure and accident data were studied in this completed research project. The accident analysis showed that most accidents occur at level crossings with half barriers or at level crossings without technical protection equipment. Most accidents involving fatalities or serious injuries are recorded at level crossings with technical protection equipment. A detailed analysis of 108 insurers' claim files showed that the behaviors that lead to accidents can be subdivided into the following categories: willfulness, problems clearing the level crossing, carelessness or a lack of visibility or recognizability.

Predicting the numbers of accidents at level crossings is not realistic for practical purposes, because the average numbers of accidents are so low that any prediction may turn out to be a substantial overestimate or underestimate. Assessing the risk at a single level crossing based on a points rating system for key parameters that can affect the numbers of accidents holds some promise. The suggested risk rating system differentiates between non-motorized and motorized road users. For the latter group, an additional distinction is drawn between the decision-making zone before the level crossing and the clearance zone after it. A large number of measures were examined in the study.

The most effective way to prevent accidents at level crossings is to remove them and replace them with underpasses or overpasses. However, the installation of full barriers at level crossings can also be an effective contribution to road safety. All other types of level crossings with half barriers or traffic light signals are significantly less safe. However, there are measures that can be recommended in these cases that can at least partially reduce the accident risk. These include:

- Structural demarcation of the lanes by means of traffic islands or road dividers
- The installation of red-light monitoring systems
- The installation of obstacle detection systems

Level crossings without technical protection equipment should be protected by means of traffic light signals, as a minimum, and possibly also be equipped with a red-light monitoring system. A field study is needed to ascertain whether replacing the saltire warning cross (road sign number 201) with a stop sign (road sign number 206) at level crossings without technical protection equipment, as many have demanded, would have the desired effect of making drivers stop.

All measures taken should be designed to prevent drivers in good time from crossing a level crossing when a train is approaching. In addition, the level crossing should be monitored by a system that sends a warning to an approaching train if the level crossing is not cleared in good time. However, it is currently only possible to implement this with a full barrier.

Pilot projects should be initiated to evaluate the effectiveness of the proposed measures at level crossings in Germany. Constructive collaboration between the two bodies with the relevant authority is of critical importance for this. In addition, suitable campaigns to make road users sensitive to this issue can also make a contribution.

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Unfallforschung der Versicherer
GDV

Gesamtverband der Deutschen
Versicherungswirtschaft e.V./
Unfallforschung der Versicherer
[German Insurers Association/
Insurers Accident Research]
Wilhelmstraße 43/43 G, D-10117 Berlin
Postfach 08 02 64, D-10002 Berlin

Phone +49 (0)30 20 20 - 58 21
Fax +49 (0)30 20 20 - 66 33

unfallforschung@gdv.de
www.udv.de
www.gdv.de

Facebook: facebook.com/unfallforschung
Twitter: @unfallforschung
YouTube: youtube.com/unfallforschung
Instagram: instagram.com/udv_unfallforschung

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GDV
DIE DEUTSCHEN VERSICHERER

Gesamtverband der Deutschen
Versicherungswirtschaft e.V. /
Unfallforschung der Versicherer

Wilhelmstraße 43/43 G, D-10117 Berlin
Postfach 08 02 64, D-10002 Berlin

Phone: + 49 (0) 30 2020 - 5000
Fax: + 49 (0) 30 2020 - 6000
www.gdv.de, www.udv.de