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Master Thesis

Development of a German Level Crossing Prioritization and Consolidation Model

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Abstract

Level crossings represent high risk for both rail and road users due to the severe consequences of any possible accident. Between 2011-2020, a total of 1602 accidents occurred at level crossings in Germany and resulted in 344 fatalities. Therefore, elimination of accident risk through consolidation of level crossings becomes a priority. However, due to the scarcity of financial resources in comparison to the high costs that level crossings consolidation or safety upgrade projects require, there is a need for the creation of tools that prioritize the level crossings for consolidation projects based on several criteria that is not related to safety only but to social, economic and environmental aspects as well. Such tool would be particularly useful for authorities and decision-makers in Germany to improve the resource allocation process and increase overall safety at German level crossings. In this project, the level crossing prioritization and consolidation models that are applied all over the world are reviewed and analyzed to benefit from the international experiences in this field. Additionally, a literature review to determine the most influencing factors on level crossing safety was performed. After that, a points-based priority score for German level crossings was developed based on analytic hierarchy process (AHP) methodology after a pairwise comparison survey was conducted to a selected level crossing group of experts. The developed model assigns a priority score from 1000 points to each level crossing. Crossings could be ranked according to their priority for consolidation and safety upgrade based on the points received as crossings with the highest priority score have a higher priority for elimination.

Plagiarism Disclaimer

I hereby declare that this thesis is my own and autonomous work. All sources and aids used have been indicated as such. All texts either quoted directly or paraphrased have been indicated by in-text citations. Full bibliographic details are given in the reference list which also contains internet sources containing URL and access date. This work has not been submitted to any other examination authority.

Zwickau, 21.09.2022 Omar Abu Saad

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List of abbreviations

AADT Average Annual Daily Traffic

AHP Analytic Hierarchy Process

ALCAM Australian Level Crossing Assessment Model

ALCRM All Level Crossings Risk Model

BEU Die Bundesstelle für Eisenbahnunfalluntersuchung (The Federal Authority for Railway Accident Investigation)

BMVI Das Bundesministerium für Verkehr und digitale Infrastruktur (The Federal Ministry of Transport and Digital Infrastructure)

BOA Verordnung über den Bau und Betrieb von Anschlussbahnen (Ordinance on the construction and operation of connecting industrial branch railways)

BÜSA Bahnübergangssicherungsanlagen (Level crossing safety systems)

BÜSTRA Bahnübergangssteuerungsanlagen (Level Crossing Control Systems)

BÜV-NE Vorschrift für die Sicherung der Bahnübergänge bei nichtbundeseigenen Eisenbahnen (Regulation for the protection of level crossings on non-federally owned railroads)

DOT Department of Transportation

EBA Eisenbahn-Bundesamt (Federal Railway Authority)

EBO Eisenbahn-Bau- und Betriebsordnung (railway construction and operating regulations)

EKrG Eisenbahnkreuzungsgesetz (Railway Crossing Act)

ERA European Railway Agency

EU European Union

FRA Federal Railroad Administration - USA

ILCAD International Level Crossing Awareness Day

ITS Intelligent Transportation Systems

LC Level Crossing

LCSIA Level Crossing Safety Impact Assessment - New Zealand

LST Leit- und Sicherungstechnik (control and safety technology)

MCDM Multi-Criteria Decision Making

NCHRP National Cooperative Highway Research Program

RCAT Railroad Crossing Assessment Tool - USA

RSSB Rail Safety and Standards Board – United Kingdom

StVO Straßenverkehrsordnung (Road Traffic Regulation)

UIC Union Internationale des Chemins de fer (International union of railways)

UK United Kingdom

USA United States of America

1 Introduction and Objectives

1.1 Introduction

A level crossing is a type of transportation infrastructure where the railway and roadway traffic systems intersect at the same elevation (Figure 1). The Railroad Construction and Operating Regulations (§11 EBO) define Level crossings as “Crossings of railroads with streets, paths, and squares” [1]. In Germany, The German Railway company (Deutsche Bahn) estimated the number of existing level crossings to be 16,098 as of 2020 [2]. Germany has the largest rail network size in Europe with 33.399 Km [3].

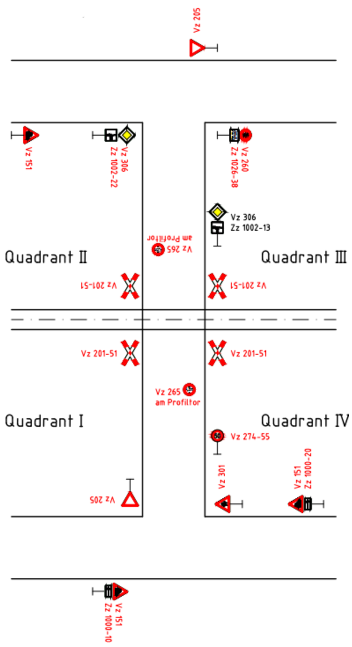


Figure 1: Level Crossing sketch

The rate of development for railway transportation is increasing rapidly due to the public orientation of increasing the reliance on it as more attempts are made to limit the reliance on road traffic. Rail transport provides many solutions to the problems of transportation at the time being due to its high speed and efficiency, its ability to cover large distances while remaining arguably one of the safest and most environmentally friendly transport methods. In order to help the development of railways, many countries have intensified the research of safety improvements in the rail transportation network and particularly at level crossings as they form one of the biggest danger points in the network.

Level crossings impose a great danger over all the users of both the railway and highway transportation networks as accidents often lead to disastrous outcomes. Germany as well as many other countries recognized the risks of the increase in Level crossing numbers that was a natural result of the expansion of both the railway and highway networks over the last century. Therefore, many plans and programs were introduced both in Germany and internationally to eliminate the risks that level crossings impose on the public by reducing their numbers. Since 1994, 44% of the level crossings in Germany were removed. In addition, the number of level crossings has been reduced by approximately 16% in the last decade as 19,173 level crossings existed in 2011 [2].

Level crossings are also considered as one of the most hazardous components of the transport network due to the severity of the potential accidents that result from the intersection of two inequivalent transport methods. The huge disproportion between the mass and speed of the train and the road vehicle is the main reason for the major losses that result from such accidents. The statistics of the German Federal Railway Authority (EBA) show that around 19% of all railway transportation fatalities in 2020 belong to the level crossing users category while 29% of the seriously injured are from the same category [4].

Level crossing accidents are usually associated with a big impact on the public in Germany. This is due to their disproportionately high level of damage despite their relative uncommonness.

German level crossings recorded an average of 160 accidents per year since 2011. Most of the accidents occur in Bavaria, Lower Saxony, and North Rhine-Westphalia, due to the fact that these states hold the highest number of level crossings too [2].

Every level crossing is considered as a source of potential risk for three types of collisions namely train-vehicle, vehicle-vehicle, and vehicle-warning device collisions. The US Federal Railroad Administration (FRA) defines accidents at level crossings as "any impact between a rail and highway user (both motor vehicles and other users) of the crossing as a designated crossing site, including walkways, sidewalks, etc., associated with the crossing." [5]

The European Union Agency for Railways reported that nearly a third of fatalities that occurred in the European railways between 2015-2019 have occurred in Level Crossings. On the bright side, the same report observed a decrease in Level Crossing accidents in the last decade. In 2010, Europe suffered from 592 significant accidents at level crossings of which 371 involved fatalities. Safety however has developed positively as the number of significant accidents was reduced to 437 accidents of which 268 involved fatalities in 2019 [6].

In addition to the high safety hazard, level crossing accidents lead to huge financial losses due to their severity with damages that could count up to millions of euros due to damage or derailment of trains as well as the damage of tracks and equipment. Moreover, a large percentage of level crossings are built in rural areas and serve very low vehicles per day. These Level crossings can present a financial challenge to the federal government, states, districts, or municipalities in terms of maintenance, operation, and construction.

In addition to the human and financial losses resulting from accidents, the frequent intersections between the road and rail networks in the form of level crossings negatively impact the level of service of the rail network as the speeds of trains are usually lowered in such sections. This also affects the capacity of the rail network, especially with the increasing demand for rail traffic. All the aforementioned factors impose financial losses on both the public and the train operating companies.

In order to overcome the safety and financial challenges that level crossings present in the German and European railways, there is a need for consolidation programs to be planned. But since consolidation programs are expensive and require high investment, an essential part of any consolidation program is to find a methodology to allocate the limited resources efficiently and to prioritize the riskiest level crossings for elimination or safety improvement. Any attempt to do so has to be formed based on criteria that are tailored to the individual country and its local traffic conditions. This project attempts to study the various international consolidation models and the criteria that form their core in order to aid the design of a possible future German model.

The created model must be consistent with national standards and laws. In Germany, the main standards that handle the regulations of level crossings are the German railway construction and operating regulations (EBO), Planning and maintaining level crossings guideline (DB-Richtlinie 815) and Regulation for the protection of level crossings on non-federally owned railroads (BÜV-NE) from the rail traffic side. From the road traffic side, the standards Road Traffic Regulation (StVO) and the General Administrative Regulation to the Road Traffic Regulations (VwV-StVO) offer the necessary guidance. An overview of the German guidelines and regulations can be found in section 2.5. Despite the available details in the aforementioned guidelines, there is still a lack of information regarding the hazard assessment of level crossings.

The topic of level crossing consolidation is discussed and studied in many countries around the world. Countries like the United States, United Kingdom, and Australia have contributed significantly to the research of consolidation and given high attention to the need of having scientific-based models for their consolidation programs. These international experiences could be benefitted from when creating a similar German model is desired. This study analyzes these models and researches in order to identify the main criteria applied.

This study, through literature review, intends to identify and propose the main criteria that will set the basis of a German level crossing prioritization and consolidation model that will help to improve the safety conditions at the local level crossings and eliminate all the negative impacts of these crossings and improve the quality of rail and road traffic in the country. This study also addresses the key case of setting an analysis methodology for the level crossings assessment in the light of several factors (safety, environmental and financial). For this goal, it is necessary to identify the criteria that have the highest effect on the safety of crossings and evaluate whether they would be required to be adopted in a German model that assesses and ranks the level crossings either for safety improvement or consolidation.

1.2 Objectives

Due to various reasons such as the high number of influencing factors and limitations of finances, there is a need to create a model that prioritizes level crossings for consolidation in a traffic network. Most of the closure decisions made in Germany are left to engineers´ judgement and experience in addition to public pressure that results from repetitive or disastrous accidents. But there is a need for a quantitative and qualitative system model that considers and prioritizes factors according to German standards and road-rail conditions.

This thesis aims to analyze the criteria used in the international level crossing assessment, prioritization and consolidation models and identify the significant criteria for creating a German model based on reviewed literature. Based on these criteria, a methodology is proposed for the assessment and ranking of German level crossings for consolidation or safety improvement with the aim of improving safety conditions and traffic quality at German real and road networks.

The main objectives of the thesis are:

- To review and analyze the international models and literature in the field of level crossing assessment and prioritization.
- Proposal of criteria to be adopted in Germany for the assessment and consolidation of existing level crossings based on international literature and local regulations.
- To set the basis of a German Level Crossings Model for the assessment and prioritization of crossings for possible consolidation or safety improvement.

1.3 Contents

Chapter 1 introduces the topic of the thesis and the problem that it addresses which leads to the suggested solution and clear demonstration of the objectives of the work. In addition, the structure of the thesis is presented.

In chapter 2, the current situation of level crossing safety in Germany is described in detail and supported with statistical evidence. Then, the types of safety technology and devices at German level crossings are listed. In addition, chapter 2 discusses the negative outcomes of level crossings. It also sheds the light on the legal aspects surrounding level crossings such as the ban on creating new crossings, how exceptions are obtained, and how expenses of consolidation projects are distributed according to German law.

Chapter 3 explores the topic of level crossing consolidation demonstrating the main key issues of consolidation, The consolidation options and alternatives, and the main incentive programs that are implemented internationally to aid and accelerate the rate of consolidation.

Chapter 4 explores the work done around the world in the field of level crossing consolidation and the various models adopted by countries for the assessment of their local crossings and the prioritization of the level crossing removal projects. An analysis is conducted to understand the mathematical basis of these models and identify the main criteria and weights those models are based on. Moreover, recent literature on some of the main factors that lead to accidents at level crossings such as human behavior are reviewed

In chapter 5, The main criteria from the international models and literature are compared and examined for their suitability for local traffic conditions in Germany and consistency with German standards and regulations. Also, in this chapter the survey results and final weights of the model criteria are presented in addition to the suggested priority scoring system concerns the weights of the selected factors. The methodology used for factors weighting ´analytic hierarchy process (AHP)´ is explained in this chapter too.

Finally, the conclusions on the topics discussed throughout the thesis are demonstrated and the remarks regarding the presented model are given.

2 Current Safety Situation at German Level Crossings

2.1 Total number of Level crossings in Germany and EU

The total amount of existing level crossings in Germany has decreased by 16% since 2011 and by an overall rate of 44% since 1994, according to information submitted by The German Railway company Deutsche Bahn. The company estimated the number of Level crossings in 2020 to be 16,098 crossings. Figure 2 demonstrates the reduction in German Level crossings in the last decade [2].

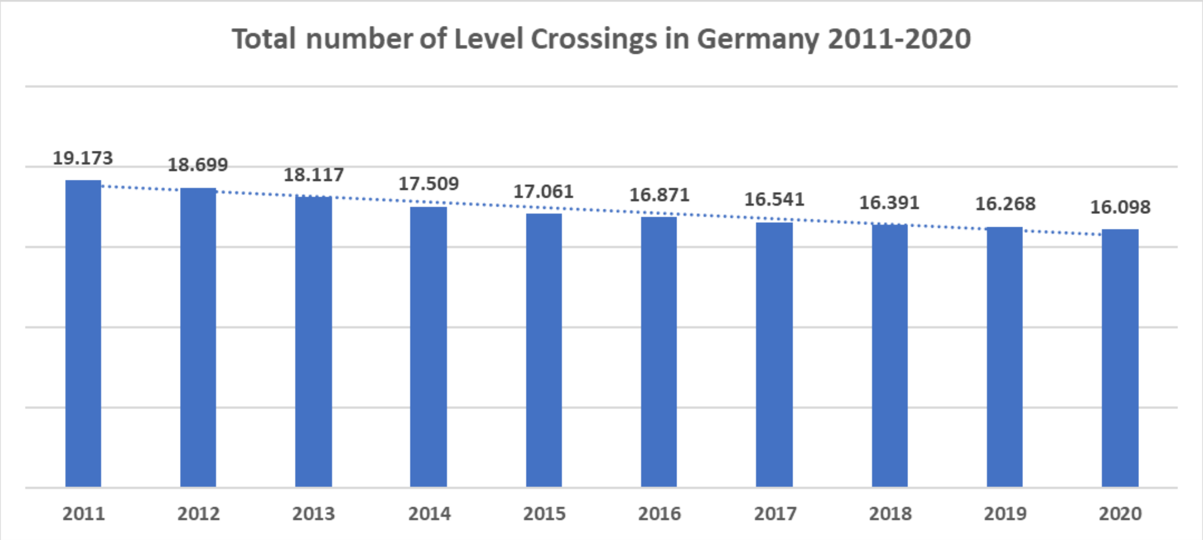


Figure 2. Total number of Level Crossings in Germany 2011-2020 [2]

Germany has a much better rate of reduction for level crossings in comparison to the average rate in Europe of 8.4%. The European Railway Agency reports a reduction in the total number of level crossings in the 28 EU member states from 114,580 in 2014 to about 105,000 in 2020 of which 49% are passive. Depending on the current reduction rates, the ERA predicts that only 35,000 Level crossings will still exist in the Union by the end of the century [7-8].

The average number of level crossings per 10 line-km in the EU is five. However, these data vary between countries. For example, the highest density of level crossings per line-km could be found in Sweden, Austria, Czech Republic, and Hungary with 75 level crossings per 100 line-km. On the other hand, the lowest density is found in Spain and Bulgaria with 25 level crossings per 100 line-km [8].

EBO does not permit having any level crossings on train routes where the max train speed exceeds 160 Km/h. This rule makes the elimination of level crossings necessary when a route is upgraded to be a high-speed rail route. Germany currently owns a high-speed rail network with a length of 1571 km with a further 147 km currently being constructed making Germany´s network the third largest European high-speed network after France (3487 km) and Spain (2734 km) [9].

2.2 Protection systems at German level crossings

Level crossings in Germany are either technically secured or without any technical protection system. Level crossings without technical protection systems are often referred to as passive crossings as well and depend entirely on signs to warn the road users of potential danger without any assistance from light signals or barriers making them very hazardous systems and exposed to constant public pressure for safety upgrades. Non-technically secured crossings make about the third (5986 crossings) of all German level crossings [2].

Various protective methods are used at passive crossings including overview of the crossing, audio signals like train whistles or bells, and slow approach to the crossing. Sometimes, barricades are used too for crossings that are exclusive for pedestrians and cyclists. It is also possible to secure the crossing with a combination of such measures. Figure 3 shows a level crossing secured with St. Andrew´s Cross only.

Securing the level crossing with human guards is also a common non-technical protection method but considered an active measure. (Figure 4)

Two-thirds of German crossings are technically secured. §11 of the German railway construction and operating regulations (EBO) divides the types of technical protection to:

- light signals or flashing lights only (Figure 5)
- light signals or flashing lights with half barriers (Figure 6)
- light signals or flashing lights with full barriers (Figure 7)
- full barriers only

Technical securing systems are the most expensive to implement but the safest type of securing measures since the protection mechanism is triggered by the train itself when it passes the Induction loops.

EBO permits having passive level crossings under certain criteria such as road traffic volume, number of train tracks, and speed of the train. Figure 10 shows a flowchart demonstrating the process of selecting the minimum protective system of a level crossing according to EBO.

Figure 3: A level crossing without technical protection (Source: MdE from German Wikipedia)

Figure 4: Human guards at level crossing [10]

Figure 5: Level crossing secured by Light signal in Flandersbach (Source: jaynightwind blogspot)

Figure 6: half barrier level crossing (source: szlz.de)

Figure 7: full barrier level crossing (Source: MdE from German Wikipedia)

Table 1 and Figure 8 demonstrate the number of Level crossings in Germany according to the type of security. By comparing Germany to the other European countries, it is found that 9 countries have a lower share of passive level crossings as demonstrated in Figure 9.

Table 1: Number of Level crossings in Germany according to the type of protection [2]

Type of security	Number of Level Crossings	%
Non-technically secured Level Crossings	**5986**	**37.18%**
Closure with Intercom	30	0.19%
Closure without Intercom	70	0.43%
Human guards	242	1.50%
Overview of the railway line	1877	11.66%
Overview and whistle	2285	14.19%
Overview, whistle and slow driving	1482	9.21%
technically secured Level crossings	**10112**	**62.82%**
Call barriers	469	2.91%
Flashing light	547	3.40%
Flashing light or light signals with half barriers	7207	44.77%
Flashing light or light signals with full barriers	1041	6.47%
Light signals	187	1.16%
Barrier guard	661	4.11%
Total	**16098**	**100.00%**

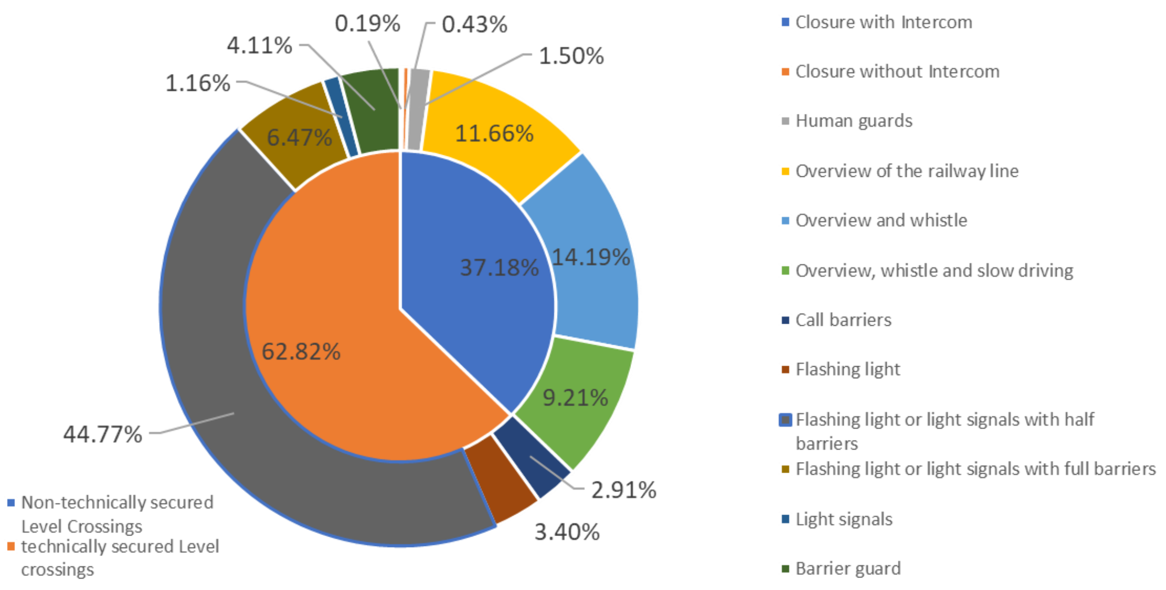


Figure 8: Number of Level crossings in Germany according to the type of protection [2]

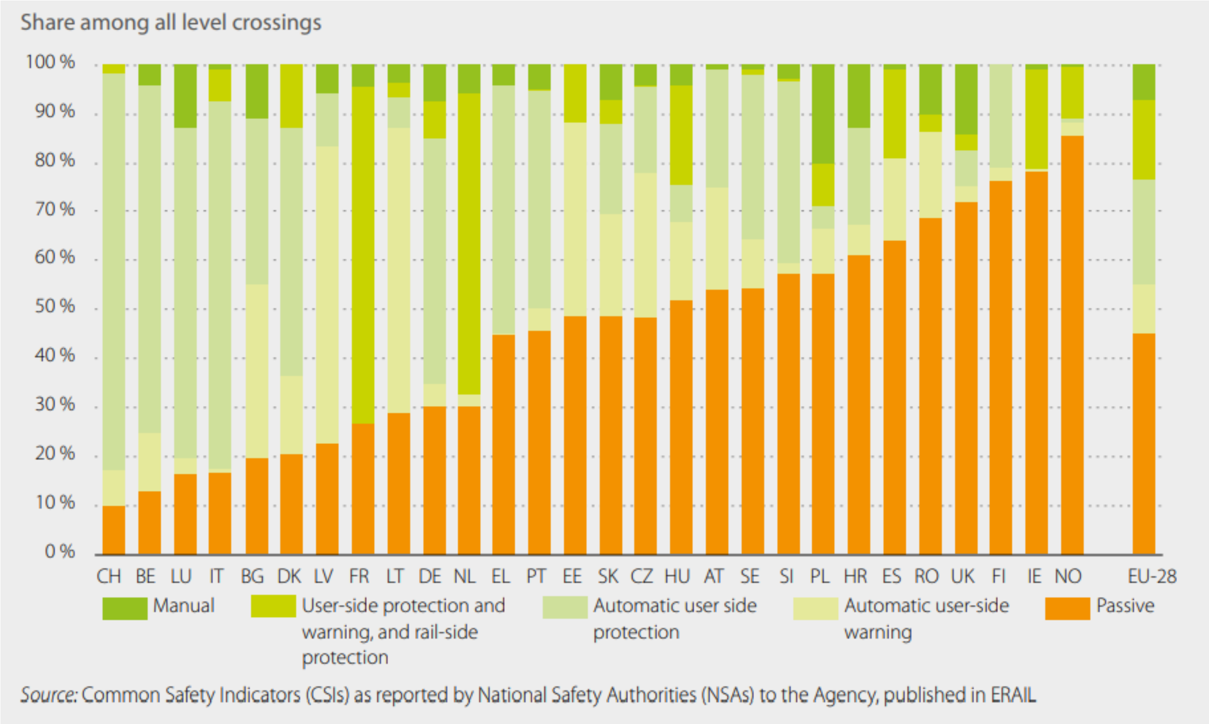


Figure 9: Level crossings per type of protection for EU countries (2018) [7]

Table 2 demonstrates the traffic signs regulated in Germany for road users to warn against the approach towards a level crossing according to StVO. The minimum requirements for the selection of type of security according to EBO and Ril 815 are described in a flowchart (Figure 10).

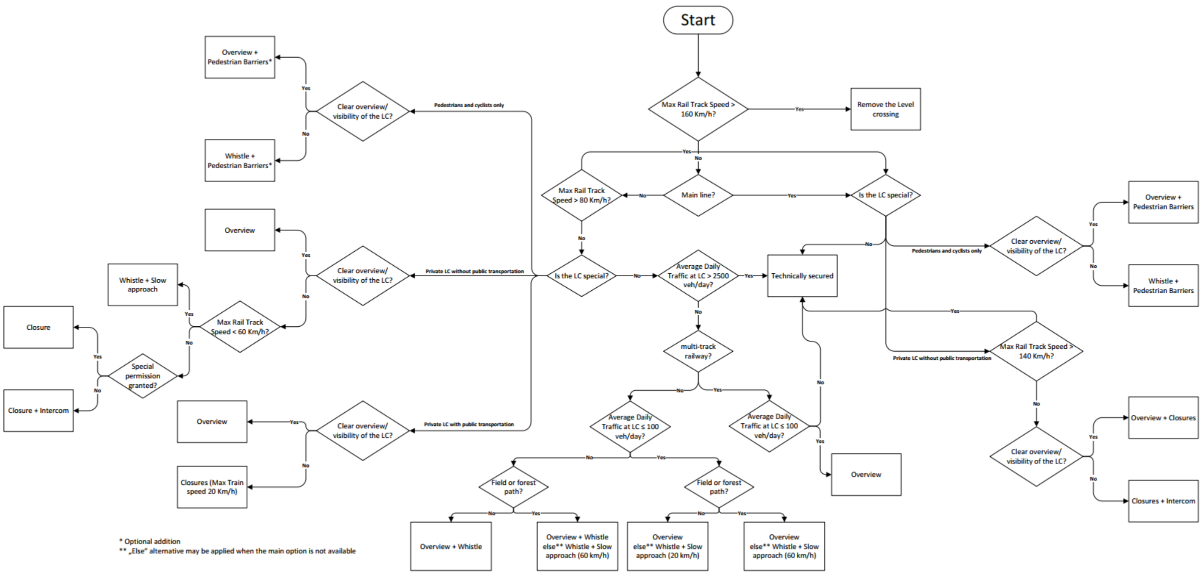


Figure 10. minimum requirements for the selection of type of security at LC

Table 2: Level crossing signs according to StVO

Sign Nr.	Sign	Location before level crossing	Description
Sign 150		240m	Level crossing with full or half barriers. The sign is outdated and no longer included in the traffic sign catalogue of StVO. However, the sign still exists in some locations.
Sign 151		240m	This sign is used to announce a Level crossing without barriers previously. Now, it is used for all types of level crossings.
Sign 156		240m	The sign with three red stripes indicates the distance to the level crossing (240m). Sign 151 is installed above.
Sign 159		160m	The sign with two red stripes indicates the distance to the level crossing (160m).
Sign 162		80m	The sign with one red stripe indicates the distance to the level crossing (80m).
Sign 201	 	At level crossing	St. Andrew´s Cross: This sign is usually directly in front of the crossing. It means that vehicle drivers must give the priority to rail traffic. An arrow in the middle of the St. Andrew´s Cross indicates the railroad has an overhead contact line.

§19 of StVO states that road users should approach the level crossing at a moderate speed to manage stopping in time before the crossing if a train approaches. The term "moderate speed" is not precisely defined by StVO, but approach speed is usually announced before the LC itself. road users are obliged to approach the LC with caution and pay attention to the sounds and signals that indicate the approach of a train. There is no STOP obligation at passive crossings, but road users are asked to approach the crossing with moderate speed, pay attention to the surroundings and wait in case the crossing was not free.

Violations of those rules are punished by the catalogue of fines BKatV with fines up to 700€, penalty points, and driving bans up to 3 months. Violations at level crossings are some of the worst that road users can commit due to the catastrophic consequences that they may cause and therefore the penalties are consequently very high. Table 3 lists the penalties for level crossing violations according to German traffic laws.

Table 3: Penalties of LC violations in Germany [11]

Violation	Fine	Points*	Driving ban
Disallowed overtaking	70 €		
Dangerous overtaking	85 €		
Overtaking leading to property damage	105 €		
Not giving priority to rail traffic at LC with St. Andrew´s Cross	80 €	1	
Not giving priority to rail traffic at LC with St. Andrew´s Cross causing danger	100 €	1	
Not giving priority to rail traffic at LC with St. Andrew´s Cross causing property damage	120 €	1	
Approaching the LC at high speed	100 €	1	
Violating the waiting obligation	80 €	1	
Violating the waiting obligation causing danger	100 €	1	
Violating the waiting obligation causing property damage	120 €	1	
Crossing despite red flashing light or yellow or red-light signals	240 €	2	1 month
Crossing despite red flashing light or yellow or red-light signals causing danger	290 €	2	1 month
Crossing despite red flashing light or yellow or red-light signals causing property damage	350 €	2	1 month
Crossing despite lowered barriers, stop command from a railway employee or an audible signal such as the train whistle	240 €	2	1 month
Crossing despite lowered barriers, stop command from a railway employee or an audible signal such as the train whistle causing danger	290 €	2	1 month
Crossing despite lowered barriers, stop command from a railway employee or an audible signal such as the train whistle causing property damage	350 €	2	1 month
Crossing despite closed Full or Half barriers	700 €	2	3 months
Crossing despite closed Full or Half barriers for non-motorized road users	350 €		

*Source: [12]

In the US, crossings are classified based on the consistency of message delivery to road users. This means that crossings are divided into two main groups; either "passive" crossings that are equipped with traffic control devices that send a constant message all the time such as pavement markings, signs, and crossbucks or "active" crossings that are equipped with traffic control devices that send variable messages to the road users depending on whether a train is nearing or not. The most common active devices used in the USA to secure active level crossings are gates, flashing lights, signals, wigwags, and bells [13]. Australia adopts a similar classification system to the US by splitting the level crossings into "passive" and "active". Only a third of all Australian level crossings are active and equipped with flashing red lights, boom gates, warning bells, or a combination of those [14].

In Europe, ERA has developed in 2004 a common European level crossing classification that divides crossings to active and passive crossing. Passive crossings can be described simply as crossings equipped with traffic signs only. Active crossings were then split to Automatic and manually operated protection systems. Level crossings in both categories are then further classified according to the traffic control method they imply such as roadside protection (barriers, gates) or roadside warning (optical, acoustic, physical), or a combination of both [15].

In the UK, level crossings are classified into three main categories [16]:

1) Railway-controlled: secured by a railway signaller or a crossing-keeper. They can be either controlled manually at site or remotely using CCTV.

2) Automatic: No railway staff is needed to control the opening and closure of the crossing. Most British automatic level crossings are equipped with half barriers as full barriers are avoided to give a chance for vehicles trapped in the crossing to leave.

3) Passive crossings: make the majority of British crossings and depend on the driver´s own behavior for security. Telephones are sometimes provided at passive crossings.

2.3 Accident statistics at Level Crossings in Germany

During the period between 2011-2020, an average of 160 accidents per year occurred at the German level crossings. Figure 11 demonstrates a comparison between the accident numbers between 2011-2020 [2]. It can be noticed that a drastic reduction in the number of accidents in 2020 was achieved compared to the previous years. The reason for this reduction could be the traffic limitations and lockdown that was imposed in the country since March 2020 as a result of the COVID-19 pandemic.

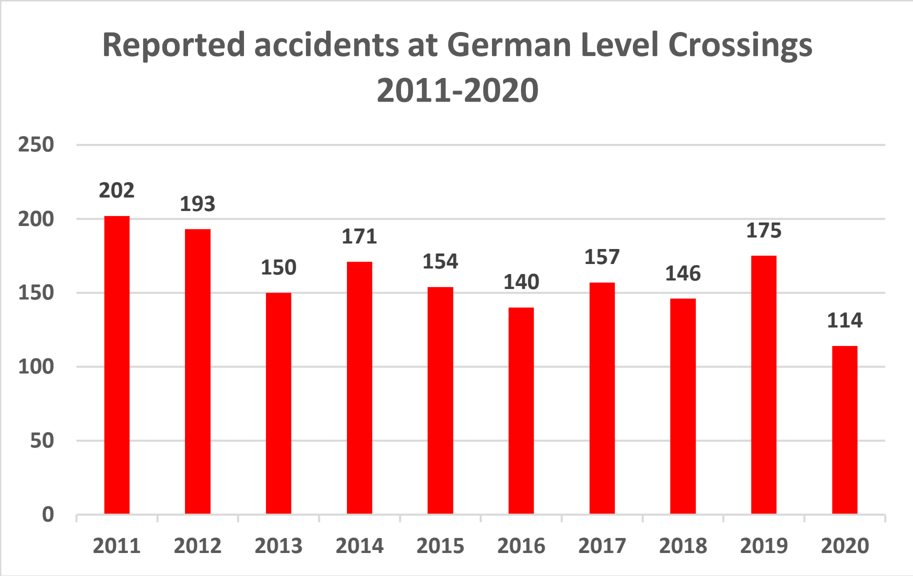


Figure 11. Reported accidents at German Level Crossings 2011-2020 [2]

Taking off the outlier year 2020, it can be observed from the slight decrease in the trend line that the number of accidents and number of level crossings are directly proportional. This proves that further removal of crossings from the network can lead to an improvement in overall safety. The numbers of accidents per 1000 crossings are presented in figure 12.

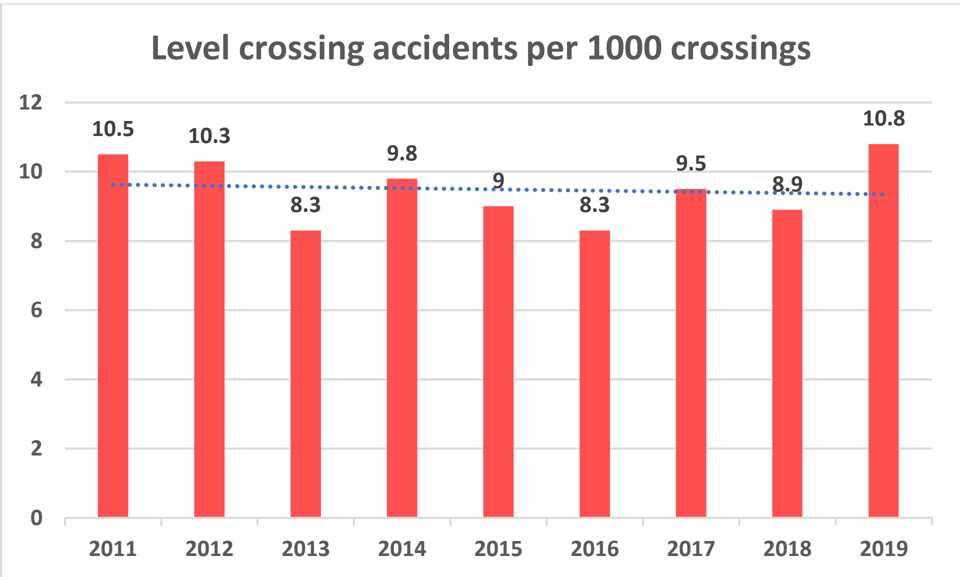


Figure 12: Level crossing accidents per 1000 crossings 2011-2020 [2]

If observed from the side of road traffic, level crossings are responsible for a very small percentage of 0.002% of the total accidents on roads and 1.12% of the road accident fatalities in 2019. On the other side, level crossings accounted for 18.46% of the overall rail accidents and 25% of all the fatalities in rail accidents in 2019 with the exception of suicides. Figure 13 show accident data for severe injuries and fatalities on German level crossings for the time period between 2010-2020 [2].

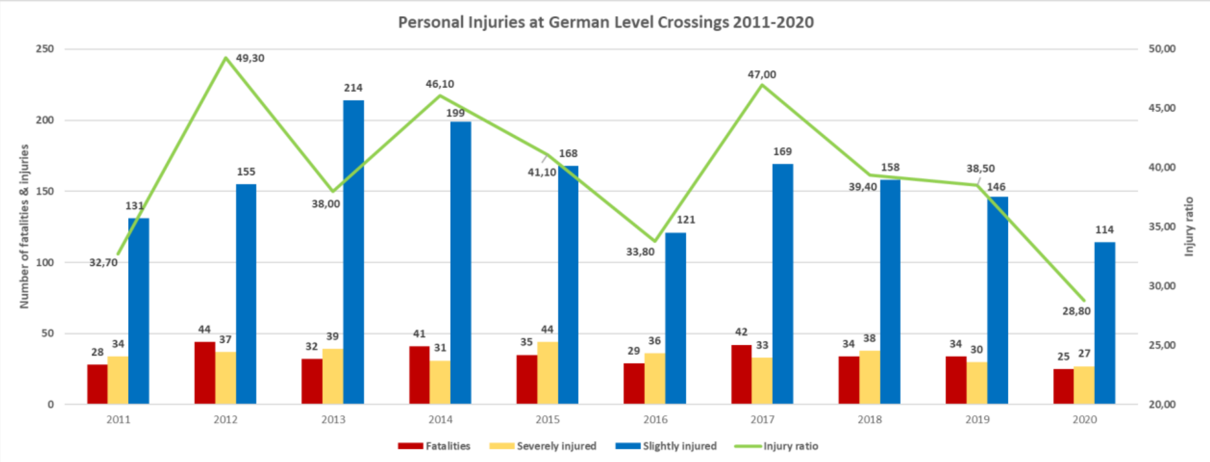
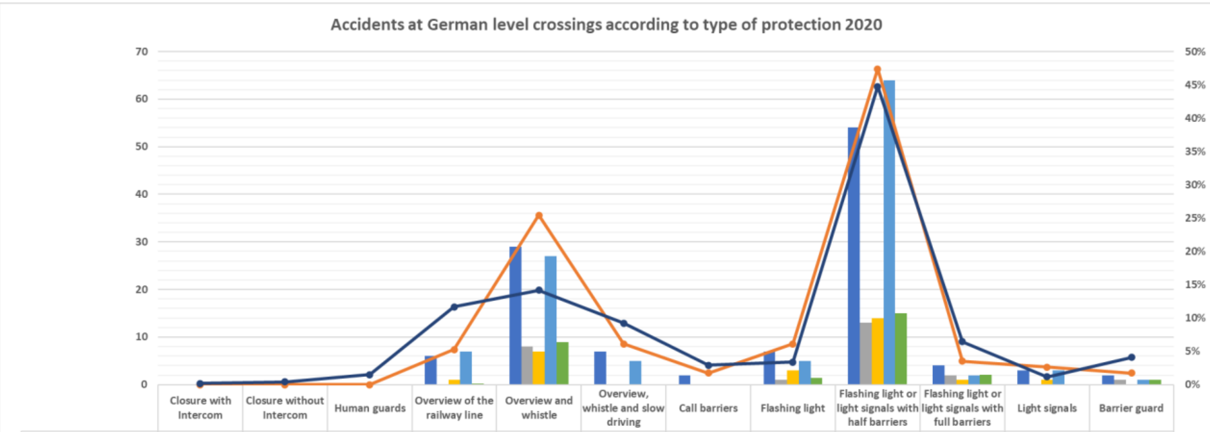


Figure 13: Personal injuries as a result of accidents at German Level Crossings 2011-2020 [2]

Deutsche Bahn suggests identifying the collective injury risk from accidents using an injury ratio that combines fatalities, Severe injuries, and slight injuries in the following form:

Injury ratio = 1 x Fatalities + 0.1 x Severe injuries + 0.01 x Slight injuries *(Eq. 1)*

In order to understand how well the different types of protection are performing, it is important to observe the accident data and draw comparisons. Figure 14 shows the number of accidents and resulting injuries at each type of security in 2020.



	Closure with Intercom	Closure without Intercom	Human guards	Overview of the railway line	Overview and whistle	Overview, whistle and slow driving	Call barriers	Flashing light	Flashing light or light signals with half barriers	Flashing light or light signals with full barriers	Light signals	Barrier guard
Number of accidents	0	0	0	6	29	7	2	7	54	4	3	2
Fatalities	0	0	0	0	8	0	0	1	13	2	0	1
Severly Injured	0	0	0	1	7	0	0	3	14	1	1	0
Slightly Injured	0	0	0	7	27	5	0	5	64	2	3	1
Injury ratio	0.00	0.00	0.00	0.17	8.97	0.05	0.00	1.35	15.04	2.12	0.13	1.01
% of accidents	0.00%	0.00%	0.00%	5.26%	25.44%	6.14%	1.75%	6.14%	47.37%	3.51%	2.63%	1.75%
% of level crossings	0.19%	0.43%	1.50%	11.66%	14.19%	9.21%	2.91%	3.40%	44.77%	6.47%	1.16%	4.11%

Figure 14: Accidents at German level crossings according to type of protection 2020 [2]

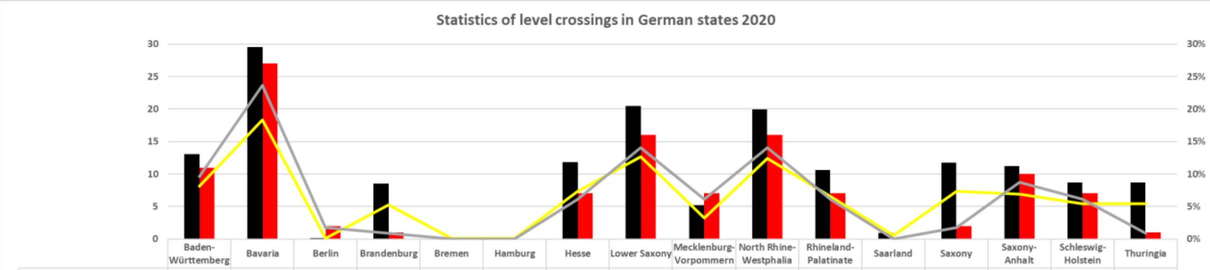
Non-technically secured crossings have a share of 36.84% in comparison to 63.16% to the technically secured. The percentages closely resemble the percentages of each security type to the overall number of crossings. The highest number of accidents occur at half barriers crossings which is not surprising considering that they make up around 45% of all the level crossings in Germany.

However, by diving into the details of the statistics and comparing every type of percentage of accidents to its percentage of existence, it is found that crossings secured by overview and whistle, flashing light, and light signals are performing worse than the others. The exceptionally high fatalities numbers and rate of accidents for overview and whistle call for an urgent upgrade to crossings equipped with this type of protection.

Nevertheless, Accidents on all technically secured crossings are rarely caused due to technical failures as reported by DB. Only 1.75% of all accidents that occurred in 2020 were a result of a technical failure while the vast majority of 97,37% happened because of misconduct from road users. DB employees were only responsible for 0,88% of all accidents [2].

Almost half of all level crossing accidents in Germany happen between a train and a personal car. The second highest percentage of involved road users are the bicycle drivers with 19%. Pedestrians and Truck drivers each make up another 9,5% of the chart. Pedestrians reasonably hold the least chances of survival in an accident as 64% of pedestrians involved in accidents pass away. The percentage is luckily lower for bicycle drivers and personal car users with 27% and 19% respectively [2].

As can be seen in Figure 15, the states with the highest number of accidents in 2020 are Bavaria, Lower Saxony, and North Rhine-Westphalia. But these statistics are not out of the ordinary considering that these states hold the highest number of German level crossings with 2951, 2044, and 1998 consecutively. However, these three states still have a higher accident percentage than their LC percentage. Particularly in Bavaria, Mecklenburg-Vorpommern, Saxony-Anhalt, and Berlin, the situation needs to be improved. On the other hand, the accident rates in Brandenburg, Saxony, and Thuringia are remarkably better.



	Baden-Württemberg	Bavaria	Berlin	Brandenburg	Bremen	Hamburg	Hesse	Lower Saxony	Mecklenburg-Vorpommern	North Rhine-Westphalia	Rhineland-Palatinate	Saarland	Saxony	Saxony-Anhalt	Schleswig-Holstein	Thuringia
Number of Level Crossings (in hundreds)	13.05	29.51	0.18	8.51	0.22	0.18	11.82	20.44	5.19	19.98	10.63	0.93	11.79	11.19	8.68	8.68
Number of accidents	11	27	2	1	0	0	7	16	7	16	7	0	2	10	7	1
% of Level Crossings	8.11%	18.33%	0.11%	5.29%	0.14%	0.11%	7.34%	12.70%	3.22%	12.41%	6.60%	0.58%	7.32%	6.95%	5.39%	5.39%
% of accidents	9.65%	23.68%	1.75%	0.88%	0.00%	0.00%	6.14%	14.04%	6.14%	14.04%	6.14%	0.00%	1.75%	8.77%	6.14%	0.88%

Figure 15: Statistics of level crossings in German states 2020 [2]

In terms of maximum speeds allowed on German level crossings, Slow speeds dominate the majority of German level crossings as 43% of crossings in Germany are located on a track section with a maximum train speed less than 60 Km/h. the highest number of crossings (4749 crossings) are located on track sections with a speed ranging between 41-60 Km/h. High speeds (100-160 Km/h) make about a quarter of all crossings [2].

In comparison, the European Union suffers from 6 fatalities and 6 serious injuries every week as reported by the European Union Agency for Railways making an approximate total of 300 casualties yearly. The agency also reports that level crossings are responsible for more than 25% of all railway accidents on EU railways. Nevertheless, the safety situation is improving annually as the agency records an annual average reduction of 3% in accidents and 4% in fatalities over the period 2010-18 [7]. Figures 16 and 17 demonstrate level crossing accidents data in the European Union and a comparison of significant accidents between the member countries.

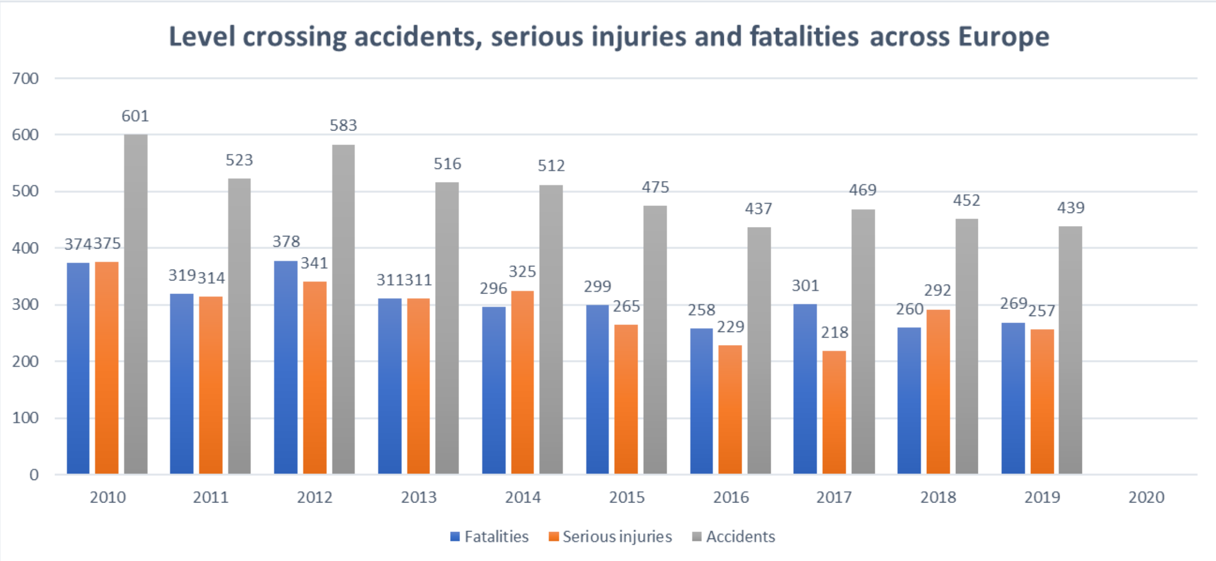


Figure 16. Level crossing accidents, serious injuries, and fatalities in the European Union (2010-2020) [7]

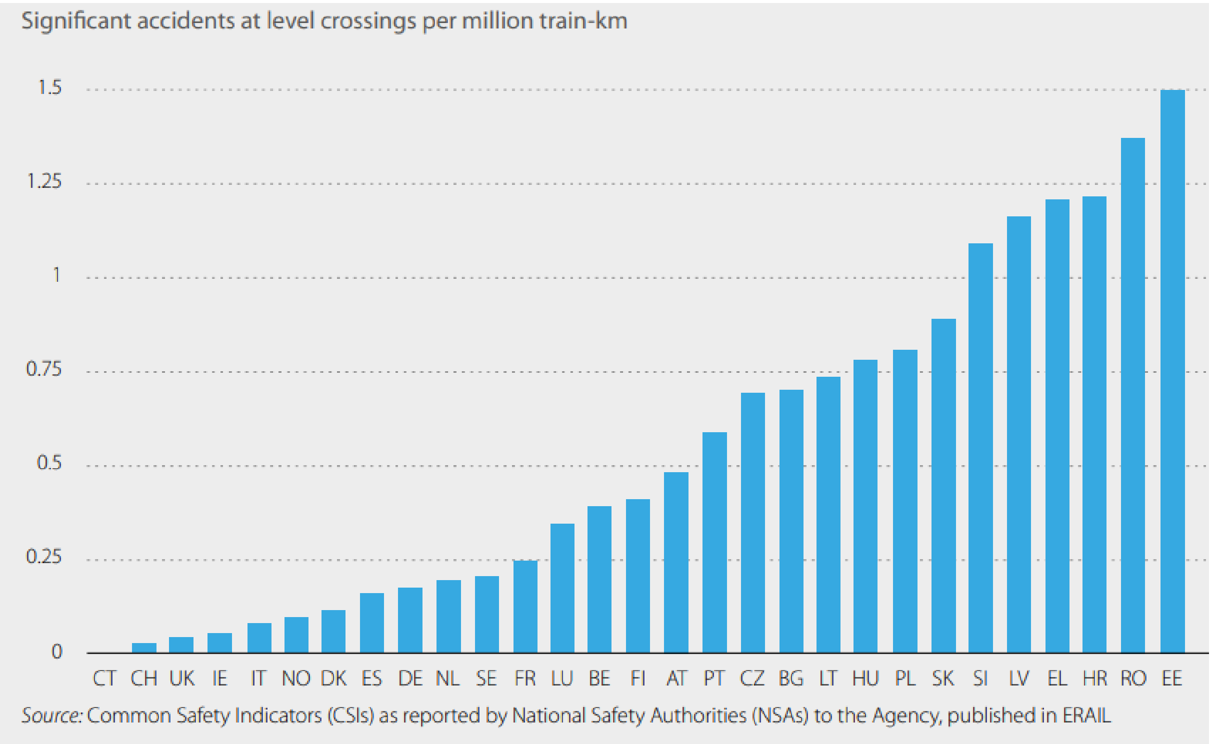


Figure 17. Level crossing accident rates per country (2016-2018) [7]

According to the European Union Agency for Railways, the improvement rate of level crossing safety levels is not matching the improvements in other railway accident categories. The reason is the slower rate of improvements in road safety compared to rail safety which is negatively impacting the level crossing safety [7].

2.4 Economical losses of level crossing accidents

In addition to the losses in lives and the emotional and psychological impacts that affect the families of LC accidents victims, collisions extend to have a negative economic impact too.

The German Federal Railway Authority (EBA) reported a total amount of 450 Mio € in accident costs for all Railway accidents for 2020 in which Level Crossing accidents contribute a significant amount. The highest damage cost was naturally the so-called societal losses that are due to fatalities and severe injuries. Societal losses form about 89% of the overall damage cost. Therefore, the damage costs are mainly proportional to the numbers of fatalities and severe injuries. Additionally, the property and environmental damages contribute to about 10% of the damage costs while costs that are a result of delays are calculated to be approximately 1% of the overall damage costs. Figure 18 compares the damage costs of railway accidents in the last years [4, 17-21].

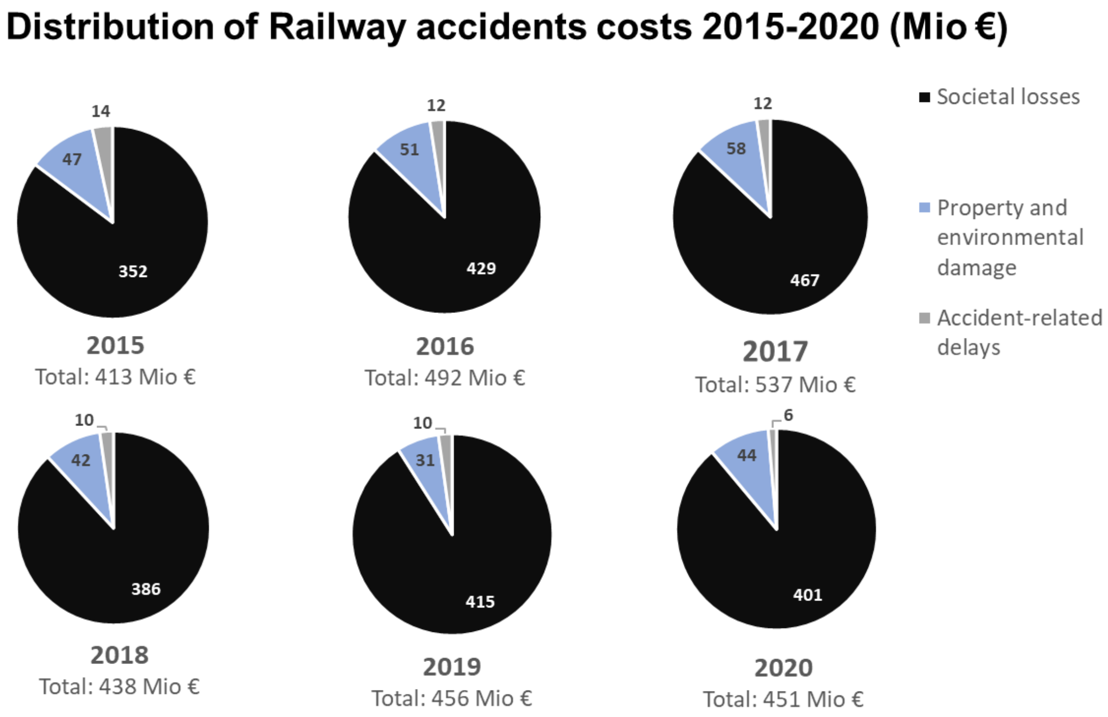


Figure 18. Distribution of Railway accidents costs 2015-2020 (Mio €) [4, 17-21]

The German Federal Railway Authority (EBA) estimated the average fatality damage cost rate at level crossings to be 1,098,341 €/person through data obtained by the Federal Highway Research Institute (BASt) based on the assumption that damage costs of casualties in rail traffic are equivalent to those in road traffic. Table 4 shows the calculated average accidents damage cost rates for the different types of injuries [22].

Table 4. Average accident damage costs [22]

	Average accident cost rate		Average accident cost per level crossing	
Type of injury	**Unit**	**Value**	**Unit**	**Value**
Property damages	€/accident	236,389	€/year	2,090
Fatalities	€/person	1,098,341	€/year	2,163
Severe injuries	€/person	114,527	€/year	239
Slight injuries	€/person	4,650	€/year	47

Different values for accident costs could be obtained from several sources depending on the number of costs considered in the calculation. Tables 5 and 6 demonstrate a comparison between the different available values.

Table 5. Accident costs according to [23] and [24]

Source	Type of casualty	2011	2012	2013	2014	2015	2016	2017	2018	2019
ERA Common Safety Indicators data (Erail, 2021)	Fatality	2,036,848	2,114,620	2,180,716	2,312,034	2,404,947	2,492,357	2,598,845	2,685,010	2,735,007
	Serious injury	281,308	292,049	301,178	319,314	332,146	344,218	358,925	370,826	377,731
BASt (BASt, 2021)	Fatality	1,177,980	1,161,892	1,182,126	1,191,397	1,191,937	1,164,328	1,150,234	1,121,888	1,146,989
	Serious injury	112,834	116,151	121,776	120,921	123,510	123,964	116,335	112,570	116,701

Table 6. Accident costs according to [25]

	Human costs			Production loss			Medical costs			Administrative costs			Total		
Country	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury
Germany	3,067,253	503,575	38,737	383,018	25,497	1,560	2,885	8,883	765	2,023	1,391	598	3,455,179	539,346	41,66
EU 28	2,907,921	464,844	35,757	361,358	24,055	1,472	2,722	8,380	721	1,909	1,312	564	3,273,910	498,591	38,51

Figure 19 shows a comparison between the accident costs for fatalities and serious injuries calculated based on the values provided by [23], [24], and [25] for the years 2011-2019. The average value of the total accidents cost per year is 97.68 Mio. €, 45.95 Mio. € and 143.04 Mio € respectively. The percentages of serious injuries costs to the fatality costs amount to 13.87%, 10.23%, and 15.71% respectively. By taking accidents cost values in relative to significant accidents numbers, it is found that every significant accident costs 1.56 Mio. €, 0.73 Mio. € and 2.28 Mio € respectively.

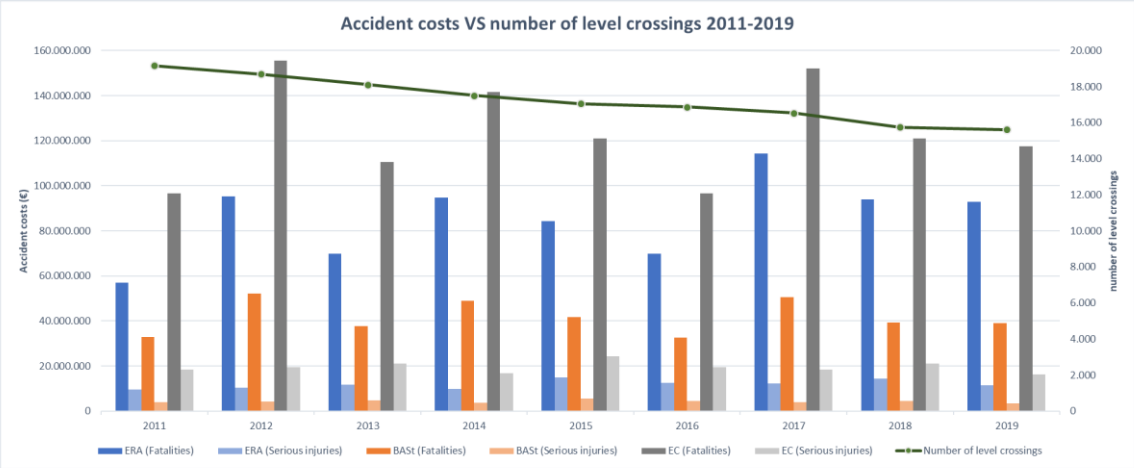


Figure 19. Accident costs VS number of level crossings (2011-2019)

By comparing the Accident costs against the decrease in number of level crossings, there is no clear correlation observed.

The total cost of railway accidents in 2018 in Europe as estimated by the European Union Agency for Railways was 3.8 billion € of which almost 1 billion € were a result of level crossing accidents [7].

The range of values of accidents costs varies between the European countries based on which types of losses are included in the calculations. For example, Latvia, Slovenia, and Spain do not include costs to society (medical treatment, legal and court costs, emergency services, net production loss) in the calculation. Also, Hungary does not take the personal loss for casualties into consideration while Italy and Portugal exclude the material damages from the calculations.

Table 7 demonstrates a comparison between the European countries in terms of valuation of safety based on the findings of the HEATCO project (Developing **H**armonised **E**uropean **A**pproaches for **T**ransport **C**osting and Project Assessment) that was concerned with developing a European guideline for the assessment of projects and transport costing.

Table 7. A comparison of safety valuation across EU countries - Cost per fatality [26]

Country	Year	Unit	Value	Conversion to Euro *
Denmark	2001	DKK	8,223,000	1,106,121
Finland	2000	Euro	1,934,161	
France	2000	Euro	1,500,000	
Germany	1998	Euro	1,176,000	
Netherlands	1998	Euro	1,500,000	
Sweden	2001	SEK	17,511,000	1,711,000
Switzerland	1995	CHF	3,330,700	3,193,890
United Kingdom	2002	GBP	1,249,890	1,471,292
Czech Republic		CZK	9,606,000	377,194
Hungary	2002	HUF	98,000,000	269,988
Italy	1998	Euro	465,000	
Portugal	2004	Euro	320,000	

* Currency conversion according to the current market prices

2.5 German level crossing standards and regulations

At the moment, there is no uniform set of standards and regulations in Germany that combines all traffic systems altogether. However, the design specifications of level crossings are distributed across various standards that are specialized in either rail or road traffic systems [27].

The following regulations regulate the planning and operation of German level crossings:

- **Railway Crossing Act** (German: Eisenbahnkreuzungsgesetz “EKrG“)
- **Rail construction and operation manuals**
  - Railway construction and operating regulations (German: Eisenbahn-Bau- und Betriebsordnung “EBO“)
  - Ordinance on the construction and operation of connecting industrial branch railways (German: Verordnung über den Bau und Betrieb von Anschlussbahnen “BOA/EBOA”)
- **Road Traffic Regulations**
  - Road Traffic Regulation (German: Staßenverkehrsordnung “StVO“)
  - General Administrative Regulation on road traffic regulations (German: Allgemeine Verwaltungsvorschrift zur Straßenverkehrs-Ordnung “VwV-StVO“)
- **Rail Regulations**
  - DB Guideline 815 “Planning and Maintaining Level Crossings” (German: DB-Richtlinie 815 “Bahnübergänge planen und instand halten”)
  - Level Crossing Regulations for Non-Federal Railways (German: Bahnübergangsvorschrift für nichtbundeseigene Eisenbahnen “BÜV-NE”)

EKrG (1963): The Railway Crossing act *Eisenbahnkreuzungsgesetz* (EKrG) is the German federal law that regulates the construction and financing of level crossings. It also determines the responsibilities of the various governmental entities and the distribution of costs for crossing projects.

EKrG which came into force in 1964 banned the building of any new level crossings with the exception of a few individual cases. §2 EKrG states that new intersections of railways and roads shall be constructed as overpasses. In individual cases, particularly in the case of low traffic, it is possible to allow exceptions with the right to order which safety measures to be implemented at the intersection [28].

§2 EKrG

(1) New intersections of railroads and roads which, by the nature of their carriageway, are suitable and intended to accommodate general motor vehicle traffic shall be constructed as Overpasses.

(2) In individual cases, especially in the case of low traffic, the issuing authority may permit exceptions. In such cases, the safety measures to be taken at the intersection can be ordered.

(3) An intersection within the meaning of paragraph (1) is new if one of the two traffic routes or both traffic routes are newly constructed.

The regulations of EKrG were based to serve the goal of gradual elimination of all level crossings (especially the ones with high traffic) over the years. The overall aim of introducing these regulations was not to serve as a remedy for a specific deficit in the level crossings but rather as a general improvement to the traffic conditions in the service of the public interest [29].

The exceptions may be allowed based on a case-by-case basis. The §2 of EKrG does not define specific cases of when the exception could be issued but only stresses the necessity of having low traffic on both traffic systems. The definition of "low Traffic" is stated in the §11 paragraph (13) of EBO as a maximum of daily traffic of 100 vehicles per day [1]. If, for example, it was proven that traffic is low for both traffic systems in a specified region taking into account the foreseeable development of traffic, an exception would likely be permitted. Also, huge financial burdens that might result from the construction of overpasses on the project initiator could be a valid reason for granting an exception.

The Federal Ministry of Transport and Digital Infrastructure (BMVI) is responsible for issuing the exceptions in the case of federal railways.

In the case of roads that do not serve motor vehicles (e.g. footpaths and cycle paths), it is permitted, although undesirable, to build new level crossings without applying for an exception as the prohibition in §2 paragraph (1) is exclusive for roads that are "intended to accommodate general motor vehicle traffic" [29].

EBO (1951): These are the regulations that organize all that is related to railways such as facilities, railway vehicles, operations, workers, and safety requirements.

Article §11 of the EBO is the article that focuses on level crossings and regulates security measures to be applied to them. This article contains details about using St. Andrew´s cross, conditions of selecting the type of security at level crossings, and closures.

The most notable aspects of EBO are defining the maximum speed of rail vehicles at lines that contain level crossings at 160 Km/h, giving priority to rail vehicles over road users at level crossings, and defining the type of security at crossings through the factors of traffic volume, max train speed, and visibility.

BOA (1966): BOA serves the same purpose as EBO but for connecting industrial branch railways.

StVO (2013): StVO is the German traffic law that involves regulations for all road users on public roads. §19 of the law is the section that deals with level crossings and set the rules for road users´ behavior at them. StVO also states that rail vehicles have priority at level crossings. In addition, it gives directions for LC approach and crossing behavior, overtaking rules at LC and, traffic signs. Rules in StVO concern all road users including cyclists and pedestrians.

A study of §19 of StVO concluded that there are no gaps or ambiguities in the German traffic law StVO that might lead to risks at level crossings, but rather violations of road users are the main sources of risk and concluded that altering these sets of regulations would likely not improve the current safety situation [30].

VwV-StVO (2001): They are the general administrative regulations that guide the road traffic authorities to implement and design traffic facilities in accordance with StVO regulations. It also organizes the work of authorities in regard to accident investigations, reporting, evaluation, and remedy measures. A notable rule in VwV-StVO is obliging road traffic authorities, police, railway companies, and public transport companies to conduct a traffic inspection every two years at every level crossing to confirm that the safety conditions are being maintained.

DB-Richtlinie 815: Ril 815 is the set of technical regulations for planning and maintaining level crossings for federally-owned railways in Germany and are prepared by DB Netz AG. This guideline is the manifestation of the state of the art for level crossing security technology and is continuously updated to remain in correspondence with the latest developments in LC technologies.

The Federal Railway Authority (EBA) recognizes DB-Richtlinie 815 as the set of technical regulations to be implemented in all federally owned railways in Germany. The standard focuses mainly on the design of safety systems at LC (BÜSA), planning of technically and non-technically secured level crossings, pavement conditions, Level Crossing Control Systems (BÜSTRA), Control and Safety Technology (LST), selection of types of LC monitoring, measures to be taken after LC accidents and maintenance of level crossings

BÜV-NE (2001): it is the guideline for the planning and execution of non-federal railways´ level crossings. It basically serves the same purpose as DB-Richtlinie 815 but for all non-federal rail lines.

3 Level Crossing Consolidation

3.1 Consolidation key issues

3.1.1 Increase in travel distances

The elimination of a level crossing could in many cases lead to an increase in travel distances for the surrounding communities which can be a reason for inconvenience and therefore objection to the consolidation of the crossing. The criteria of increased travel time and distance between both sides of the crossing can be major for the consolidation decision.

3.1.2 Emergency response delay

One of the worst potential outcomes for the consolidation of a level crossing is the negative impact it could have on response time for emergency services. Special attention should be paid to crossings that are located close to hospitals, medical emergency centers, civil defense, etc.

3.1.3 Access to nearby facilities

For both major cities and small towns residents, the ability to reach nearby important everyday necessary facilities is important. Those facilities include schools, business centers, or markets. In rural areas, farms are also considered. The more facilities affected by the level crossing closure and the more travel distance and time increases, the more negative influence it could have on the closure decision.

3.1.4 Community resistance

It is usual that the responsible authorities face resistance from the public after announcing a consolidation plan due to some of the removal disadvantages such as delays and increased travel distances. It is recommended to include the public in the decision-making process and to organize public awareness campaigns to convince them of the importance of closure by demonstrating the benefits resulting from the closure and the threat that this crossing poses on the community.

3.1.5 Funding

Funding remains the greatest challenge in front of Transportation authorities and traffic planners all around the world. Authorities are often required to allocate their resources wisely.

3.1.6 Lack of laws

Authorities are also challenged with the lack of clear laws that stimulate and organize consolidation efforts.

3.2 Elimination options

3.2.1 Closure

There is currently no defined set of laws to regulate the closure decision anywhere in the world. Every country and each state picks the closure candidates as well as the methodology of prioritization freely. However, the Highway-Rail Crossing Handbook suggests the following criteria for the DOT in all states when considering candidates for closure [31]:

- AADT < 1000
- Alternate access within 1 mile
- Increase in trip distance by not more than 2.5 miles

Authorities sometimes avoid the option of level crossing closure because of the multiple challenges it creates. The main problem resulting from closure is the increase in travel times for users and difficulties of access to some regions which often leads to community protests. Moreover, closure sometimes does not eliminate the accident risk but shifts the collision risk points to other areas. More studies regarding the impacts of closure on nearby intersections and level crossings are required to better understand the limitations of this alternative.

3.2.2 Grade separation

This is considered the safest, most efficient, and most popular option to eliminate all risks resulting from a level crossing existence without negatively impacting the traffic network. However, the high costs of construction overpasses or underpasses make this option undesirable for authorities sometimes.

The Highway-Rail Crossing Handbook recommends considering Grade Separation when one or more of the following conditions exist [31]:

Table 8: Grade Separation Conditions [31]

Criteria	Highway speed	AADT	Max train speed	Train Volume per day	Number of passenger trains per day	Number of transit trains per day	Number of freight trains x AADT	Number of passenger trains x AADT	Number of Transit trains x AADT	Expected accident frequency for active devices with gates	Vehicle delay (vehicle hours per day)
Urban	≥ 55 mph	> 30,000	> 79 mph	≥ 30	≥ 75	≥ 150	> 900,000	> 2,250,000	> 4,500,000	> 0.5	> 30
Rural	≥ 55 mph	> 20,000	> 79 mph	≥ 30	≥ 30	≥ 60	> 600,000	> 600,000	> 1,200,000	> 0.5	> 30

3.2.3 Banning road traffic

The Highway-Rail Crossing Handbook recommends banning road users from using the level crossing as remedial measure for locations with the following description [31]:

- In or adjacent to rail yards and locations near industrial spur tracks where trains pick up or set out blocks of cars or switch local industries
- Passing tracks primarily used for holding trains while waiting to meet or be passed by other trains

- Locations where train crews are routinely required to stop for crew changes or for cross traffic on intersecting rail lines
- In the proximity of stations where trains dwell for extended periods of time and block the crossing

3.2.4 Relocation or closing the rail line

Relocating the rail line can improve the overall traffic situation and eliminate multiple level crossings at the same time. Relocating rail lines to areas further from residential communities increases the safety condition at the areas where the track used to be located and can also contribute to a better quality of life as noise and pollution levels improve in addition to more freedom of movement for residents and faster response rates from emergency services. Additionally, relocating the rail line can give more space for urban communities to expand. However, this is considered a very complicated and expensive solution as complete tracks, safety devices and buildings will be needed to get demolished and then rebuilt again at the new location.

3.3 Consolidation Alternatives

The end goal of consolidation is to achieve better safety conditions in the transportation network and to minimize risk for all road and rail users. Any solution that contributes to this goal can be a good alternative to consolidation, particularly when there is insufficient funding. In some cases, applying one alternative is not enough to reduce the risk and a combination of alternatives is needed to improve safety.

Nelson argues that the solution to improve safety at level crossings is the correct application of the five E approach (Enabling, Education, Engineering, Enforcement, and Evaluation). Enabling consists of creating better cooperation and communication frameworks between road and rail authorities along with allocating enough funding for closure projects. Engineering entails the design of safe level crossing geometrically and applying the right safety systems that ensure the maximum safety level possible. It also consists of utilizing technology in improving safety conditions at level crossings. Education involves creating national programs to raise awareness for all road users of the correct ways of using level crossings and the most common risky behaviors. Enforcement aims to achieve safety and ensure compliance with level crossing laws through strict punishments for reckless behavior. Enforcement can also include the process of setting the best legal regulations that achieves the best safety situation. And finally, through continuous evaluation, authorities can determine the riskiest level crossings and apply short- or long-term solutions to minimize danger [32].

3.3.1 Upgrading protection systems and warning devices

One of the best alternatives to full consolidation is the upgrade of the implemented protection system since protection systems have the highest controlled influence on safety at level crossings.

Studies that investigated the safety improvements resulting from upgrading the protection systems are discussed in detail in chapter 5.5.3.

Sometimes upgrading the protection system used to a more modern version of the same system or renewing the light signals or traffic signs can increase safety.

3.3.2 Awareness campaigns

Awareness campaigns fall into the education part of Nelson´s 5 E approach and aim to spread knowledge amongst the general public and particularly targeting heavy level crossing users and vulnerable users. The campaign would mostly aim to educate users about the correct way to use level crossings and teach the rules and regulations regarding that.

Awareness programs can take many forms and utilize all media platforms to convey the messages. Vulnerable users like school children, senior and disabled citizens could be targeted as well by visits to schools, retirement homes, and disabled care centers. In addition to the traditional media like newspapers, magazines, posters, radio, and

TV, awareness campaigns can employ social media platforms to reach a wider and younger audience.

An example of a very successful awareness campaign is “Operation Lifesaver” which started in the United States in 1972 before it became international as Argentina, Canada, Estonia, South Africa, and Mexico joined. Operation Lifesaver offers free rail safety education programs to school students, community audiences, commercial drivers, law enforcement officers, and emergency responders by certified and trained instructors. Studies have shown that the number of crashes and fatalities in a state are reduced by 15% and 19% respectively once Operation Lifesaver is implemented in the state [33].

Internationally, the International Union of Railways (UIC) started an initiative with the support of railway organizations globally under the name of “The International Level Crossing Awareness Day (ILCAD)”. The initiative involves 57 participating countries including Germany as of 2022. The United States hosted the 2022 ILCAD campaign in June 2022.

In Germany, an awareness campaign was initiated in 2002 under the name “*Geblickt? Sicher drüber!”* (Look – Cross Safely) as a joint action between the Employers’ Liability Insurance Association (VBG), Federal and Railway Accident Insurance (UVB) The German Railway company (DB), German Automobile Club (ADAC) and Federal Police. The campaign involved spreading videos, brochures, and posters that contain information on the correct behavior at level crossings or catchy phrases to get the attention of young users. Moreover, the campaign was part of many events and an infotruck was driving on the roads to advertise the campaign. Figure 20 shows some of the campaign attempts to raise awareness.

Figure 20: Geblickt? Sicher drüber! campaign [34]

3.3.3 Regulations improvements and law enforcement

Improving national laws and regulations of level crossings can be a solution to improve the safety situation. The main pillar of any improvements is scientific research so countries are advised to invest in traffic safety research and be flexible with adjusting the laws to improve overall safety.

It is important also to ensure the enforcement of those laws and create punishment systems that fit the severity and potential risk that the crime or reckless behavior imposes on the public.

Technology such as camera and video monitoring of the level crossing can help law enforcement authorities enforce the regulations. In some prioritization models, the existence of monitoring technology is considered one of the factors for prioritization.

Carroll and Warren studied the effect of applying a photo enforcement system at US level crossings. The system captures a photo of the driver´s face and license number once a violation is committed. The results of the investigation show that photo enforcement successfully reduced drivers and pedestrians violations by 36-92% with a decrease in the number of accidents by 70%. The results led to a conclusion that using photo enforcement can be a cost-effective method to modify risky driver behavior especially when it is accompanied by community education [35].

The presence of law enforcement officers is arguably the most effective way to eliminate risky human behavior at level crossings. This was proven by Barić et al when they measured the effect of the presence of police officer against the presence of a monitoring camera on the behavior of cyclists and pedestrians at a level crossing in Zagreb, Croatia. Results showed that violations were almost completely eliminated when the police officer was watching as the percentage of users who committed violations while crossing dropped from an average of 41.7% to 0.8% only. In comparison, the camera reduced the percentage of violators to 24.7% [36].

However, allocating a police officer to stand at every level crossing is naturally not a viable option because of the shortage in manpower in the police forces in comparison to the very high number of level crossings in addition to it being a financially unfeasible option. Nevertheless, it can be a good short-term solution for level crossings that witness abnormal road user violations.

Penalties for violating level crossing rules in Germany are presented in Table 3 in section 2.2.

3.4 Incentive programs

In order to overcome the safety and financial challenges that level crossings present in the German and European railways, there is a need for consolidation programs to be planned. Many countries have already gone a long way in creating level crossing consolidation models that are suitable for the local road and rail conditions. For example, In the United States of America the federal government was aware of the necessity to pressure the states into improving the safety conditions of highway-rail intersections following several fatal rail accidents between 2002 and 2008. Therefore, the congress has passed the Rail Safety Improvement Act of 2008 (RSIA) which, among other things, directed the 10 states with the highest number of railway-highway accidents to develop their own State Grade Crossing Safety Action Plan (SAP) under supervision from The Federal Railroad Administration (FRA). As a result, Alabama, California, Florida, Georgia, Illinois, Indiana, Iowa, Louisiana, Ohio, and Texas developed and implemented Safety Action Plans (SAPs) which aimed to find specific solutions to improve the safety conditions at level crossings with a focus on the crossings that experienced high accidents rate. The solutions naturally included level crossing closures and grade separations [37]. To assist the consolidation process, many US States launched several incentive programs. It is reported that at least 22 states have some form of incentive programs for level crossing consolidation [38]. The existing incentive programs in the US include:

- Cash Incentive programs
- Nearby Crossing Improvement programs
- Nearby Crossing Grade Separation programs
- Road Improvement programs
- Track Relocation programs

The applicability of the incentive programs stands as one of the biggest barriers in the face of level crossing consolidation efforts. Minimum effort has been made to study and evaluate the effectiveness of each incentive program. Based on survey results distributed by The Louisiana Transportation Research Center to 292 railroad company and DOT experts all over the US, it was found that current incentive programs suffer from being either very costly or from lack of efficiency [39].

In Germany, the federal ministry of transport and digital infrastructure provides a yearly financial support for level crossing consolidation projects that amounts to 75 million euros per year [40].

4 International consolidation models review

Studying the work done internationally is crucial to learn from the many experiences and build upon them. However, it must be comprehended that every country has unique conditions and therefore such differences must be accounted for. A model applied in one country does not necessarily perform as well in another country. A clear example is the application of the Australian Level Crossing Assessment Model (ALCAM) in New Zealand. The model did not perform as well as in Australia and special modifications needed to be introduced to match the conditions in New Zealand despite the similarities between the two countries. Therefore, developing any model for risk assessment in any country is recommended to be based on specific data and specifications of the country itself. For countries with huge areas and big differences between their regions, it is wise to adopt a different model for each region or state.

4.1 Basics of models

4.1.1 Risk

Risk is the combination of the frequency of occurrence of an accident and the consequence of such accidents. This means that risk can be measured by calculating the probability of a certain accident to happen and the extent of damage that this accident causes. Figure 21 shows a standard risk matrix.

		Consequence				
		Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	5 Almost certain	Moderate 5	High 10	Extreme 15	Extreme 20	Extreme 25
	4 Likely	Moderate 4	High 8	High 12	Extreme 16	Extreme 20
	3 Possible	Low 3	Moderate 6	High 9	High 12	Extreme 15
	2 Unlikely	Low 2	Moderate 4	Moderate 6	High 8	High 10
	1 Rare	Low 1	Low 2	Low 3	Moderate 4	Moderate 5

Figure 21: A standard risk matrix [41].

The steps to perform a risk assessment include three major stages. The first is risk identification. The second stage is the risk analysis which covers analyzing the consequences, likelihood, and existing protection measures of the identified hazards.

Finally, the last stage is the risk evaluation in which various identified and analyzed risks are compared and decisions are taken based on tolerability and priorities [41].

4.1.2 Accident and Hazard prediction models

Accident and hazard prediction models form the core of level crossing prioritization tools and are used to develop the level crossing rating formulas. The main difference between accident prediction models and hazard prediction models is that the accident prediction model forecasts a number of accidents over a time period while the hazard prediction model evaluates how prone the crossing is to accidents based on certain characteristics [42].

4.1.3 Models by type of algorithm

Researchers at Arthur D. Little in a research conducted on behalf of the British Rail Safety and Standards Board (RSSB) inspected the use of risk models internationally to compare it with the British model ALCRM in terms of build-up and implemented criteria in order to suggest improvements to the British model. As a result of the inspection, the report suggested classifying the international models and approaches based on the type of algorithm used into four types [43]:

A) **Parameter Gate:** simple approaches that utilize simple parameters for decision-making and selecting the protection systems at level crossings. The chosen parameters indicate their high significance from the point of view of responsible authorities. The most chosen parameter in most parameter gate approaches is traffic exposure. The researchers at Arthur D. Little argue that this kind of approaches cannot be considered as a ´model´ because of the absence of risk prediction. Parameter gate is used in many countries for the prioritization of level crossings or the selection of protection type such as the Train Vehicle Unit approach in India, Level Crossing Danger Index in Japan, and Rail and Road Intensity Matrix in Russia.

B) **Simple Weighted Factor:** approaches that utilize factors with simple weighting methodology for each factor. The weight of factors indicates the significance of this factor in contributing to risk at the level crossing. ALCAM is considered the most popular example of models that employ Simple Weighted Factor methodology.

C) **Complex Weighted Factor:** Approaches that utilize factors with weights derived using complex methodologies. Risk assessment techniques that can be considered as complex methodologies include fault trees and event trees. Such models often take into consideration the relationship between factors and therefore produce more accurate predictions. Additionally, some of the complex models do not only consider quantitative values for accidents but a complete accident story including causing factors. The most popular example of models that employ the Complex Weighted Factor methodology is ALCRM.

D) Statistically Driven Approach: Approaches that build the weights of factors based on accident statistics and accident history of each crossing. Most models developed in North America take the Statistically Driven Approach. Models based on statistically driven algorithms are popular in countries that have a large number of level crossings and constantly updated databases that include a big number of factors to enable driving statistical relationships.

The RSSB investigation is the last comprehensive investigation for international approaches for the assessment of risk and prioritization of level crossings. The investigation identified 23 approaches implemented in 13 countries worldwide. However, since the investigation dates back to 2007, there have been many changes and updates to the prioritization tools and approaches globally. Table 9 demonstrates the approaches investigated in the RSSB report [43].

Table 9: International models and type of algorithms implemented [43]

Country	Approach	Type of algorithm	Risk prediction
USA	USDOT Accident Prediction Formula	Statistically Driven Approach	Accidents frequency only
	GradeDec.Net	Statistically Driven Approach	Accidents frequency and consequences + other consequences (non-safety related)
Canada	Collision Prediction Model	Statistically Driven Approach	Accidents frequency only
	GradeX	Statistically Driven Approach	Accidents frequency and consequences + other consequences (non-safety related)
Australia	Risk Based Scoring System (RBSS)	Simple Weighted Factor	Frequency and consequences
	Australian Level Crossing Assessment Model (ALCAM)	Simple Weighted Factor *Update: since 2007 the model was updated to include Complex Weighted Factor and Statistically Driven Approach algorithms*	Frequency and consequences
	RAAILc	Statistically Driven Approach	Accidents frequency only
New Zealand	Product Assessment	Simple Weighted Factor	Accidents frequency only
	Accident Prediction Model	Statistically Driven Approach	Accidents frequency only
Great Britain	Automatic Level Crossings Model	Complex Weighted Factor	Accidents frequency and consequences
	All Level Crossings Risk Model (ALCRM)	Complex Weighted Factor	Accidents frequency and consequences + other consequences (non-safety related)

	Event Window Model	Complex Weighted Factor	Accidents frequency and consequences
	COBA Junction Model	Statistically Driven Approach	Accidents frequency and consequences
Ireland	Network Risk Model	Complex Weighted Factor	Accidents frequency and consequences + other consequences (non-safety related)
	Level Crossing Prioritisation Tool	Complex Weighted Factor	Accidents frequency and consequences
Northern Ireland	Risk Assessment and Investment Appraisal	Simple Weighted Factor	Accidents frequency and consequences
Spain	Crossing categorising criteria	Parameter Gate	No risk prediction
	FMEA method	Complex Weighted Factor	Accidents frequency and consequences
Sweden	Factors to determine crossing protection	Parameter Gate	No risk prediction
Russia	Rail and Road Intensity Matrix	Parameter Gate	No risk prediction
India	Train Vehicle Unit	Parameter Gate	No risk prediction
Japan	Closed Road Traffic Indicator	Parameter Gate	No risk prediction
	Level Crossing Danger Index	Parameter Gate	No risk prediction

The risk assessment and prioritization models in all investigated countries except for Australia and New Zealand had no major alterations since the completion of the report in 2007. In Australia, ALCAM have been updated in 2008 to a complex weighting factor model. The weights of factors of ALCAM were upgraded again in 2012 before the new ALCAM that is based on a combination of complex weighting factor and statistically driven algorithms was released in 2014 [44]. The new ALCAM is still implemented in Australia to this day. ALCAM was also adopted in New Zealand in 2007 before it was decided to create an altered version of ALCAM to overcome the shortcomings resulting from differences between Australia and New Zealand. The new model was named ´the Level Crossing Safety Impact Assessment (LCSIA)´ and was implemented for the first time in 2016 [45]. ALCAM and LCSIA in addition to older risk assessment models in Australia and New Zealand are presented in detail in chapter 4.3.

4.1.4 Factors Influencing safety at level crossings

Factors that influence the number of accidents and level of hazard at level crossings can be generally divided into operational characteristics, Physical characteristics, vehicle and train characteristics, Spatial characteristics, temporal characteristics, environmental characteristics, and driver behavior factors [46].

A lot of work was performed internationally to study the correlations between certain factors and accident numbers. Naturally, it is very important to consider that the results and significance of factors vary between different countries and regions due to the nature of laws and driver behavior in addition to differences in the essence of the factors themselves. For example, the types of protection used are not the same in all countries, and such differences by having extra or fewer types should be naturally considered. Therefore, specific analysis of each region´s accident data is advised.

Singh et al analyzed accident data of 578 level crossings in Florida from 2010 to 2019 using Chi-square statistical test to select the highest statistically significant factors that led to those accidents and benefit from the results for prioritizing level crossing upgrades across Florida [46]. The factors included operational and physical characteristics, environmental and temporal characteristics, and characteristics related to driver actions. The chi-square test results showed that the following factors effectively impact the number of accidents:

Table 10: Analysis results of factors significance [46]

Factor	Influence on the number of accidents
Type of crossing (Public or private)	influential factor
Illumination	influential factor
Type of protection	influential factor
Whistle bans	influential factor
Crossing surface	influential factor
Road class	influential factor
Condition of the road	influential factor
Presence of highway monitoring devices	influential factor
Type of pavement markings	influential factor
Number of lanes	influential factor
Nearby intersections	influential factor
Presence of traffic signals at the nearby intersection	No influence
Area classification (Urban/Rural)	influential factor
Number of daytime through trains	influential factor
Number of nighttime through trains	influential factor
Number of switching trains	influential factor
Max train speed	influential factor
Number of main tracks	influential factor
Number of other tracks	influential factor
Type of train	influential factor
AADT	influential factor
percentage of trucks	influential factor
school buses	influential factor
Road vehicles speed	influential factor

* p-value ≤ 0.05: Low significance; p-value ≤ 0.01: Mid significance; p-value ≤ 0.001: High significance

Keramati et al. investigated 30-years of accident records at US level crossings and ranked the most influential factors on crashes based on a proposed mathematical model named as the competing risks model as follows [47]:

Table 11: Ranking of factors according to the competing risks model [47]

Rank	Factor
1	Type of train detection
2	Type of train service (Passenger, freight)
3	Existence of road pavement
4	Number of lanes
5	Daytime train volume
6	Availability of commercial power
7	Nighttime train volume
8	Trucks percentage
9	Total switching trains
10	Maximum train speed
11	Angle of intersection
12	Distance to closest intersection
13	Annual average daily traffic (AADT)

In light of those factors, it can be deduced that accidents at level crossings occur as a result of:

- Shortcomings in design or variation in operational characteristics of level crossing users over time; including rail and road users.
- Inadequate design or variation in physical characteristics of the crossing and its surrounding area over time such as a deterioration in its pavement quality or an increase in sight obstructions or decrease in illumination which limit visibility over time.
- Shortcomings in the design standards regarding the geometric requirements of the crossing
- Changes in local and national laws and regulations such as prohibition of train whistles
- Human error for all users
- Dereliction in level crossing inspection and maintenance
- Insufficient economical resources to perform upgrades or consolidation of hazardous level crossings
- Low public awareness of level crossings hazards and the correct driver behavior at them and the lack of enough state-organized awareness campaigns that employ seminars and training sessions to increase the public awareness
- Disagreements between the different authorities involved in level crossing projects regarding decision-making and resource allocation

Ril 815 divides hazard points at level crossings into concrete hazard which calls for immediate measures to be performed and normal hazard that requires elimination within a reasonable period of time. Hazard points identified by Ril 815 are:

- Inadequate pavement size or quality at LC and road: LC pavement insufficient in size or in bad condition, scratch marks at LC area and in the clearing sections

- Inadequate right-of-way rules that may cause a tailback and blockage of the LC: unsecured left-turn relationship, “right before left” right-of-way, missing “priority to incoming traffic” rule in case of insufficient width of road
- Inadequate geometric standards of the rail track and highway at the LC area: Curvature, insufficient width of road
- Changes in rail and road traffic volumes
- Missing safety devices and traffic signs (e.g. Whistle boards)
- Existence of other traffic components within the clearing section of LC: Roundabouts, bus stops, pedestrian crosswalks
- Inadequate visibility
- Inadequate speed restrictions for road users
- Inadequate illumination
- Inadequate approach times
- Failures in safety systems or lack of protection for all LC users: lack of dependency between traffic signals in the clearing section and the LC, lack of technical protection for pedestrians and cyclists

4.1.5 Human error in Level crossings

The factor of human error is involved in 94% of all collisions at level crossings in Germany [48]. Therefore, human behavior must be taken into consideration when safety measures are applied to determine the effectiveness of those measures. The high percentage of human error involvement in accidents obliges us to design the maximum number of our level crossings and equip them with safety measures that eliminate the highest possible percentage of human error for all users (drivers, pedestrians, and cyclists).

Studying the driver behavior and human errors is particularly important at passive level crossings where no security system is applied, and the safety of all users could depend particularly on how the road user behaves.

To study driver behavior, researchers often employ one or a combination of the following research methods:

a) Driving-simulation technology

b) On-field study

c) Mathematical models and artificial intelligence models

d) Surveys and questionnaires

Ngamdung and DaSilva found that 39.5 % of drivers do not look for the train when passing the level crossing by measuring the amount of head movement of the driver while only 29.7% of the drivers look for both directions and 30.8% look in one direction [49].

Brown et al analyzed accidents at passive rural level crossings and detected 9 issues related to human error, five of which were related to the decision-making of the driver. Figure 22 shows all the human factors identified by Brown et al [50].

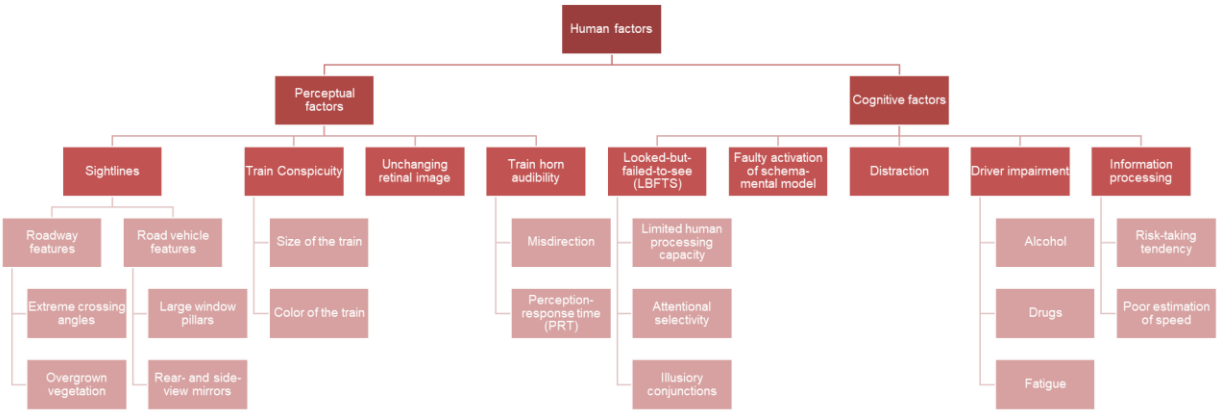


Figure 22. Issues related to human error at level crossings [50]

Some argue that the newly emerging intelligent transportation systems (ITS) that aim to limit human error could have a negative impact on drivers´ cognitive load by overwhelming the drivers. However, Larue et al studied three ITS systems that were considered to be implemented in Australia which are an in-vehicle visual ITS, an in-vehicle audio ITS, and an on-road valet system. The results showed no significant changes in cognitive load for the drivers as they approached the crossings [51].

There is clear evidence that driver behavior is connected to and affected by the type of security at the level crossing. Lenné et al. found that drivers were less compliant when driving at level crossings equipped with passive warning devices (stop sign) in comparison with level crossings equipped with active warning devices such as flashing lights and traffic signals [52].

Passive crossings are quickly becoming a growing safety threat in many countries due to the higher risk compared to active crossings. Kasalica et al. studied the driver behavior at passive crossings further and found a relation between visibility and risk of accidents. In the study that included 61 road vehicle drivers in a situation of an approaching train at a passively secured urban level crossing, it was found that drivers with limited visibility failed to estimate the speed of the approaching train which increased the likelihood of them taking more risky decisions that could lead to accidents. The results show that 57% of the drivers did not comply with the stop sign of whom 23% did not even slow down. The safety margin between the vehicle crossing the tracks and the train’s arrival ranged from 10 to 86 seconds, with a mean of 32.7 seconds. Such results prove that passive warning devices are not sufficient to ensure safety [53]. More worrying findings were found previously as stopping compliance at 9 passive level crossings was investigated and found that 79% of the drivers ignored the STOP sign [54].

Several other studies have revealed the significance of various demographic factors in forming the responses of drivers to different traffic devices such as age and gender of the driver. In a sample of 155 fatal accidents that occurred in Canada between 1993 and 2001, it was found that male drivers had the highest frequency of deadly accidents with 49% compared to 17.4% for females. Additionally, more traffic violations are committed by male than female drivers as males committed 64% of all violations and had the majority in each violation severity category [55]. However, male drivers show a better reaction to situations that require deceleration at intersections overall than female drivers, but female drivers performed better at high-crash intersections. Moreover, female drivers tend to brake more suddenly when unforeseen situations are presented which could expose female drivers to greater risk for accidents at intersections. As for age differences, the middle age group (35-55 years old) are more compliant with stop and yield signs than younger and older drivers in addition to a tendency to enter intersections with significantly less brake pedal differential time [56, 57].

Mohseni et al studied the data from all level crossing accidents that occurred in the United States between 2004 and 2013 to find if certain factors contribute differently to injury severities between male and female drivers. Results show that generally female drivers have a higher chance of getting involved in a more severe accident than male drivers. Additionally, the study linked weather and the presence of an audio warning system to crash severity of male drivers. Meanwhile, female drivers were more affected by the angle of intersection between the highway and railway, pavement condition, and the presence of crossbucks. Train speed, driver age, vehicle speed, and light condition were found to be common factors between both genders [58].

In addition to the driver demographics (gender and age), environmental factors like weather and time of day play a role as well in changing the driver behavior. For example, drivers from both genders tend to perform worse while driving at night. Also, female drivers perform worse while driving under rain but better when it is snowing. The snow condition has a negative impact in general with the consideration of the influence of traffic control devices [59]. Furthermore, accidents that occur in foggy conditions were found to cause more severe injuries than in clear weather conditions. The age group that is affected the most from by foggy conditions are the older drivers due to their slow reaction times [60].

4.2 North America

Due to the huge size of the country and the major differences between states, there are no unified set of rules to organize the consolidation decision throughout the United States. Each state has the freedom to pick the closure candidates as well as the methodology of prioritization. Around 34 national models were identified to be applied in the United States.

However, most of the state models are alterations of 6 main formulas. These formulas were developed between 1941 and 1986. The USDOT Accident Prediction Formula is considered the most widely used and most comprehensive of all developed formulas in USA. The main formulas that form the basis of all state formulas in addition to the web-based tool `GradeDec.Net´ developed by FRA are discussed in this section.

4.2.1 US Hazard and Accident prediction formulas

4.2.1.1 Peabody Dimmick Formula (1941)

The Peabody Dimmick Formula is considered one of the first models developed for the purpose of prioritization of level crossings in the US. It was developed by L.E. Peabody and T.B. Dimmick of the U.S. Bureau of Public Roads in 1941 based on accident data collected from 3563 rural crossings across 29 states. A modified version of this formula is still used only in the state of Georgia.

The formula is very basic and considers only three variables that are the Annual Average Daily Traffic (V), Average Daily Train Traffic (T), and type of traffic control device (P) as a coefficient.

$$A_5 = 1.28\ \frac{(V^{0.170}\ T^{0.151})}{P^{0.171}} + K \qquad \textit{(Eq. 2)}$$

The fact that the Peabody Dimmick Formula was based on rural crossings only is considered as one of its greatest shortcomings beside its very old age that leaves the considered control devices outdated.

4.2.1.2 National Cooperative Highway Research Program (NCHRP) Hazard Index (1964)

The NCHRP index was introduced after a joint effort between the American associations of highways and railroads in 1964 as a response to a surge in level crossing accidents. [42]

The NCHRP index as opposed to the Hampshire Index depends on factors that are based on the same criteria of Average Daily Traffic and type of traffic control device. But the Average Daily Train Traffic is not factorized. Additionally, the NCHRP index takes the urban/rural classification into consideration.

$$EA = A\ x\ B\ x\ CTD \qquad \textit{(Eq. 3)}$$

Where:
EA = expected accident frequency
A = Factor based on highway vehicles/day
B = Factor based on the type of protection and urban/rural classification
CTD = Current Trains per Day

4.2.1.3 New Hampshire Index (1971)

The New Hampshire Index is also a very simple accident prediction model that was introduced in 1971 to act as an improved version of the Peabody Dimmick Formula. The basic version of this formula keeps the same factors used in the Peabody Dimmick Formula with a slight change for the protection device factor as it only considers a protection factor for 3 types of protection systems, Gates (0.1), Flashing lights (0.6) and Passive (1). However, several states introduced their own modified versions of the New Hampshire Index that involved more factors which will be discussed later.

$$HI = V \ x \ T \ x \ PF \qquad \textit{(Eq. 4)}$$

A survey performed by Bowman showed that 5 of the 6 states that depend on the New Hampshire index as the main accident prediction model were generally satisfied with its performance [61]. However, many states have updated the New Hampshire Index by adding several more factors to develop their own formulas.

4.2.1.4 Coleman-Stewart Model (1976)

The Coleman-Stewart model was developed by Janet Coleman and Gerald R. Stewart from the Federal Highway Administration in 1976 based on accident data collected from 45 states. The main criteria adopted in the model are area classification (urban/rural), number of tracks, protection device, and both traffic volumes.

$$\log_{10} A = B_0 + B_1 (\log_{10} C) + B_2(\log_{10} T) + B_3(\log_{10} T)^2 \qquad \textit{(Eq. 5)}$$

Where:
A = Average number of crashes per crossing-year
C = Average daily traffic volume
T = Average daily train volume
B0, B1, B2, and B3 = coefficients of the accident prediction equation.

4.2.1.5 United States Department of Transportation (USDOT) Accident Prediction Model (1982)

The USDOT model which was developed in 1982 is considered as the most comprehensive accident prediction model applied in the United States as it takes into calculation the widest set of factors related to a crossing. USDOT or a version of it is used in 11 states of the USA and is considered as the most popular US model currently. 82% of the states that use the USDOT reported a general satisfaction with its performance [61]. The produced ranking of USDOT is a result of three calculations.

The first calculation is designed to predict an initial expected number of crashes per year at a crossing and is based on several factors that reflect a certain important physical characteristic of the crossing through a set value or an equation. The foundation factors of the calculation are: Traffic control devices, highway traffic (AADT), Train traffic, number of main tracks, Time (day/night), existence of highway pavement, maximum train speed, street type, Area classification, and number of lanes.

$$a = K\ x\ EI\ x\ MT\ x\ DT\ x\ HP\ x\ MS\ x\ HT\ x\ HL \qquad \textit{(Eq. 6)}$$

Where:
a = initial predicted accidents per year
K = constant
EI = Factor of exposure Index
MT = Factor for number of main tracks
DT = factor for number of through trains per day during daylight
HP = factor for highway pavement
MS = factor for maximum train speed
HT = factor for highway type
HL = factor for number of highway lanes

The second calculation intends to include the accident history as a factor in predicting future accidents. The number of years for accidents records is important in the equation. The model considers any accident records older than 5 years to be irrelevant due to the developments that occur over time to every crossing in characteristics [13].

$$B = \frac{T_0}{T_0+T}(a) + \frac{T_0}{T_0+T}\left(\frac{N}{T}\right);\ \text{where}\ T_0 = \frac{1}{0.05+a} \qquad \textit{(Eq. 7)}$$

Where:
B = second predicted accidents per year
a = initial predicted accidents per year
N = Number of accidents
T = Number of Years of accident records

The third and final calculation is simply an adjustment to the resulting value (B) by multiplying it with a normalizing constant specific to each type of protection device.

In addition to estimating the number of accidents, the model includes another calculation to estimate the severity of accidents predicted at a level crossing. Separate equations to calculate the probability of accidents with fatalities and accidents with injuries were developed for the model. The probability equations for fatal accidents and injury accidents are demonstrated in eq. 8 and eq. 9 respectively.

$$P(\frac{FA}{A}) = \frac{1}{1 + 695\ x\ MS^{-1.074}\ x\ (TT+1)^{-0.1025}\ x\ (TT+1)^{0.1025}\ x\ e^{0.188UR}} \qquad \textit{(Eq. 8)}$$

$$P\left(\frac{IA}{A}\right) = \frac{1 - P(\frac{FA}{A})}{1 + 4.280\ x\ MS^{-0.2334}\ x\ e^{0.1176TK}\ x\ e^{0.1844UR}} \qquad \textit{(Eq. 9)}$$

Where:
MS = Maximum train speed in mph
TT = Number of through trains per day
UR = 1 for urban crossings and 0 for rural crossings
TK = Number of tracks

Austin and Carson criticized the USDOT formula in regard to the complexity of its three stages and claimed that the accuracy of the formula´s accident prediction declines over time which they addressed by suggesting a simplified negative binomial regression model [62]. These and other limitations of the model were later addressed with the creation of a new model [63].

Nevertheless, results of statistical analysis in 1986 showed that USDOT performance surpassed all other US models at that time based on the accident prediction capabilities and hazard estimation. It is no surprise that until today, 11 states of the US still use USDOT as the main accident prediction formula [64].

4.2.1.6 FRA New Model for Highway-Rail Grade Crossing Accident Prediction and Severity (2020)

USDOT developed a new accident prediction model in 2020 to improve the accuracy of predictions and to address the issues and limitation of the 1982 USDOT model. It is reported that the new model´s performance, that is based on Zero Inflated Negative Binomial (ZINB) regression along with the Empirical Bayes (EB) adjustment method, in terms of risk ranking, resource allocations and statistical significance assessment ability of variances is better compared to the old model [65].

Factors such as number of tracks, Track type (Main or side track), number of trains in daylight, road pavement, road type, number of lanes and train types were no longer included in the new model. In the other hand, the factor of crossing surface type was introduced to the new model.

The new model predicts first the number of crashes (Eq. 10) then adjusts the predicted value by calculating the probability that the crossing has a number of crashes >0 (Eq. 11 and 12). The predicted value is then adjusted to correct for “regression-to-mean” bias using Empirical Bayes (Eq. 13).

$$N_{CountPredicted} = e^{[-8.3592+(0.1902xAADTxT)-(0.2848xD_2)-(0.8577xD_3)+(0.3935xRU)+(0.1318xCS)+(0.6876xS)+(0.1063xAADT)]} \quad \textit{(Eq. 10)}$$

$$P_{InflatedZero} = \frac{Z}{1+Z}\text{; where } Z = e^{-1.1708-(1.0109xT)} \quad \textit{(Eq. 11)}$$

$$N_{Predicted} = N_{CountPredicted}\, x\, (1 - P_{InflatedZero}) \quad \textit{(Eq. 12)}$$

$$N_{Expected} = wxN_{Predicted} + (1-w)xN_{Observed}\text{ ;} \quad \textit{(Eq. 13)}$$

Where: $w = \frac{1}{1+\frac{V[N_{Predicted}]}{N_{Predicted}}}$; and

$$V[N_{Predicted}] = N_{Predicted}x\left[1 + \left(N_{CountPredicted}x\left(P_{InflatedZero} + \frac{1}{\theta}\right)\right)\right]$$

Where:

N = Number of accidents
T = Number of daily trains
D2 , D3 = factors for type of protection
RU = factor for area classification (Rural/Urban)
CS = Crossin surface factor
S = Train speed

4.2.1.7 Jaqua Formula

Jaqua Formula considers many more factors than the other US models to predict the number of accidents like type of train (n), number of trains (T), number of cars in the train (C), AADT (V), speed of train (S), intersection angle, approach grade, curvature of the highway, existence of entrances and exits to streets, number of blind quadrants, number of lanes, number of tracks, speed of vehicles and trains, and street intersections near a level crossing, Type of protection and area classification (urban/rural).

$$ACC5 = \frac{AxBxC}{1610} ; \quad \text{where } A = \sum_{i=1}^{n} T_i \left(\left(\frac{C_i x V}{3 x S_i} \right) + V \right) \qquad \textit{(Eq.14)}$$

4.2.2 US Prioritization models

4.2.2.1 GradeDec.NET

The Federal Railroad Administration (FRA) developed GradeDec.NET in 2014 as a web-based tool to support states and local authorities in prioritizing resource allocation for level crossing projects. The application employs a cost-benefit analysis to assess crossings for investment [66].

After inspection, 31 factors were found significant for GradeDec.NET which makes it the level crossing assessment tool with the highest number of criteria in the US. The model is designed to consider not just the existing traffic volumes of road and rail but also predict future volumes and take them into account for prioritization. The model focuses more on the traffic and operational factors of the crossing than the physical factors. GradeDec.NET is considered a comprehensive model since it also includes several economic and environmental factors for the cost-benefit calculation which is the core of the model. The costs of the project, costs of accidents, costs of delay, operating costs and environmental costs are all considered as significant in GradeDec.NET.

However, social factors were not implemented as the model only takes the savings from accidents as a monetized representation of the social benefits of consolidation. The prediction of both the number and severity of accidents in GradeDec.NET are based on the USDOT accident prediction model.

4.2.2.2 Florida Priority Index Formula

Pasha et al. examined several accident and hazard prediction models to recommend a model to be used for the level crossing consolidation in the state of Florida. The models were evaluated using the chi-square statistic approach, grouping method of crossings based on the actual accident data, and Spearman rank correlation coefficient approach [67].

4.2.2.3 CPUC Priority Index Formula

CPUC Priority Index Formula follows a point system where every criterion is designated a specific number of points and a priority index number is finally found through a formula. The formula of CPUC Priority Index can be found in Appendix A. Table 12 shows the points system that the index follows.

Table 12: Points system in CPUC Priority Index Formula

Main criteria	Sub criteria	Alternatives	Points
ADT			1 per vehicle
Train Volume			1 per train
Light Rail Train Volume			1 per train
Number of accidents			3 per accident
Cost			1 per 1000$
Special Conditions	Blocking delay		0-5
	Road vehicles speed limit (mph)	0-30	0
		31-35	1
		36-40	2
		41-45	3
		46-50	4
		≥51	5
	Train maximum speed (mph)	0-25	0
		26-35	1
		36-45	2
		46-55	3
		56-65	4
		66-75	5
		76-85	6
		≥86	7
	Sight distance		0-4
	Skewed crossing angle		0-2
	Number of main tracks		0-2
	Elevated surface profiles		0-4
	Parallel Road		0-1
	Traffic signal within 200 ft		0-1
	Entrance/exit within 100 ft		0-1
	Raised median		0-1

Main criteria	Sub criteria	Alternatives	Points
	Track curvature		0-1
	Passenger Train Volume	1-2	1
		3-5	2
		6-10	3
		11-20	4
		21-30	5
		31-40	6
		41-50	7
		51-60	8
		61-70	9
		>70	10
Other Factors	School buses		0-3
	Passenger buses		0-3
	Hazardous material trucks		0-3
	Community impact		0-10

4.2.2.4 Kern County Grade Separation Prioritization Report

Kern county follows a model that considers both quantitative and qualitative criteria to prioritize crossings for grade separation. The model assigns high priority for traffic delay compared to similar models. Additionally, it considers economical and community aspects such as feasibility and quite zone potential as well as future growth predictions for road and rail traffic. The criteria considered are road traffic volume, train volume, accidents in the last 10 years, Average vehicle delay, average queue length per lane, constructability (feasibility), Traffic growth, train growth, geometrics, vehicle speed, train speed, number of passenger trains, school bus routes, transit routes, emergency vehicles routes, quiet zone potential and high-speed rail. Table 13 demonstrates scoring points for some of the quantitative measures in the Kern County Grade Separation Prioritization model [68].

Table 13: Scoring system in Kern County Grade Separation Prioritization model [68]

ADT	Average daily trains	Accidents (10 years)	Average Vehicle Delay (sec/veh)	Average Queue Length Per Lane (ft.)	Points
0-2500	0-3	0	0-60	0-25	0
2501-5000	4-6	1	61-120	26-50	2
5001-7500	7-10	2	121-180	51-75	4
7501-10000	11-13	3	181-240	76-100	6
10001-15000	14-17	4	241-300	101-150	8
15001-20000	18-20	5	>300	>150	10
20001-25000	21-24	6	-	-	12
25001-30000	25-27	7	-	-	14
30001-35000	28-31	8	-	-	16
35001-40000	32-34	9	-	-	18
>40000	>34	>9	-	-	20

4.2.2.5 Grade Separation Priority Update Study for Alameda Corridor East (Riverside County)

This prioritization methodology was developed by InfraConsult LLC in 2012 to rank level crossings in Riverside County based on multiple criteria including safety, delay, emissions, noise, and nearby grade separations. The weighting of criteria was based on the judgement of a committee of experts. Table 14 demonstrates the weights of factors for the approach [69].

The approach considers the highest value from each range for every criterion. For example, If the APMV* value for a crossing was calculated as 0.16 but the LAPMV** calculated as 12 then the crossing receives 1250 points for the safety criterion. The model also considers both current and future delays.

The model gives higher priority to projects that have higher readiness and need less further work and preparation. The three project elements recognized for measuring the readiness of the project according to this model are:

- Whether or not environmental clearance is obtained
- Whether or not plans, specification and estimates is completed
- Whether or not right-of-way (ROW) acquisition is secured

The maximum scoring points from the main 8 criteria that any crossing can receive are 5000 points. However, there is a bonus criterion called “Isolated location” which measures the accessibility of the level crossing. Any crossing that is located in an isolated area where no alternative routes are available after consolidation or if the consolidation significantly increases the out of distance travel for users; the crossing receives an extra 250 points. Therefore, 5250 points are the maximum points any crossing can have. The crossing with the highest points has the highest priority for consolidation.

Table 14: Scoring system in Riverside County [69]

Criteria	Weight	Range 1	Range 2	Points
Safety	25%	APMV* > 0.2	LAPMV** > 10	1250
		0.15 < APMV* < 0.2	5 < LAPMV** < 10	1000
		0.10 < APMV* < 0.15	3 < LAPMV** < 5	750
		0.05 < APMV* < 0.1	1 < LAPMV** < 3	500
		0.001 < APMV* < 0.05	0 < LAPMV** < 1	250
		APMV* = 0	LAPMV** = 0	0
Existing Vehicle Delay	15%	> 30 vehicle hours/day	-	750
		20-30 vehicle hours/day	-	600
		15-19 vehicle hours/day	-	450
		10-14 vehicle hours/day	-	300
		5-9 vehicle hours/day	-	150
		<5 vehicle hours/day	-	0
Future Vehicle Delay (25 years)	15%	> 150 vehicle hours/day	-	750
		100-150 vehicle hours/day	-	600
		50-99 vehicle hours/day	-	450
		25-49 vehicle hours/day	-	300

Criteria	Weight	Range 1	Range 2	Points
		10-24 vehicle hours/day	-	150
		<10 vehicle hours/day	-	0
Emissions	10%	Emissions score (0-100) x 5	-	0-500
Residential Noise	10%	Noise score within 1600 ft (0-100) x 5	Noise score within 6400 ft (0-100) x 5	0-500
Nearest grade separation	10%	> 1.0 mile	-	500
		0.5 – 1.0 mile	-	300
		0.25 – 0.5 mile	-	100
		< 0.25 mile	-	0
Local Priority	10%	Local priority (1-25) x 20	-	20-500
Project Readiness	5%	All project elements completed	-	250
		2/3 project elements completed	-	166.67
		1/3 project elements completed	-	83.33
Bonus: Accessibility	-	-	-	250

*APMV: Accidents per million vehicles
**LAPMV: Local accidents per million vehicles (within 250 feet of Crossings)

4.2.2.6 Railroad Crossing Assessment Tool (RCAT)

RCAT is a multi-criteria evaluation tool that was developed in 2019 by a research team led by Olsson Associates to prioritize level crossings for grade separation projects within a specific rail corridor. RCAT is considered one of the most modern and comprehensive level crossing assessment tools in the US since it does not focus only entirely on the factor of safety in the ranking of crossings but also takes into consideration the economic, environmental and community livability factors and produce weighted score for every level crossing through a series of calculations. 22 factors were found to be significant in RCAT [70].

RCAT has four main pillars that all contribute toward the final overall score of the level crossing. Those pillars are the safety score, economic score, environmental score, and the community score. A total of 29 criteria were identified in RCAT during review.

Safety score: Angle of intersection, distance to closest intersection, number of tracks, Maximum timetable train speed, posted highway speed limit and Crossing surface are the main factors considered as significant and therefore used to produce the safety score. maximum train length and queue length were also identified as significant but were not included in the model because of unavailability of data.

The safety score in RCAT is only an adjustment of the USDOT accident prediction formula and is calculated for each type of protection as follows:

- **For level crossings with barriers:** RCAT safety score = USDOT accident prediction value + (0.017 x TS) + (0.017 x NHI) + (0.011 x CS)
- **For level crossings with flashing lights:** RCAT safety score = USDOT accident prediction value + (0.047 x TS) + (0.005 x HS) + (0.005 x CS)
- **For passive level crossings:** RCAT safety score = USDOT accident prediction value + (0.047 x TS) + (0.005 x CA) + (0.005 x CS)

Where:
TS = Maximum timetable train speed factor
NHI = Distance to nearby highway intersection factor
CS = Crossing surface factor
HS = posted highway speed limit factor
CA = Crossing angle factor

Table 15: factors of safety score in RCAT [70]

Variable	Categories	Factor	Variable	Categories	Factor
Maximum Timetable Train Speed (mph)	≤ 10	0.1	Crossing surface	Unconsolidated	1
	10-20	0.2		Timber	0.5
	20-30	0.3		Asphalt	0
	30-40	0.4		Rubber	-0.5
	40-50	0.5		Concrete	-1
	50-60	0.6	Posted highway speed limit (mph)	≤ 20	-2
	60-70	0.7		20-30	-1
	>70	0.8		30-40	0
Distance to nearby highway intersection	<75	1		40-50	1
	75-200	0.5		50-60	2
	200-500	-0.5	Crossing Angle	<60	-0.25
	>500	-1		≥60	0.5

Economic score: Includes quantitative and qualitative economic criteria such as operating costs for personal and commercial vehicles that results from wasted travel time and idling fuel costs. Also, the model considers factors like the economic impacts on the population surrounding the LC based on population density, economic losses to surrounding landowners, impact on land use, economic development opportunities and supply chain savings.

Some examples of the scoring of qualitative economic factors of RCAT are demonstrated in table 16.

Table 16: Example of qualitative economic factors scoring in RCAT [70]

Land use density	Impacts on land use	Supply chain savings	Score
Rural/Industrial	Industrial	Trucks%: < 5%	1
-	-	Trucks%: 6-10%	2
Suburban/Medium residential density	Suburban residential	Trucks%: 11-15%	3
-	-	Trucks%: 16-25%	4
Urban (City center, High population density)	Urban (City center, High population density)	Trucks%: >25%	5

Environmental score: RCAT takes into consideration a wide range of environmental factors. The scoring of the environmental score is set according to the number of environmental factors affected by the level crossing. In total, the model considers 15 environmental factors. For every three factors affected, the environmental score increases by 1 with 1 being the basic score.

The 15 considered environmental factors are:

1. Coastal management areas
2. Critical habitat for threatened and endangered species
3. Wetlands
4. Wild and scenic rivers
5. Air quality non-attainment areas
6. Superfund sites
7. Tribal lands
8. Federal or state-owned lands
9. Military installations
10. Historical properties
11. Parks and recreational areas
12. Low-income populations
13. Minority populations
14. Limited English-proficiency populations
15. Community severance

Community score: The community score in RCAT considers all the factors that contribute to the quality of life of all residents surrounding the level crossing. This may include their own safety in terms of risk of derailment and release of hazardous materials. Additionally, the time savings of nearby population and the response delays for emergency vehicles in the area.

Community livability factors and their scores are presented in table 17

Table 17: Community livability factors scoring in RCAT [70]

Variable	Categories	Score
Maximum Timetable Train Speed (mph)	≥ 10	2
	25-40	4
	40-60	6
	60-80	8
	>80	10
Posted highway speed limit (mph)	< 35	2
	35-40	4
	45-50	6
	55-60	8
	≥ 65	10
Large vehicle exposure (Trucks %)	< 5	2
	5-9	4
	10-14	6

Variable	Categories	Score
	15-19	8
	≥ 20	10
Presence of hazardous train cars	Yes	1
	No	0
Population density within 1/2 square mile of crossing	Low	1
	Medium	3
	High	5
Presence of Vulnerable populations within 1/2 square mile of crossing	Yes	1
	No	0
Presence of police station, fire station, or hospital within 1/2 mile of crossing	Yes	1
	No	0

4.2.3 Summary of US models

It is clear that the US models developed over the years since the first Peabody Dimmick Formula in 1941 and gradually increased in complexity to include more significant factors. The simplicity of the first models is appealing but at the same time makes them hardly applicable for highly complex modern traffic networks due to their shortcomings in terms of prediction precision and risk elimination capabilities. Additionally, the older models were rarely updated to involve the technology advances in protection systems.

Many attempts were made to improve and eliminate the shortcomings of existing US models. One of the significant suggested models was the negative binomial regression model by Austin and Carson [62]. After studying the accident data of 80962 US crossings, their result model adopted new criteria such as the crossing surface and pavement markings (stop lines) after spotting an increase in accident probability at paved crossings compared to gravel. The authors suggested that such criteria might not be independent as paved crossings are usually located where traffic volumes are higher. A remarkable finding was also that only nightly train volume influenced the accident frequency instead of the total train volume which gave special importance to the number of crossing vehicles at particular timings. Such finding can be further study to suggest partial level crossing closures to train traffic at certain times such as night train ban of the day as an alternative to full consolidation.

Qureshi et al evaluated 7 selected states models to improve the Missouri exposure index formula that was unchanged since 1970´s. The consultations of an expert panel resulted in the decision to combine the Kansas Hazard Rating Model with the original Missouri EI to create the modified Missouri EI [71].

A creative approach to the prioritization process of level crossings was developed by Arellano et al. and adopted by the North Carolina Department of Transportation (NCDOT). Instead of taking each crossing separately, the authors proposed a methodology that focuses on freight corridors. The suggested framework provides an advantage of considering and improving the overall system rather than specific crossings [72].

In this project, 65 US models were reviewed with a majority of them being currently applied national models within states in addition to 10 research models. The results of the inspection of models adopted nationally show that some factors were present abundantly such as AADT which was detected as a factor in almost all national models except the formulas of Detroit, Mississippi, and Alameda Corridor East. Similarly, the daily train volume factor was heavily present in almost all models except four. In addition to Mississippi and Washington models, the daily train volume factor was missing from the consolidation rating formula in Iowa but present in the accident prediction formula of the state.

Out of reviewed US national models, the factor of type of protection was identified as significant in 74% of the models, accidents history in 72% of models, train speed in 62% and number of tracks in 60% of the models. Figure 23 shows the top 10 factors used in national US models.

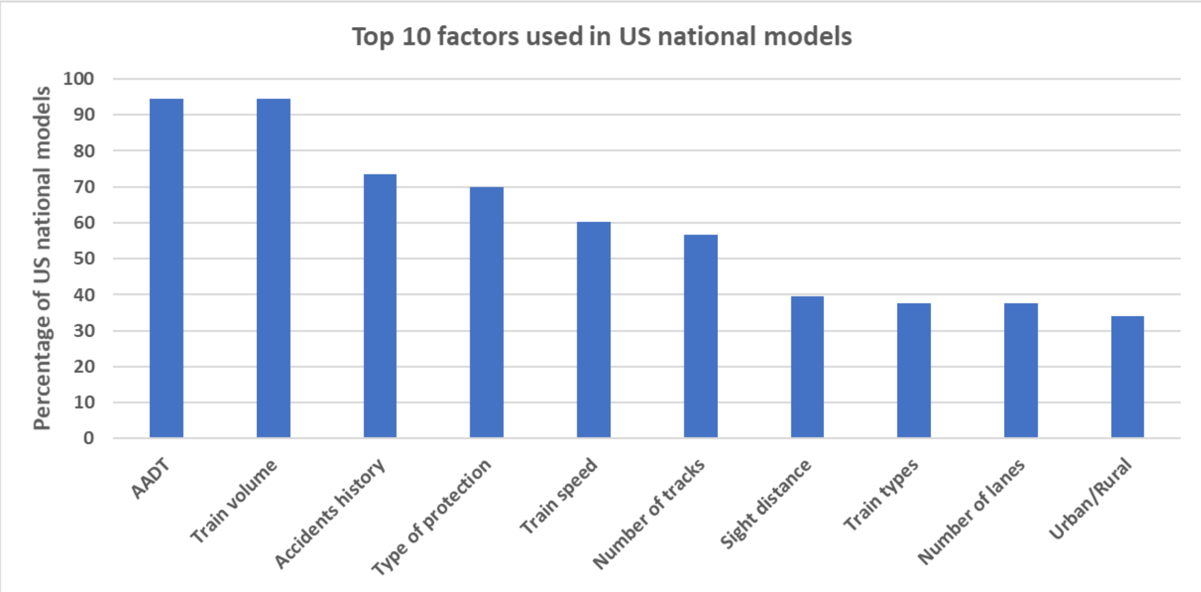


Figure 23: Top 10 factors used in US national models

The US prioritization tool that included the highest number of factors was GradeDec.Net with 31 criteria while Mississippi Formula was found to be the simplest as it uses two parameters only to calculate risk which are sight distance and accidents history.

A complete overview of the criteria identified in the reviewed US models and research is presented in Appendix B.

4.2.4 Risk and consolidation models in Canada

Governments in Canada paid a special attention to improving level crossings since the early 1900´s as it was reported that in 1909 the ´Railway Grade Crossing Fund´ was established. One of the first attempts to create a hazard index for Canadian level crossings was done by Zalinger et al. in 1977 with the development of an integrated hazard regression model. Their work identified a small number of factors (12 only) to be significant and rejected 5 other factors [73].

Efforts to create a Canadian model for risk assessment and prioritization of level crossings were pushed further in the early 2000´s after The Canadian Transportation Safety Board (TSB) reported that level crossing accidents cause 45 fatalities and 60 injuries yearly. As a response, Transport Canada created a nationwide program called ´Direction 2006´ that aims to reduce level crossing accidents by at least 50% by 2006. Therefore, it was necessary to create tools that helps with the resource allocation and prioritize the highest risk crossings in the country [74].

Although the program failed to meet its 50% accident reduction goal since by 2006, LC accidents and trespass incidents were reduced by 26% and 34% only respectively, the program accelerated the efforts to create risk models and prioritization tools significantly [75].

One of the main efforts to create an accident prediction model during the early 2000´s was the model for evaluating countermeasures developed by Saccomanno and Lai. The researchers first selected the significant factors to be included in the model based on statistical review of LC and accidents data in Canada. Then according to the identified factors, level crossings were grouped in 4 different groups [76]:

- **Group 1:** Crossings with high road volumes and equipped with active protection. Crossings with the highest scores in this group are usually located in urban areas.
- **Group 2:** Crossings with high train volumes and speeds. Road volumes are low. These crossings are a mix of active and passive devices and are usually found in rural areas on secondary highways.
- **Group 3:** Crossings with low road and train volumes, equipped with passive protection. These crossings are found in suburban and rural areas with shallow intersection angles and whistle prohibitions.
- **Group 4:** Crossings with low road and train volumes, and low vehicle speeds. These crossings are also found in rural areas with angles of intersection that exceed 70°.

Following the grouping of crossings, the authors developed the collision prediction model using Poisson regression but when the results were unsatisfactory it was decided to implement the negative binomial method which yielded more accurate results after being validated using a chi-square goodness-of-fit test.

4.2.4.1 GradeX

The efforts of program ´Direction 2006´ were crowned with the development of a web-based risk assessment and decision-support tool for Canadian level crossings called ´GradeX´ by a team of engineers from the University of Waterloo.

GradeX is based on a research model developed by Saccomanno et al. in 2004 in which a model to predict number of accidents and consequences for crossings was designed. Crossings with unacceptable risk levels were later referred to as ´Blackspots´ or ´hotspots´ in the model and prioritized for consolidation [74].

GradeX model is a based on statistically-driven approaches. Users can choose the risk assessment methodology to be implemented from four options: accident history, or accident prediction modelling using binomial equations, or accident prediction using Empirical Bayes methods, or relative risk through comparing crossing specific risk to the average risk of similar crossings.

After the potential high-risk level crossings (hotspots) are identified using data from national crossing and accidents databases, GradeX runs a detailed safety assessment and ranks crossings in a finalized hotspot list. The model then designs a list of recommended countermeasures to be applied at each crossing according to its individual risk assessment.

GradeX has also the advantage of including the economic factor by calculating the costs of accidents, fatalities, and injuries.

A complete overview of the criteria identified in the reviewed Canadian models and research is presented in Appendix B.

4.2.5 Additional factors in North American research and studies

Most often, resource allocation methodologies focus on safety factors and neglect economical or environmental factors. Nevertheless, Schrader and Hoffpauer designed a resource allocation model for Arkansas that is built upon 7 quantitative and qualitative factors. In addition to safety, the often-neglected factors of noise, community cohesion, delay, accessibility, connectivity, and geographic distribution were considered [77].

Remarkably, the work of Schrader and Hoffpauer invented the concept of community cohesion which measures the dependency of the community in each half of the crossing on the other. The authors provided three alternatives to quantify cohesiveness based on the desire of community A to travel to B and desire of B to travel to A. The alternatives are namely full cohesive communities where both sections depend on each other (CCF=0), non-cohesive communities where both neither section need the other (CCF=1) and semi-cohesive communities where one section needs the other ($0<CCF<1$).

Additionally, Schrader and Hoffpauer used the concept of accessibility as a factor in their suggested model. Accessibility is defined as the additional distance to be travelled when the crossing is closed. The distance is naturally greater in rural areas than urban areas since road intersections are more and closer within cities. Therefore, the removal of a level crossing in a rural area could have greater effects on the surrounding community in terms of distances travelled and time delays which translates into economical disadvantages for the residents. Hans et al. suggested a similar factor in their model for Iowa state under the name of “out of distance travel” [78].

The factors that Schrader and Hoffpauer used in their model are Population within 0.83 km (P), Average daily train traffic (ADTT), Community cohesion (CCF), Average train length in km (L), Train speed (S), signal activation time in mins (AT), AADT, average duration of delay in mins (D), Difference in distance as a result of detour (D_1-D_2), road classification (FC), number of highway–railway grade separations per km along the railroad subdivision (GS), total number of at-grade and grade-separated crossings per km along the railroad subdivision (TC) and type of warning device (XD). In addition, Peak trains per day, number of main tracks, existence of highway pavement, number of highway lanes and number of accidents are needed to predict accidents per year (A). The factors are demonstrated in the following formulas:

- Noise: $NF = \frac{P\ x\ ADTT}{1000*250}$ *(Eq. 15)*
- Community cohesion: $CCF = 1 - \frac{D_{A-B}}{D_{B-A}}$ *(Eq. 16)*
- Delay: $DF = \frac{\left[\frac{Lx60}{S}+AT+0.1667\right]xADTT}{1440} xAADTx\frac{D}{60}x\frac{1}{480}$ *(Eq. 17)*
- Accessibility: $AF = \frac{D_1-D_2}{24}$ *(Eq. 18)*
- Connectivity: $CF = \frac{AADT}{\frac{FC}{20000}}$ *(Eq. 19)*
- Geographic distribution: $GDF = 1 - \frac{GS}{TC}$ *(Eq. 20)*
- Safety: $SF = \frac{A}{XD}$ *(Eq. 21)*

4.3 Australia and New Zealand

4.3.1 Australia

Australia faced a severe problem with level crossing accidents in the late 1990´s particularly in accidents where a pedestrian is hit by a train which made 53% of all railway fatalities in that period. This resulted in a series of governmental measures being taken to control risks at level crossings such as launching public awareness and media campaigns, introduction of level crossing monitoring using CCTV and increased funding for level crossing safety research. The efforts were finally crowned with the introduction of the Australian Level Crossing Assessment Model (ALCAM) in 2003 [43].

In 2015, a special authority was formed to supervise and manage level crossing removal projects under the name `Level Crossing Removal Authority (LXRA)´ and a major 10- year project was initiated with the aim of removing 85 level crossings by 2025. 66 Level crossings were removed as part of the program so far.

4.3.1.1 Australian Level Crossing Assessment Model (ALCAM)

ALCAM is the successor of the Risk Based Scoring System (RBSS) which is the first prioritization model developed in Australia in 1999. It was decided that ALCAM will be adopted in all Australian states in May 2003 after all transport ministers agreed to implement ALCAM as the main risk assessment model in their states. New Zealand joined the ALCAM group and started implementing the model as its national model in 2007 before switching to an improved and country-specific version of it called LCSIA in 2016.

ALCAM includes a large number of traffic, physical and safety factors. In this study, 44 factors were identified in ALCAM; more than any US model. The weighting of factors of ALCAM was done using the judgement of experts with a panel of experts from Australia and New Zealand.

ALCAM produces a risk score for every level crossing. The risk score is the product of multiplication of three individual factors which are the infrastructure factor, the exposure factor, and the consequence factor. The infrastructure factor reflects the contribution of physical characteristics of the crossing towards the yearly accidents rate. The exposure factor considers the train and users volumes along with other traffic and operational characteristics. The consequence factor represents the types of expected injury types resulting from accidents.

$$\text{ALCAM Risk Score} = \text{Infrastructure Factor x Exposure Factor x Consequence Factor} \quad \text{(Eq. 22)}$$

The infrastructure factor is calculated in ALCAM by multiplying the raw infrastructure factor by an infrastructure modifier. The raw infrastructure factor indicates how much does the physical characteristics of the crossing influence the accidents mechanism. The raw infrastructure factor has a maximum value of 800 and could be obtained from two matrices called the ´characteristics matrix´ which represents the physical characteristics of the crossing and the ´controls matrix´ that represents the type of protection. In both matrices various accident mechanisms are implemented and weighted using 6X6 probability matrix that consists of occurrence and collision probabilities. The occurrence probability reflects the likelihood of occurrence of the accident mechanism while the collision probability reflects the likelihood of an accident to occur when the accident mechanism happens. This results in a weighting score between 1 and 36.

The raw infrastructure factor is multiplied then by an infrastructure modifier to get the infrastructure factor. The infrastructure modifier is a linear equation that was determined using 10 years of accident data. The equation is different for every type of protection at LC. The multiplication of the raw infrastructure factor by the infrastructure modifier produces an infrastructure factor with a baseline of 1. This means that any value obtained over 1 translates to increase in risk. For example, If the infrastructure factor was calculated to be 1.08, then the LC has a crash risk of 8% more than the baseline.

For the exposure model, the first version of ALCAM adopted a simple linear approach by multiplying the volume of daily trains by AADT. However, it was found later that this approach did not produce very accurate predictions. Therefore, a number of international exposure models from USA, UK and Australia were investigated and it was decided to adopt the Peabody Dimmick Formula from USA as the exposure model of ALCAM. However, the linear approach is still used for pedestrian crossings.

The number of predicted accidents per year could be calculated by multiplying the infrastructure factor by the exposure factor. The probabilities of individual accident scenarios are calculated with the aid of the consequence factor. The consequence factor is obtained from an event tree that assigns a probability for different accident scenarios. Due to the events tree approach, ALCAM is able to predict the probability of various accident scenarios such as fatalities, injuries and minor injuries, train derailment, damage to railway equipment or infrastructure, train colliding with another train, the risk of release of hazardous goods, and the probability of fire.

The level crossing could be ranked based on the risk score obtained by multiplying infrastructure, exposure, and consequence factors. However, ALCAM provides another advantage of treating level crossings based on individual factors since level crossings are distributed according to each factor into five bands that each involves 20% of level crossings. This helps identify where exactly does risk come from. For example, if a level crossing was in the lower band (safest) for infrastructure factor, exposure factor and overall risk score but was in the high band (highest risk) for infrastructure factor, it indicates that this LC has a very poor infrastructure and requires an upgrade in this particular branch. Although it could be useful to look into and rank crossings by individual factors but using the overall ALCAM risk score remains to be the best and most comprehensive way of ranking [44].

ALCAM has an additional advantage that it includes a separate model to calculate risk at pedestrians only crossings with a separate set of factors.

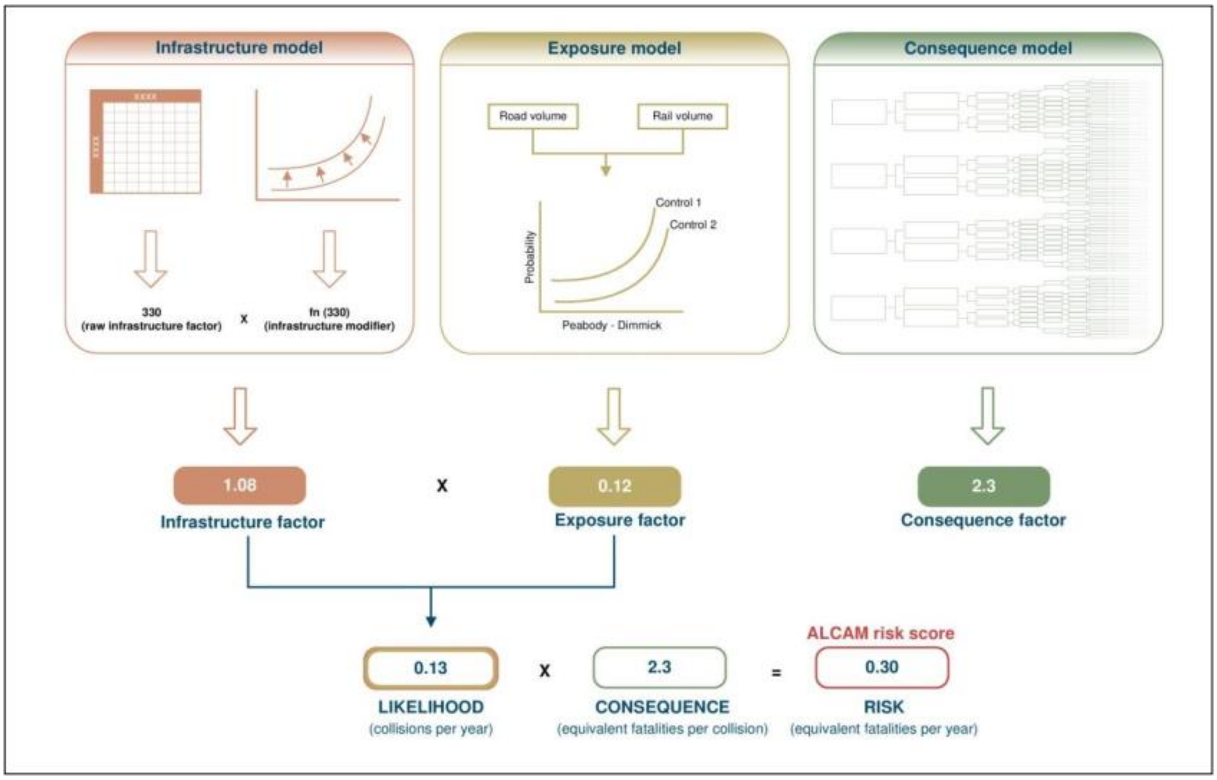


Figure 24: ALCAM structure [44]

4.3.1.2 The Multi-Criteria Approach (MCA)

In 2009, Taylor and Crawford were tasked by the Victorian Department of Transport to create a methodology to rank 177 crossings in Melbourne for grade separation. The developed methodology was based on multiple quantitative and qualitative criteria from various non-safety related aspects including economic, social, and environmental aspects [79].

The weights of criteria in the model were derived using the judgement of three groups of railway and road engineers. Each group was asked to assign a percentage of importance to each criterion and sub-criteria and the average percentage from the inputs of all three groups was taken as the weight of criteria.

Table 18 summarizes the selected factors of the MCA model and the final weights of criteria:

Table 18: Weights of criteria in MCA approach [79]

Main Criteria	Sub Criteria	Type	Weight
Economic	Benefit-cost ratio	Quantitative	36.7%
Social	Risk of death or injury	Quantitative	9.3%
	Community severance	Qualitative	4.1%
	Visual amenity	Qualitative	2.1%
	Noise amenity	Qualitative	2.1%
	Development opportunities	Qualitative	3.1%
	Connectivity/Accessibility	Qualitative	6.2%
	Impact on sites of social significance	Qualitative	3.1%

Main Criteria	Sub Criteria	Type	Weight
Environmental	Energy consumption and emissions	Quantitative	9.7%
	Local nature environment	Qualitative	1.9%
Strategic fit	Road network operating objectives	Quantitative	21.7%

The Benefit-cost ratio is calculated based on the project costs and other economic benefits that could be gained from the implementation of a grade separation project such as savings in travel time for road users based on the calculation of expected future delay, savings in vehicles and train operating costs, and accidents savings based on accidents and near misses history.

All criteria were given a score that represents the foreseeable change (improvement or worsening) resulting from replacing the current LC with a grade separation. For example, for the visual and noise amenity factors, each possible project type was assigned a score between -5 and 5. Rail underpasses were determined to provide the best improvement to the visual and noise situation and were assigned a +5 score. Road underpasses were determined to be a good solution also and were assigned 3 points. On the contrary, rail overpasses were determined as a negative solution for noise and visual amenity and were assigned a -3 score for visual amenity and -5 for noise amenity. Road overpasses were also determined negative and received -3 for noise and -5 for visual amenity [79].

The MCA model deducts points from projects that have a high impact on neighbor sites of social significance that might be removed as part of the project. For example, If the projects result in removing two or less local sites then 1 point is deducted. If multiple local sites will be impacted, then 2 points are deducted. If the project impacts a shopping or activity center, then 3 points are deducted. 5 points are deducted if the project requires the removal of highly important site that could lead to community concern such as heritage sites, churches, and community facilities.

As for the environmental criteria, the Energy consumption and emissions factor accounts for the improvements or worsening in predicted rates of consumed energy, emitted greenhouse gases and overall air quality. Meanwhile, the Local nature environment factor is a qualitative factor of the impact of the project on the surrounding environment such as whether a significant number of trees will need to be removed and if nearby water bodies will be impacted.

4.3.2 New Zealand

4.3.2.1 Product Assessment Model

The attempts to create a risk assessment formula and a prioritization methodology in New Zealand began in the 1980´s with the development of the ´Product Assessment´ formula which relied on a number of factors such as number of day and night trains, daily road vehicles volume, view factor, number of tracks and accidents history to determine a risk score for each crossing [43].

$$Product\ Assessment = [(2xTD) + TN]\ x\ RV\ x\ VF\ x\ HF \qquad \text{(Eq. 23)}$$

Where:
TD = daily trains volume
TN = Night trains volume
RV = daily road vehicles volume
VF = View factor
HF = Hazard factor (1 for single track, 1.25 for mainline track plus sidings, 2 for second line or loop track)

The authorities in New Zealand used to prioritize crossings that score 10,000 or more in Product assessment for upgrade to lights and bells. In addition, if the crossing scores 50,000 or more it was prioritized for upgrade to half barriers [43].

4.3.2.2 Accident Prediction Model

In 2002, a new statistically driven methodology was developed based on accidents data specific to New Zealand´s level crossings. The model is very simple and considers only traffic volumes of rail and road and the type of protection. The model predicts only the number of yearly accidents with injuries at the crossing with no regard to detailed consequences modelling [43].

$$A_T = b_0\ x\ (daily\ trains\ volume)^{b1}\ x\ (road\ vehicles\ volume)^{b2} \qquad \text{(Eq. 24)}$$

Where b_0, b_1 and b_2 are factors extracted based on type of protection.

4.3.2.3 Australian Level Crossing Assessment Model (ALCAM)

New Zealand used the Accident Prediction Model for 5 years only before it was decided to adopt the ALCAM model from Australia in 2007 and include the accidents database of New Zealand in the ALCAM model calculations. The details of ALCAM are explained in detail in section 4.3.1.

New Zealand continued to rely on ALCAM as its national model for risk assessment of level crossings and for prioritizing crossings for consolidation and upgrade projects for 9 years. It was realized in 2016, that results that ALCAM model provide were not optimum and the level of prediction accuracy was determined as unsatisfactory by KiwiRail. The factors and weights adopted in ALCAM were more suitable to Australian conditions and did not reflect the required safety levels in New Zealand in equal manner. KiwiRail also identified a number of general shortcomings in ALCAM that limited its capabilities such as ignoring the judgement of experts and railway engineers in the selection process of crossings and the disregard to the surrounding transport network. Moreover, the risk assessment methodology in ALCAM was not reflecting the changes in infrastructure and advancement in protection systems technologies [45].

Therefore, KiwiRail decided to develop a new model specific for New Zealand´s level crossings that is based on ALCAM with alterations of factors weights and introduction of new factors that reflects better the specific conditions at New Zealand´s level crossings. The new model in New Zealand for level crossings risk assessment and prioritization was named ´the Level Crossing Safety Impact Assessment model (LCSIA)´.

LCSIA is different than ALCAM in three main fields [45]:

- ALCAM is designed based on general accidents data from New Zealand and Australia but does not consider individual crash history of each level crossing. This point was improved in LCSIA with the introduction of a Crash and Incident History Analysis for each level crossing. LCSIA includes the number of accidents and a detailed consequences modelling that considers beside fatalities and injuries the incidents of near misses and specific types of incidents such as when a driver drives through barriers.
- Including the judgement of railway experts and engineers in the safety evaluation process of LCSIA while it is ignored in ALCAM.
- Including surrounding transport network in LCSIA while it is disregarded in ALCAM.

4.3.2.4 The Level Crossing Safety Impact Assessment Model (LCSIA)

The risk rating of crossings in LCSIA is determined through the Level Crossing Safety Score (LCSS). LCSS has a maximum score of 60 in which a higher score indicates a higher level of risk. The risk score calculated through ALCAM has a weight of 50% of the LCSS score.

LCSS score is the combined result of the following scores:

- ALCAM score (30 points)
- Crash and incident history score (10 points)
- Site-Specific Safety Score (SSSS) (10 points)
- Railway and road engineers’ risk assessment score (10 points)

Based on the results of LCSS, level crossings are classified into 5 different risk bands:

- High (LCSS score: 50-60): The riskiest level crossings. The potential of fatalities and serious injuries accidents to occur is high.
- Medium-High (LCSS score: 40-49): risky crossing with a medium-high potential of fatalities and serious injuries accidents to occur. Level crossing is surrounded by several safety concerns.
- Medium (LCSS score: 30-39): crossing with a medium potential of fatalities and serious injuries accidents to occur. Level crossing is surrounded by some safety concerns.
- Medium-Low (LCSS score: 20-29): relatively safe crossing with a medium-low potential of fatalities and serious injuries accidents to occur. Level crossing has few safety concerns.

- Low (LCSS score: ≤19): safe crossing with a low potential of fatalities and serious injuries accidents to occur. Level crossing rarely has any safety concerns.

The laws in New Zealand state that constructing new level crossings is strongly discouraged. However, any newly constructed LC must be at the Low or Medium-Low bands of LCSS score. The existing crossings that are selected for upgrade are recommended to be upgraded to achieve a LCSS score of 29 or less.

The scoring methodology of the four LCSS scores to obtain the final LCSS score is performed in the following manner.

A- ALCAM score

The details of calculation of ALCAM risk score are explained in section 4.3.1. LCSIA assigns risk points to level crossings according to their ALCAM risk band following the ranking performed by ALCAM. LCSIA risk points are assigned as follows:

Table 19: LCSS score based on ALCAM score

ALCAM Risk Band	High	Medium-High	Medium	Medium-Low	Low
LCSS Points	25-30	19-24	13-18	7-12	1-6

B- Crash and incident history score

This score is the summation of the Crash Analysis System (CAS) score, Integrated Regional Information System (IRIS) score, and New Zealand Road Assessment Programme (KiwiRAP) score. However, if any fatal crash occurred at the crossing in the last 10 years, the crossing gets the full score of 10 automatically.

The three scores are obtained using 10 years of accident data. The IRIS score depends directly on the number of crashes as each crash scores 1 point with a maximum of 10 points. The CAS and KiwiRAP scores are calculated as follows:

Table 20: CAS and KiwiRAP scores

CAS score	KiwiRAP score	Points
No accidents	-	0
Non-DSI accidents*=1	KiwiRAP collective risk band: low, medium-low, or medium	1
Non-DSI accidents*=2	KiwiRAP collective risk band: medium-high for a nearby road	2
Non-DSI accidents*=3	KiwiRAP collective risk band: high for a nearby road	3
Non-DSI accidents*=4 or Serious Injury accidents=1	KiwiRAP collective risk band: medium-high for the LC road	4
Non-DSI accidents*≥5 or Serious Injury accidents≥2 or (Serious Injury accidents=1 and non-DSI accidents*>3)	KiwiRAP collective risk band: high for the LC road	5

* Accidents that does not involve any fatalities or serious injuries

$$Crash\ and\ incident\ history\ score = \frac{IRIS\ score + CAS\ score + KiwiRAP\ score}{2}$$ *(Eq. 25)*

C- Site-Specific Safety Score (SSSS)

The SSSS includes four factors in the calculation of score which are: Queuing (Q), Nearby intersections (NI), Grounding out (GO) and compliance rate (CR). Queuing factor depends on the percentage of time in which queues are formed during peak hours. Nearby intersections factor depends on the existence of nearby intersections, the number and location of legs of intersection and queues likelihood. Grounding out factor depends on the history of grounding out incidents, nearby intersections, trucks percentage, and AADT. The compliance rate score gives a score based on the compliance rate of users, type of protection and visibility condition.

For pedestrian-only crossings the factors selected for SSSS are: Crossing type (CT), Flange gaps (FG), Volume of vulnerable users (VU), Distraction or inattention factor (DI) and cycle patronage (CP). The crossing type factor depends on type of protection, visibility condition and availability of signs. The flange gap factor was included to account for risk of wheel entrapments for pedestrians on wheels including wheelchair users, scooters, baby prams, rollerblades, roller skates, and skateboards. The size and condition of flange gaps are used to determine the score. The vulnerable users factor includes visually impaired, school children, physically disabled, elderly, and intoxicated users. However, in case of school children, if the crossing was supervised by an adult during peak crossing periods the score is reduced by 50%. The factor of distraction is based on whether the crossing is located on Urban or rural area and the number of pedestrians and cyclists. The factor of cycle patronage is directly related to number of daily cyclists. Table 21 demonstrates an example of the scoring system for the pedestrians-only crossings SSSS.

Table 21: Example of SSSS scores in LCSIA for pedestrian crossings

Number of daily vulnerable users	Cycle Patronage: number of daily cyclists	Score
0	0	0
<10	<20	1
11-20	21-50	2
21-35	50-100	3
36-50	101-200	4
51-75	>200	5
76-100	-	6
101-140	-	7
141-170	-	8
171-200	-	9
>200	-	10

$$SSSS = \frac{Q\ score + NI\ score + GO\ score + CR\ score}{3.5}$$ *(Eq. 26)*

$$SSSS_{Pedestrian/Cyclist\ crossings} = \frac{CT\ score + FG\ score + VU\ score + DI\ score + CP\ score}{3.5} \qquad \textit{(Eq. 27)}$$

D- Railway and road engineers' risk assessment score

The Railway and road engineers' risk assessment score is determined by consulting one Railway engineer and one Engineer from Road Controlling Authority (RCA). Each engineer gives a risk rating for each studied crossing. The railway engineer gives a score out of 10 while the roads engineer gives a score out of 5. The score is a combination of both scores given by the two engineers with an advantage in weight in favor of Railway engineer (2/3) compared to the road engineer (1/3) on the basis that railway engineers are more involved and get exposed more to level crossing projects. The overall score has a maximum of 10 points [45].

$$Engineers\ assessment\ score = \frac{Railway\ engineer\ score + RCA\ engineer\ score}{1.5} \qquad \textit{(Eq. 28)}$$

A complete overview of the criteria identified in the reviewed models and research from Australia and New Zealand is presented in Appendix B.

4.4 Europe

A level crossing consolidation program exists in Belgium and is funded from the infrastructure authority's overall budget. Meanwhile, the situation in France is similar to Germany when it comes to legislations related to level crossing closure. However, the rate of consolidation is much slower in France compared to Germany as only 572 level crossings were consolidated in the period from 2013 to 2019 with an average of 82 level crossing per year. The rate of consolidation in France is 3.66% annually compared to 16% in Germany [80]. The reason of the slow level crossing removal rate might be the absence of any governmental-funded consolidation program. However, the governmental interest in safety at level crossings has increased in France since a tragic accident in 2017 between a school bus and a train that led to life loss of 6 children. In 2018, SNCF Réseau spent €51.8 million for the removal of level crossings [81].

The funding of such projects is endured mostly by local and regional public bodies which bears almost 70% of the funding [82]. Like Germany, the prioritization of projects in France is subject to prior safety data and the judgement of experts.

In Ireland, the closure of level crossings is financed by the government which considers the closure of level crossings and risk elimination a priority. The prioritization of projects is assigned to the national railway network operator Iarnród Éireann which applies a safety performance-based risk model [82].

In the Netherlands, the focus is more directed towards upgrading level crossings rather than consolidation due to difficulties in planning a grade separated alternatives because of the topography of the country [82].

Sweden has its own level crossing consolidation and upgrade program supported by the Swedish government. However, the funds are allocated on the basis of no formula or model. The distribution of costs is determined by negotiations between the infrastructure operator, the highway authorities and local authorities [82].

In the United Kingdom, there is no single agency responsible for the consolidation of level crossings nor a defined procedure for such process. Any initiative is probably initiated by Network Rail but other non-rail industry bodies have also the right to initiate a closure project. A level crossing closure order is also possibly acquired from the magistrate's court with the approval of Secretary of State [82].

A number of joint efforts in Europe to produce a methodology of level crossing risk assessment were made throughout the last years. The most remarkable was the Safer European Level Crossing Appraisal and Technology (SELCAT) project which was performed under the patronage of EU as a joint effort between several European countries. The project aimed to gather information and experiences from around the world related to the safety of level crossings with the goal of benefitting from the international experiences in the application of advanced technologies and methodologies that may raise the safety situation at European level crossings.

The challenge was to develop a model that can quantify risk at different countries with different characteristics and safety situation. The developed model measures the operational and safety impacts that results from introducing new technologies.

Another joint effort was done in 2018 as researchers from Czech Republic, Austria, and Hungary joined efforts to create accident prediction models for the three countries. The authors then compared the three resulting models to identify the differences in significant criteria between the countries. A summary of the findings regarding the significance of criteria studied and a comparison between countries is presented in table 22 [83].

Table 22: Significance of factors for Austria, Czech Republic, and Hungary [83]

Criteria		Austria	Czech Republic	Hungary
Traffic exposure	Road traffic volume	Significant	Significant	Significant
	Rail traffic volume	Significant	Significant	Significant
Speed	Road speed limit	Significant	Not significant	Not significant
	Rail speed limit	Significant	Not significant	Not significant
	Speeding above 60 km/h	Not significant	Significant	Not significant
Visibility	Risk of poor visibility due to vertical alignment	Not significant	Significant	Not significant
	Sight distance	Not significant	Not significant	Not significant
Physical characteristics	Angle of intersection	Significant	Not significant	Significant
	Distance to nearest intersection up to 50m	Significant	Not significant	Not significant
	Road width	Significant	Not significant	Significant
	Road pavement / marking	Not significant	Not significant	Not significant

4.4.1 United Kingdom

In Europe, the most extensive efforts to design risk and prioritization models for level crossings were made in the United Kingdom. The first attempt was in 1996 when the Automatic Level Crossing Model was introduced to assess all British level crossings annually and select candidates for upgrade or improvements. This model was the corner stone for the development of a more comprehensive risk model in 2003 that is still implemented till this day in UK and is called the “All Level Crossings Risk Model (ALCRM)” [43].

In comparison with ALCRM, the Automatic Level Crossing Model is a simpler model and revolves only around safety risks. Using the Automatic Level Crossing Model is easy as the model was designed as a spreadsheet with a simple user-interface. The user is asked to enter the crossing details, traffic volumes, types of users and train details and the model then predicts number and severity of accidents annually at each crossing using fault and event tree analysis using the concept of ´time window`. This concept considers mainly the number of road users and trains, their speed and total daily closure time of the crossing and assumes the time users spend inside crossing area as an indication to the likelihood of a collision. The Automatic Level Crossing Model also includes a simple derailment prediction [43].

However, due to its simplicity and many limitations, the Automatic Level Crossing Model was later replaced by ALCRM in 2006. The main shortcomings of the Automatic Level Crossing Model that incentivized the change were that the model was exclusively limited to automatic crossings with no possibility to assess passive crossings. The model was also based on outdated data which made the development of a modern updated model after 10 years of use necessary [43].

Both ALCRM and the Automatic Level Crossing Model are complex weighted factor models. However, ALCRM is considered to be better. The two main advantages of ALCRM over the Automatic Level Crossing Model is the inclusion of all types of crossings and the introduction of a cost-benefit analysis.

Unlike the Automatic Level Crossing Model, ALCRM is based on the concept of ´choking´ introduced by Prof. Stott rather than ´time window´. This concept is based on the idea that the probability of a vehicle to get involved in a LC crash decreases if it was not the first to arrive after activation based on the argument that drivers are more effected by vehicles ahead than protection or safety devices. Therefore, a vehicle using a LC located in a high traffic frequency area has a lower probability of a crash than in a moderate traffic area. The suggested ´choking´ concept by Prof. Stott for automatic level crossings is shown in figure 25. However, for passive crossings a linear model is applied.

A more detailed derailment consequences module based on the geographic layout of the LC is involved in ALCRM too.

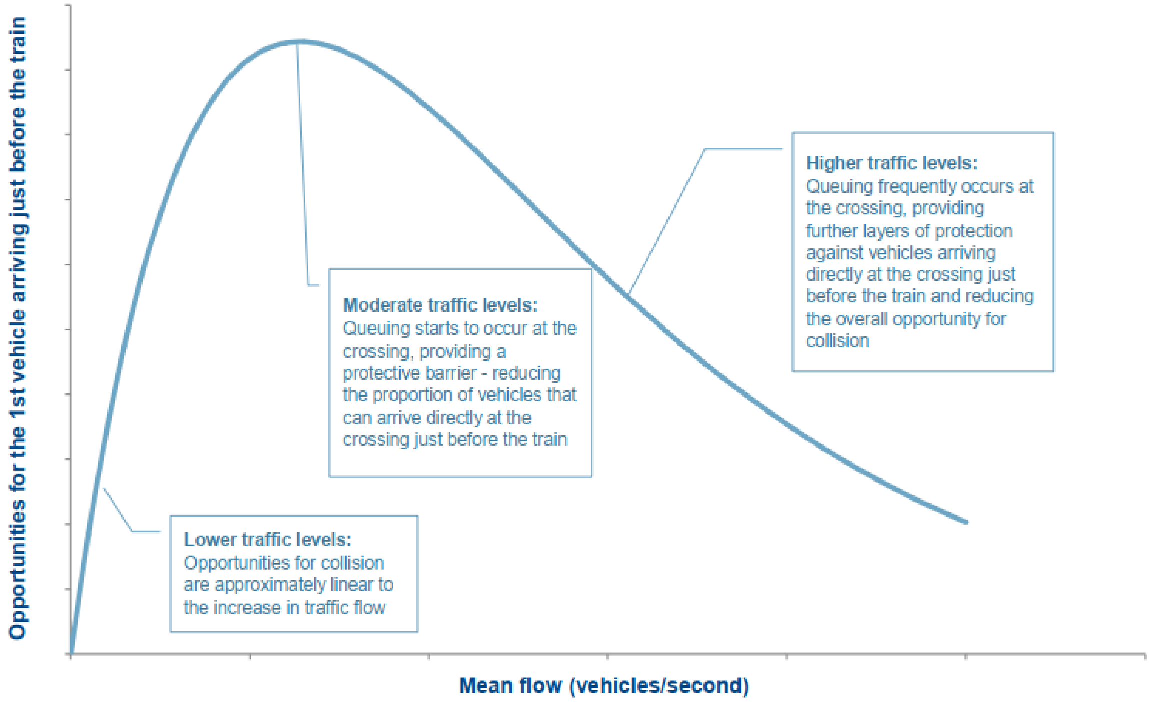


Figure 25: ´Choking´ concept by Prof. Stott [84]

ALCRM revolves around three main accident scenarios which are accidents between trains and road users, accidents between road users and LC equipment, and road user incidents (No collision).

To compliment ALCRM, RSSB introduced in 2006 another web-based tool called the "Level Crossing Risk Management Toolkit (LXRMTK)" that explores human factor risks at level crossings and presents information for practitioners and the public about measures to reduce risk. The main goal of the tool is to help designers and engineers to implement cost-effective measures that effectively eliminates certain human behavior risks at level crossings without the necessity of major solutions or projects. Therefore, LXRMTK was selected to support the cost-benefit analysis implemented in ALCRM. Moreover, LXRMTK was introduced with the intention of raising awareness and influencing public behavior. The tool is designed under the concept that the vast majority of accidents at level crossings occur because of human errors or violations [85].

Another model used in UK is the Event Window Model which was designed by Halcrow to help Network Rail select which level crossings in the West Coast Route Modernisation project are to be kept, consolidated, or upgraded.

The algorithm of the Event Window Model is different than the other UK models as it does not rely on fault and event trees but rather the ´ Monte Carlo simulation model´ that is based on the concept of randomness in arrival for train and road users. The Event Window Model produces a prediction of number of yearly fatalities for each level crossing. One of the main shortcomings of the model is the absence of consequences variety since the model assumes that all collisions result in fatalities.

Another major difference between the Event Window Model and other UK models is that it does not use Accident history to predict the number of fatalities but rather calculates the probability of a human error to occur based on some input parameters using HEART (Human Error Assessment and Reduction Technique) analysis. For that reason, the numbers and consequences of previous accidents are irrelevant for the determination of predicted future fatalities at any level crossing using the Event Window Model.

4.4.2 Ireland

Two prioritization tools were developed in Ireland since mid-1990´s to prioritize Irish level crossings. The first attempt was the Level Crossing Prioritisation Tool developed by Arthur D Little as a tool to create risk model for crossings to assess their performance. This model was developed in a similar manner to the UK´s Automatic Level Crossing Risk Model. Accidents history and traffic moment form the basis of this model in addition to several significant factors such as approach grade, sight distances, temporary sight obstructions such as low sun, road width, train and vehicles speed, vulnerable users, and hazardous goods.

The model works by calculating an individual risk of fatality and collision rate after inserting the required inputs of crossing data. Then the crossings are assigned to three bands based on the calculated risk of fatality [43].

- **Black band:** Risk of fatality ≥ 1/10000 per year. This risk is considered intolerable and requires special solutions to improve safety.
- **Grey band:** For crossings with a risk of fatality between 1/10000 and 1/20000 per year or a collision rate ≥ 1/100 per year. Crossings in this band require further evaluation from safety engineers to decide necessity of improvement.
- **White band:** Risk of fatality < 1/20000 per year and a collision rate < 1/100 per year. Crossings in this band are generally safe and have low priority for improvements.

The second attempt was in 2003 when the ´Network Wide Risk Model´ was introduced as a model to aid in the resource allocation process for all railway projects including level crossing improvements.

Since the model was designed to create risk models for all railway hazards, it is not very specific to level crossings, and this reflects on the input data required as they are more general. For example, the model gives a special significance to factors such as train speeds, train types, and train and vehicles volumes. The model is also general with calculation of risk at level crossings as it does not calculate risks on each individual crossing but rather gives the same risk value for all crossings on the same line since the model does not consider the individual physical factors of crossings in the assessment process.

The model prioritizes investments based on a cost-benefit analysis using data obtained from the risk model. The risk model performs fault and event trees analysis with a variety of accidents consequences to calculate fatality and individual risks for each studied investment type [43].

4.4.3 Hungary

Borsos et al. proposed an improvement to the Hungarian methodology of level crossings safety ranking by including statistical data and a model was created using Generalized Linear Modeling approach (GLM). Table 23 demonstrates the factors applied in the Hungarian model and the proposed changes on weights resulting from the work of Borsos et al. [86].

Table 23: Factor weights in the Hungarian model [86]

Factor	Weight (2008 model)	Weight (2015 model)
Traffic Exposure	25%	30%
Accidents history	30%	25%
Type of protection	15%	20%
Traffic signs	9%	9%
Recognizability, drivability, geometry	8.5%	8.5%
Road and rail speeds	10%	5%
Other factors	2.5%	2.5%

4.4.4 Serbia

There were numerous research attempts to develop a model for the prioritization of Serbian level crossings. In 2013, Ćirović and Pamučar developed an Adaptive Neuro Fuzzy Inference System (ANFIS) to prioritize crossings based on predicted risk in a multi-criteria analysis. The researchers used fuzzy multi-criteria decision making and fuzzy clustering techniques to train a set of data obtained using the judgement of 20 road and rail traffic experts [87].

The panel of experts selected six quantitative and two qualitative criteria to form the model. These criteria were identified as the most significant factors for the prioritization of a level crossing to receive an investment. The model developed by Ćirović and Pamučar then produced the following weights for the eight selected criteria:

Table 24: Weights of factors of the ANFIS model [87]

Factor	Factor type	Weight
Rail traffic volume	Quantitative	12%
Road traffic volume	Quantitative	19%
Number of tracks	Quantitative	11%
Train speed	Quantitative	8%
Angle of intersection	Quantitative	15%
Number of accidents (1 year)	Quantitative	12%
Visibility	Qualitative	14%
Investment value of activities related to the width of the level crossing	Qualitative	9%

Another attempt to develop a methodology to rank level crossings was made in 2018 by Pamučar et al. using the same criteria except the ´investment value´ factor. The researchers applied a FUCOM-MAIRCA (Full Consistency Method – Multi Attributive

Ideal-Real Comparative Analysis) model. This approach is based on the ranking of individual factors to obtain the weights of factors and then by performing a sensitivity analysis the final weights are obtained [88].

The ranking of factors was performed by four experts and produced the following results:

Table 25: Weights of criteria of FUCOM-MAIRCA model [88]

Criteria	Expert 1			Expert 2			Expert 3			Expert 4			Average weight
	Rank	Comparative Significance	Weight	Rank	Comparative Significance	Weight	Rank	Comparative Significance	Weight	Rank	Comparative Significance	Weight	
Rail traffic volume	4	1.18	0.1318	4	1.15	0.1319	4	1.20	0.1294	4	1.17	0.1327	0.1314
Road traffic volume	1	1	0.2190	1	1	0.2145	1	1	0.2140	1	1	0.2051	0.2132
Number of tracks	6	1.10	0.1141	6	1.15	0.1147	7	1.20	0.0910	6	1.17	0.1134	0.1083
Train speed	7	1.38	0.0827	7	1.25	0.0917	6	1.15	0.1093	7	1.30	0.0872	0.0927
Angle of intersection	2	1.28	0.1711	2	1.31	0.1638	2	1.22	0.1754	3	1.12	0.1552	0.1664
Number of accidents	5	1.05	0.1256	5	1	0.1319	5	1.03	0.1256	5	1	0.1326	0.1289
Visibility	3	1.10	0.1556	3	1.08	0.1516	3	1.13	0.1553	2	1.18	0.1738	0.1591

Starčević et al. conducted a survey to inspect how highly different factors influence risk and accident mechanisms at level crossings. The survey was answered by railway safety experts worldwide. Since the obtained answers form the collective opinion of experts from different continents, the results could be useful for any model under development regardless of location. Experts were asked to determine the degree of importance of each criteria using a scale of 1-5 where 1 is the least important and 5 is the most important. Table 26 summarizes the importance values of each criterion picked by the majority of the international experts [89].

Table 26: Results of factors importance survey [89]

Criteria	Importance	Number of experts	Percentage of experts
Advance warning signs were not visible due to vegetation, damage or they were "drowned" among other signs	2 and 4	19/75 each	25.33% each
Existence of objects outside vehicle that can cause driver distraction	4	26/75	34.67%
In-vehicle distraction (cell phones, managing stereo systems, conversation with passengers, attending to children, etc.)	5	33/75	44%
Not knowing traffic rules for level crossings	5	28/75	37.33%
Not knowing characteristics of train movement (unable to stop, long stopping distance)	5	24/75	32%
Driving too fast on approach to level crossing	5	29/75	38.67%
Number of railway tracks	3	20/75	26.67%

Criteria	Importance	Number of experts	Percentage of experts
Bad pavement condition on approaching roads	3	23/75	30.67%
Steep road gradient on approach to level crossing	3	24/75	32%
Bad weather conditions (rain, hail, snow, fog, ice)	3 and 4	21/75 each	28% each
Miscalculation of train speed	5	28/75	37.33%
Crossing angle between road and railway tracks	4	24/75	32%
Sun glare	2	21/75	28%
Familiarity with level crossings (daily usage)	5	27/75	36%
Level crossing closure time	4	29/75	38.67%
Time between start of the warning signal and actual train arrival at crossing	3	24/75	32%
Lack of police surveillance at level crossing sites	3	22/75	29.33%
Lack of appropriate repression measures	5	23/75	30.67%

4.4.5 France

Liang et al. developed an accident prediction model for the French level crossings in 2018 to address the issue of absence of risk modelling for level crossings in France. The developed model uses 9 criteria to predict the number of accidents which are the daily road traffic volume, daily train volume, train speed, crossing width, crossing length approach grade, road curvature, region risk and accident history [90].

The accident history factor of the model uses accidents data from the last year only. The daily road traffic volume, daily train volume, train speed, crossing width, and crossing length are all quantitative criteria that are applied directly in their numerical form in the model. On the other hand, the remaining four are criteria that are represented in factors. For example, the number of accidents is used twice in both accident history and region risk factors to obtain a certain factor that is applied in the equation. While accidents history factor is the standard factor of the number of accidents that occurred at LC over a certain period, the region risk factor is a special factor that measures the collective performance of the level crossings in the region and assigns a factor of risk for each region.

The horizontal and vertical alignments of road are both qualitative indicators that are entered in the equation in the form of a factor. The model classifies horizontal alignments to three qualitative groups: ´straight´, ´curve´, and ´S-shaped´. Similarly, it classifies the vertical alignment to two classes: ´normal´ and ´hump or cavity´.

4.4.6 Austria

In 2012, The Austrian federal railways (ÖBB) had the desire to apply a solid statistical methodology for the assessment of Austrian level crossings in terms of hazards. The task was assigned to the Road Safety Board (KFV) and Austrian Institute of Technology (AIT) [91].

The developed model that was based on 10 years of accident statistics on 350 Austrian level crossings produces a predicted number of accidents and a risk score based on 9 quantitative and 8 qualitative criteria.

The quantitative criteria in the model are: Number of accidents, Time range for applied type of protection in the statistical dataset, maximum train speed, average daily train volume, Road speed, Average daily road traffic, Angle of intersection diversion from 90°, Number of tracks, and maximum road width.

The qualitative criteria in the model are: Type of protection, Road direction from east to west, Illumination, Usage intensity, Agricultural type of land, Spatial structure, horizontal alignment of the road, and distance to the nearest intersection.

The factor of time range is applied to guarantee that only relevant accidents statistics are applied in the model as it accidents data of a level crossing become irrelevant after changing the type of protection. The road direction factor exists to address the sun glare issue that obstructs the visibility of the drivers. The spatial structure is a factor that defines the vertical alignment of the road.

A complete overview of the criteria identified in the reviewed European models and research is presented in Appendix B.

4.5 Prioritization models in other countries

4.5.1 Brazil

Until 1989 the ´Degree of Importance´ was the sole method to select the type of protections at level crossings and to determine priorities for level crossing upgrades. As part of the efforts to prioritize level crossings for upgrades or removal in Brazil, two additional risk indicators were developed in 1989 and included in the Brazilian guidelines [92].

Indicator 1: Degree of Importance (DI)

$$DI = daily\ trains\ volume\ x\ daily\ road\ vehicles\ volume\ x\ F \quad \text{(Eq. 29)}$$

Where F is a function of visibility, approach grade, trains speed average, road Vehicles average speed, and composition of road users percentages.

Brazilian regulations recommend the type of protection to be installed at crossings based on the DI indicator. For example, passive protection is allowed for crossings with DI value that does not exceed 20,000.

Indicator 2: Weighed Factor of Accidents (WFA)

This indicator is used to give a quantified representation of accidents risk based on accidents data obtained from the last 5 years.

$$WFA_5 = (9.5\ x\ M) + (3.5\ x\ F) + D \quad \text{(Eq. 30)}$$

Where:
M = Number of accidents involving fatalities in the last 5 years
F = Number of accidents involving injuries in the last 5 years
D = Number of accidents involving material damage only in the last 5 years

Indicator 3: Moment of Circulation (K)

It is a more complex version of the Degree of Importance indicator and considers in addition to the factors included in DI the factor of time for both rail and road users as it differentiates between vehicles that pass the crossing during night or day in term of weighting.

$$K = [(V_d\ x\ T_d) + ((1.4\ x\ V_n)\ x\ T_n)]\ x\ L \quad \text{(Eq. 31)}$$

Where:
V_d = Volume of road vehicles during the day
T_d = Trains volume through day
V_n = Volume of road vehicles during the night
T_n = Trains volume through night
L = Factor for number of tracks

The Brazilian regulations determine the type of protection to be selected based on the K value obtained, the Road class, availability of electricity in the area, number of pedestrians and area classification (urban or rural).

Indicator 4: The Critical Index (CI)

This indicator was proposed in 2007 by Carmo et al. as a combination of the DI and K indicators that brings the best factors of both indicators together in one indicator. The Critical Index simply replaces the L factor in K indicator with a new factor.

$$CI = [(V_d \ x \ T_d) + ((1.4 \ x \ V_n) \ x \ T_n)] \ x \ F \qquad (Eq.\ 32)$$

The weights of F factor were determined using the judgement of experts through a questionnaire that was answered by a panel of Brazilian railway experts and engineers. Table 27 demonstrates the weights of factors to determine the value of factor F in the Critical Index indicator. Factor F can have a minimum value of 1 and a maximum value of 2.

Table 27: Weights of factors in the critical Index indicator (CI)

Criteria	Alternatives	Weight
Visibility	>300m	0.2
	150-300m	0.3
	<300m	0.4
Maximum approach grade	<3%	0.14
	3-5%	0.21
	>5%	0.28
Train speed	<40 Km/h	0.14
	40-80 Km/h	0.21
	>80 Km/h	0.28
Number of tracks	1	0.12
	2	0.18
	>2	0.24
Maximum posted highway speed	<50 Km/h	0.1
	50-80 Km/h	0.15
	>80 Km/h	0.2
Percentage of pedestrians	≤5%	0.04
	5-20%	0.06
	>20%	0.08
Road lanes	1	0.1
	2	0.15
	>2	0.2
Pavement Condition	Inexistent	0.08
	Not Regular	0.12
	Regular	0.16
Illumination	Inexistent	0.08
	Insufficient	0.12
	Efficient	0.16

Indicator 4: The Safety Level Index

Campos et al. proposed using a new indicator that combines accidents history with the level crossing operational and physical characteristics and therefore developed the Safety Level Index based on the Critical Index (CI) developed by Carmo et al. and the Weighed Factor of Accidents (WFA_5) developed in 1989 [92].

$$SLI = \frac{CI}{10000} + (1.5 \ x \ WFA_5) \qquad (Eq.\ 33)$$

4.5.2 India

There is no advanced methodology to evaluate and prioritize level crossings for improvements in India yet. However, an evaluation technique exists to decide the type of protection to be installed at level crossings and when does the crossing becomes a candidate of grade separation or protection improvement called ´Train Vehicle Unit (TVU)´ [93].

TVU is simply the traffic exposure parameter which is the product of multiplication of road vehicles daily volume by the volume of daily trains. In addition to traffic exposure, the Indian TVU states that all unmanned crossings must have at least 600m of sight distance for road users. If this condition is not met, a crossing is prioritized to be manned. Also, when the TVU value exceeds 100,000 The crossing is prioritized for grade separation. The type of protection to be installed based on the TVU criteria are as follows:

Table 28: TVU approach in India [93]

TVU Value (traffic exposure)	Sight distance	Type of crossing
TVU < 6,000	≥600 m	Unmanned
6000 ≤ TVU < 10,000	-	Prioritized to be manned if unmanned
10,000 ≤ TVU < 100,000	-	Manned
TVU ≥ 100,000	-	Grade separation

4.5.3 Japan

Japan used to depend on a simple approach to assess the level crossings for consolidation. The approach was simply an improved version of the traffic exposure by multiplying it with the crossing closure time. It was decided to take this approach instead of the simple traffic exposure because it was found that many crossings with very high exposure perform very well in terms of safety compared to other crossings exposed to less traffic. Therefore, the idea was to prioritize the crossings based on economic losses resulting from wasted time at crossings and thus a new indicator was selected for prioritization called ´Closed Road Traffic Indicator (CRT)´ [43].

$$CRT = daily\ trains\ volume\ x\ daily\ road\ vehicles\ volume\ x\ Crossing\ closure\ time \quad (Eq.\ 34)$$

Japanese authorities have set a CRT value of 10,000 as the threshold for grade separation. When the CRT value of any crossing exceeds 10,000 the LC is recommended to be grade separated. However, this rule was not strictly applied since it was reported that some crossings exist with CRT values that exceed 10,000 and even 100,000 in some cases.

The Closed Road Traffic Indicator (CRT) method was applied for a short term only in Japan as a new methodology was developed later called ´Level Crossing Danger

Index´. This new index is also based on a parameters gate algorithm same as CRT but is considered a bit more advanced since it includes 7 factors instead of 3.

The significant parameters that make up the Level Crossing Danger Index are daily road vehicles volume, daily train volume, daily train passengers, number of tracks, road width, crossing width and accident history.

$$\text{Level Crossing Danger Index} = \text{number of accidents per year} + \text{daily train volume} + \text{daily road vehicles volume} + \text{number of train passengers per day} + Z \quad \text{(Eq. 35)}$$

Where Z is a function of the difference in width of level crossing and road, the distance between fixed warning signs and first rail, and the number of tracks [43].

4.5.4 Russia

The Russian Federation Railways use a matrix for determining the type of protection at Russian level crossings called the ´Rail and Road Intensity Matrix´. This matrix classifies all crossings into four classes depending on the road and rail traffic volumes only. Only class 1 is required to be manned and protected by barriers [93].

However, the Rail and Road Intensity Matrix is not obligatory and only used as aiding guideline as the type of protection in most cases is determined by The Russian Federation Railways after an individual case study of each candidate crossing. Case studies usually consider various factors such as sight distances and visibility, rail and road traffic volumes, and availability of electricity. The same applies for selecting crossings for protection upgrade or consolidation [93].

Table 29: Russian Rail and Road Intensity Matrix [93]

Daily train volume	Daily road vehicles volume				
	≤200	201-1000	1001-3000	3001-7000	>7000
≤16	4th Class	4th Class	4th Class	3rd Class	2nd Class
17-100	4th Class	4th Class	3rd Class	2nd Class	1st Class
101-200	4th Class	3rd Class	2nd Class	1st Class	1st Class
>200	3rd Class	2nd Class	2nd Class	1st Class	1st Class

4.6 Summary of all reviewed models

In this project, 112 International risk assessment and prioritization models were reviewed. While most of the models were national models that are either currently or formerly applied, many reviewed models were research attempts to create a risk assessment, prioritization model or simply an attempt to study factors that significantly influences the safety at level crossings.

The methodologies applied in USA, Canada, Australia, New Zealand, and UK were found to be the most advanced and comprehensive on the international level. The models in each geographical area are fairly similar and countries often use the experiences of neighbor countries to develop their own models. This could be clearly noticed when you consider the fact that LCSIA of New Zealand is developed on the basis of ALCAM of Australia.

The models in Australia and New Zealand were found to be the most comprehensive in terms of adopted factors in the model while the models in USA and UK adopted a similar number of factors for evaluation. Figure 26 demonstrates a comparison of international approaches and models in terms of considered factors.

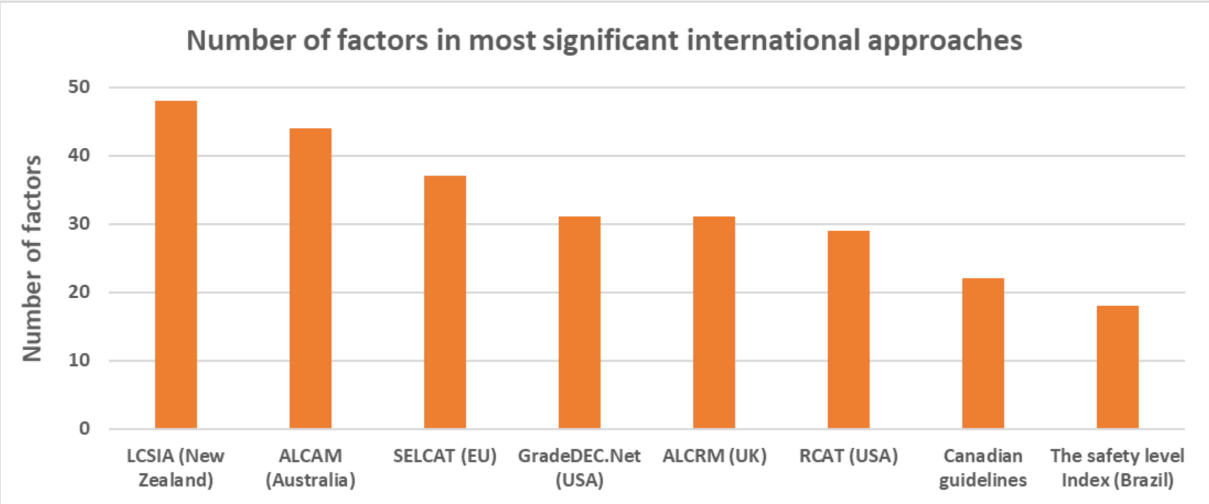


Figure 26: Number of factors in most significant international approaches

As for individual factors, it is observed that the rail and vehicles daily volume remain to be the most dominant in all models with a presence in 91% of models. Train speed was a significant factor in 71% of models while safety factors such as type of protection and Accident history were used in 58% and 57% of models respectively. Figure 27 demonstrates the top 11 factors identified in the 112 reviewed models in this project and their respective percentages of presence.

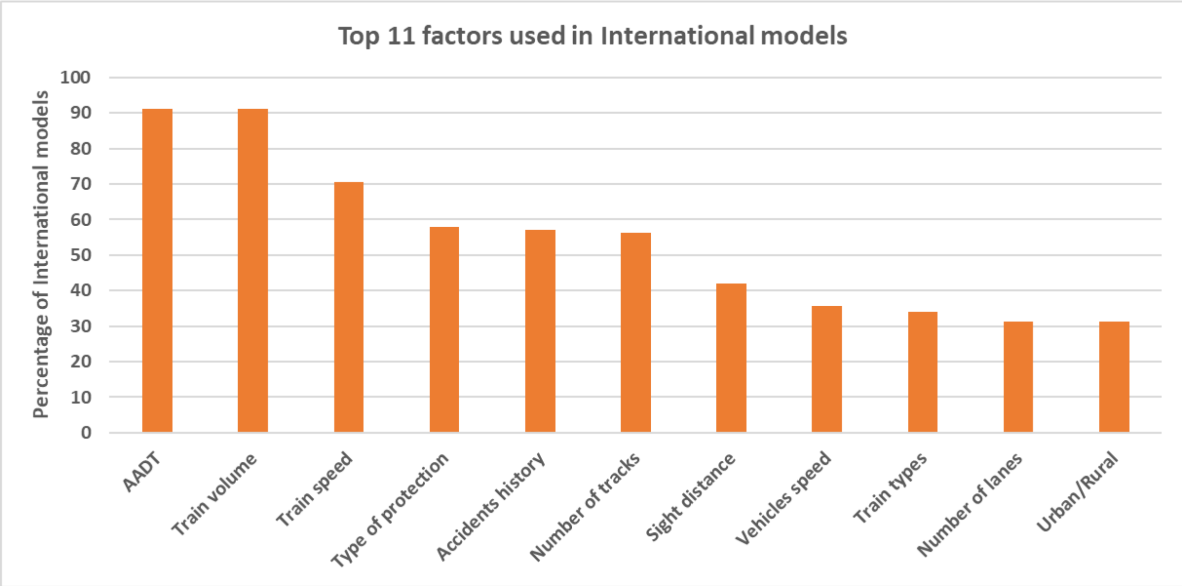


Figure 27: Top 11 factors in international models

By comparing the results of top 10 factors in US models (Figure 23) and top 11 factors in international models (Fig. 27), it is observed that a very close pattern and percentages exist in both. Therefore, it is safe to assume that these identified factors are indeed the most significant. To obtain a satisfactory level of prediction accuracy, every risk assessment and prioritization model must include those highly present factors.

5 Development of German Level Crossing Consolidation and Prioritization Model

5.1 History of German Level crossing models

Schöne reported six historical attempts to study the main factors of safety or create a model to select the appropriate type of protection or evaluate risks at German level crossings [30].

First attempt: Professor Friedrich Raab developed a statistical model in 1955 based on accident data to evaluate the relative safety of level crossings. The model was proposed to determine the appropriate type of protection at crossings using limit values derived from the statistical data [30].

Second attempt: An investigation performed by Müller in 1965 to determine the accident probability for every type of protection used at level crossings and suggest criteria for selecting the type of protection [30].

Third attempt: The German federal highway institute (BASt) conducted a study in 1980 to determine whether the attention of the drivers is different when they approach flashing lights compared to approaching light signals. The study concluded that there were no significant differences and suggested several level crossing physical design requirements as an outcome of the study [30].

Fourth attempt: An investigation study performed by Amann, Körner and Kröh in 1981 to determine the significant factors on level crossings´ safety by analyzing several operational and physical factors in addition to factors related to driver behavior based on accidents statistics. The study found that road vehicles characteristics such as road vehicles volume and speed significantly influence the number of accidents. In addition, it was found that the factor of familiarity is significant for safety at level crossings. It means that drivers who are more familiar with the crossing or users who use the LC more frequently have a higher risk of accident due to a tendency of ignoring safety rules particularly at passive crossings. It was also found that drivers perform worse if too many traffic signs were present because of a possible distraction. The study also found that the visibility of the crossing has a big influence on accidents numbers [30].

Fifth attempt: Heilmann developed an accident prediction model that focused on the misbehavior of drivers and other users like pedestrians and cyclists in relation to the type of protection. Heilmann recommended that passive crossings secured by overview to have an angle of intersection of 90° with the road to ensure sufficient level of visibility on both sides. The author also questioned the effectiveness of protecting crossings by whistle signal due to the likelihood of failure to perceive the signal by drivers. Schöne criticized the level of detail considered in Heilmann´s model as the model does not consider the road users misconduct at specific crossings [30].

Sixth attempt: Basler & Partner AG investigated 3-years accidents data (1982-1984) to develop decision-making criteria for upgrading the type of protection at German level crossings including safety and economic considerations. Schöne reported that the study that was published in 1986 concentrated on the type of protection as the basis of evaluation and ignored other important factors like the type of road users, LC and road design factors, and visibility [30].

Seventh attempt: The derivation of several qualitative design requirements for level crossings on the basis of an users behavior study conducted in 1989 by `The Research Association for Underground Transportation Facilities (STUVA)´ [30].

Eighth attempt: Ellinghaus und Steinbrecher conducted a survey for road users in 2006 which helped understand further the behavior of road users when using level crossings [30].

Despite all the previously mentioned attempts to identify the most significant risk factors at German level crossings, there was no reliable model to quantitively assess and prioritize crossings in Germany until 2013 when Schöne developed a risk assessment procedure to evaluate level crossings based on various factors and aid the selection procedure for the appropriate type of protection. The model was developed using accidents data between 2003-2009 [30].

Schöne investigated the influence of individual factors on individual and collective risk for a set of road users including cars, trucks, Buses, motorcycles, cyclists, and pedestrians. Factors identified as significant for investigation were selected after conducting extensive literature review and empirical investigations. The list of investigated factors included train length, train speed, trains volume, pre-blocking time, road traffic volume, average road users speeds, angle of intersection, type of protection, visibility or sight distance and queuing. In addition, risk acceptance limits were defined for individual and collective risks. The study also covered the evaluation of some of the risk control measures. Table 30 summarizes the most important findings of Schöne´s work [30].

Table 30: Influences of factors on individual risk [30]

Factor	Influence on risk for motorized users	Influence on risk for non-motorized users
Train length	Weak	No influence
Train speed	Strong	Strong
Trains volume	Medium	Medium
Pre-blocking time	Medium	0-60s: No influence 60-240s: Medium
Road traffic volume	Strong	No influence
Road users speed	Highly dependent on other parameters	Highly dependent on other parameters
Angle of intersection	Weak	Strong
Type of protection	Strong	Strong
Sight distance	Strong	Strong
Queuing	Strong	Strong

Schöne has called for further research on several more factors that contribute to the safety of level crossings in Germany. However, the lack of sufficient thorough statistics obstructs the efforts to analyze risk factors. According to Schöne, it is necessary to create an extensive German database for level crossing accidents data that includes relatively rare or low consequence incidents including near misses. Such database could accelerate the research efforts at the level crossings field [30].

In 2016, a research team from CERSS commissioned by the German Insurance Association (GDV) created a quantitative and qualitative risk assessment and analysis model.

The developed model involved the creation of an accident prediction equation for every type of protection that was based on crossing data of 1040 level crossings in Germany in addition to an accidents database of 103 accidents during the years 2005-2011 that was prepared by the research team.

$$U = 0.008 \; x \; ADT^{0.346} \; x \; e^{(-3.899xPT)-(0.958xC)+(1.171xS)} \qquad \textit{(Eq. 36)}$$

Where:
ADT = Average daily traffic for road vehicles
PT = Factor for type of protection (1 for full barriers, 0.577 for half-barriers, 0 for flashing light or light signals)
C = Road curvature (gon/m)
S = Factor for train speed (121-160 km/h: 1, 101-120 km/h: 0.57, 0-100 km/h: 0)

Another accident prediction formula was derived for cases when the daily traffic volume is missing:

$$U = 0.105 \; x \; e^{(-3.574xPT)-(0.837xC)+(1.164xS)} \qquad \textit{(Eq. 37)}$$

Where S= Factor for train speed (121-160 km/h:1, 101-120 km/h:0.59, 0-100 km/h:0)

And a third accident prediction formula for passive crossings:

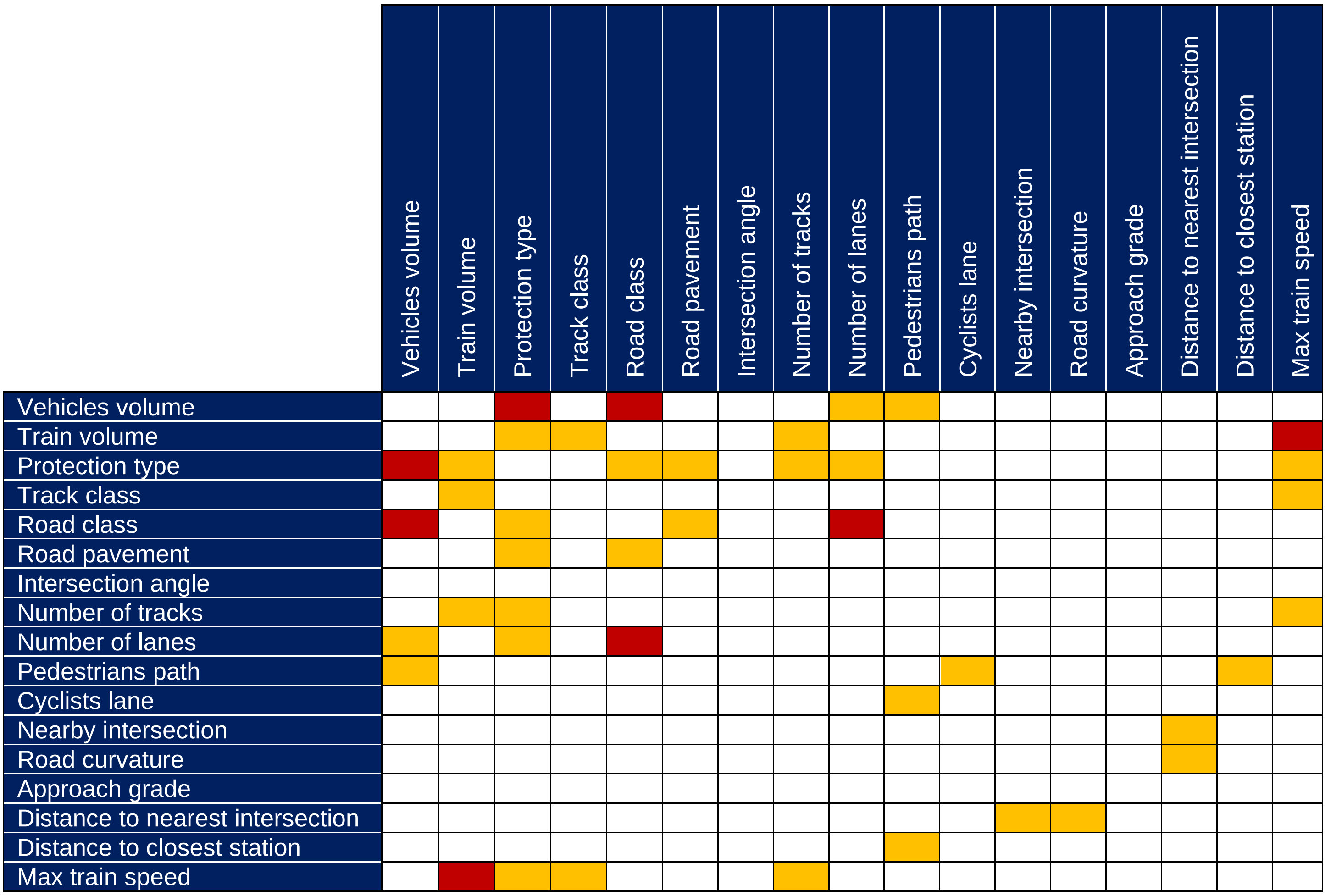
$$U = 0.019 \; x \; e^{(-0.483xRC)-(1.203xRP)-(0.006xNI)} \qquad \textit{(Eq. 38)}$$

Where:
RC = Factor for road class (pedestrians or cyclists path: 1, Other road classes: 0)
RP = Factor for road pavement (unpaved=1, paved=0)
NI = Distance to closest intersection (m) [Maximum: 300m]

The factors selected to form the model were: average daily road vehicles volume, trains volume per day, type of protection, track class, road class, existence of road pavement, angle of intersection, number of tracks, number of lanes, existence of separate pedestrian path, existence of separate cyclists lane, road curvature, approach grade, existence of a nearby intersection within 250m from LC, distance to the closest nearby intersection, distance to the closest train station, and maximum train speed [94].

The authors measured the correlation of factors upon each other to find out the factors which were more reliant on other and the factors that were independent in influencing risk. Table 31 summarizes the findings. Red marked cells indicate a strong correlation, orange cells indicate medium correlation while white cells indicate weak correlation.

Table 31: Factors correlation matrix [94]



The authors developed a points-based system to rate crossings according to their level of risks based on the risk values calculated by Schöne in 2013. 1 indicates the lowest level of risk while higher scores indicate higher risks. The risk point system is demonstrated in table 32.

Table 32: Risk points system for German level crossings [94]

Main criteria	Non-motorized		Motorized	
	Alternatives	Points	Alternatives	Points
Train volume	≤20	1	≤20	1
	20-60	2	20-60	2
	>60	3	>60	3
Train Speed	≤40 km/h	1	≤40 km/h	1
	41-60 km/h	2	41-60 km/h	2
	61-80 km/h	3	61-80 km/h	3
	81-100 km/h	4	81-100 km/h	4
	101-120 km/h	5	101-120 km/h	5
	121-140 km/h	6	121-140 km/h	6
	141-160 km/h	7	141-160 km/h	7
Type of protection	Full barriers	1	Full barriers	1
	Half barriers	2	Half barriers	5
	Light signals	3	Light signals	7
	Passive	4	Passive	9

Main criteria	Non-motorized Alternatives	Points	Motorized Alternatives	Points
Pre-blocking time	Passive: all or light signals: 0-30s or half barriers: 0-60s or full barriers: 0-120s	1	Passive: all or light signals: 0-60s or half barriers: 0-120s or full barriers: all	1
	Light signals: 31-60s or half barriers: 61-120s or full barriers: 121-240s	2	Light signals: 61-120s or half barriers: 121-240s	2
	Light signals: >60s or half barriers: >120s or full barriers: >240s	3	Light signals: >120s or half barriers: >240s	3
Number of daily users	≤100	1	≤100	1
	101-300	2	101-300	2
	301-1000	3	301-1000	3
	1001-3000	4	1001-3000	4
	>3000	5	>3000	3
Visibility	Approach time > Clearance time	1	Approach time > Clearance time	1
	(0.66 x Clearance time) < Approach time ≤ Clearance time	2	(0.66 x Clearance time) < Approach time ≤ Clearance time	2
	(0.33 x Clearance time) < Approach time ≤ (0.66 x Clearance time)	3	(0.33 x Clearance time) < Approach time ≤ (0.66 x Clearance time)	3
	Reaction time < Approach time ≤ (0.33 x Clearance time)	4	Reaction time < Approach time ≤ (0.33 x Clearance time)	4
	Approach time ≤ Reaction time	5	Approach time ≤ Reaction time	5
Detectability	-	-	Good	1
	-	-	Road curve before LC	2
	-	-	Intersection before LC	3
Tail-back risk	-	-	No clearance problems	1
	-	-	Some compensated clearance problems: e.g. light signal ahead	2
	-	-	Some uncompensated clearance problems or many problems partially compensated	3
	-	-	Many uncompensated clearance problems: e.g. intersection ahead with heavy traffic	4

According to the model, crossings could be classified into 3 risk bands based on the obtained risk points score:

- **Low-risk band:** There is no immediate action needed for crossings in this band. This band includes crossings that score 6-13 points for non-motorized or 7-15 points for motorized.
- **Medium-risk band:** Level of risk for crossings in this band is accepted but a comprehensive assessment is advised to decide whether risk control measures

are needed. This band includes crossings that score 14-22 points for non-motorized or 16-24 points for motorized.

- **High-risk band:** Immediate action is needed for crossings in this band. This band includes crossings that score 23-27 points for non-motorized or 25-34 points for motorized.

5.2 Methodology

The decision-making process to select or prioritize level crossings for consolidation or safety upgrade is a very complex decision and rely on various criteria as demonstrated in the previous chapters. These criteria are not exclusively related to safety but also several social, economic, and environmental factors are also key factors and ought to be considered by decision makers. Therefore, it was decided that a Multi-Criteria Decision Making (MCDM) approach would be the most suitable approach for the creation of a level crossing prioritization model.

The majority of reviewed models used statistically driven approaches for the creation of models. This aligns with the findings of RSSB review of international models. Despite a statistically driven approach being the mostly used methodology internationally, it is difficult to create a model based on this methodology due to the lack of reliable databases for German level crossings accidents and characteristics. The model created by Hantschel et al. remains the best available statistically driven approach developed using accidents and LC data from Germany.

This model is based on a complex weighted factor method that was found to be used in many countries with limited statistical data. The criteria selected in the model were based on an extensive literature review of international models that were presented in chapter 4. And a review of various researched individual criteria extracted from multiple factors significance research studies presented in this chapter. This model also builds on the models developed by Schöne and Hantschel et al. The risk scoring of criteria from both models were taken into consideration while selecting the criteria of this model.

As for the weighting methodology, the Analytic Hierarchy Process (AHP) was selected to develop weights for the selected factors based on a survey conducted and answered by German railway and level crossing experts from both the academic and professional fields. In the survey, all experts were asked to compare the selected factors against each other in a pairwise comparison approach. The results of experts survey were then analyzed to calculate the weights of each main and sub criterion.

AHP was developed in the 1970´s by Saaty as a methodology to mathematically analyze complex decisions through pairwise comparisons. It is considered one of the best available methods for multi-criteria decision making (MCDM) and have been used to create many models in various sectors including the railway sector. Since its development, AHP has shown great effectiveness for MCDM and resource allocation purposes.

The AHP methodology recommends a maximum of 9 factors to be compared at each stage. If the model involves more factors, it is advisable to group the criteria at multiple hierarchy levels. Due to the big amount of criteria considered in this model, all factors were grouped into three hierarchy levels with 5 main factors at the first level, 21 factors in the second level, and 32 factors in the third level of hierarchy. Therefore, the total number of considered criteria in this model is 43 criteria.

In addition to the easily manageable way of structuring, the hierarchies of AHP provide a major advantage of flexibility to the model. The weights are distributed on all levels and therefore, if any future modifications to the model through adding or removal of factors were later desired, there will be no need to perform a completely new weighting process but rather the weighting of the sub-group where factors were modified is only required. In this case, the weight from the criterion on the higher hierarchy level will be redistributed to the new set of factors.

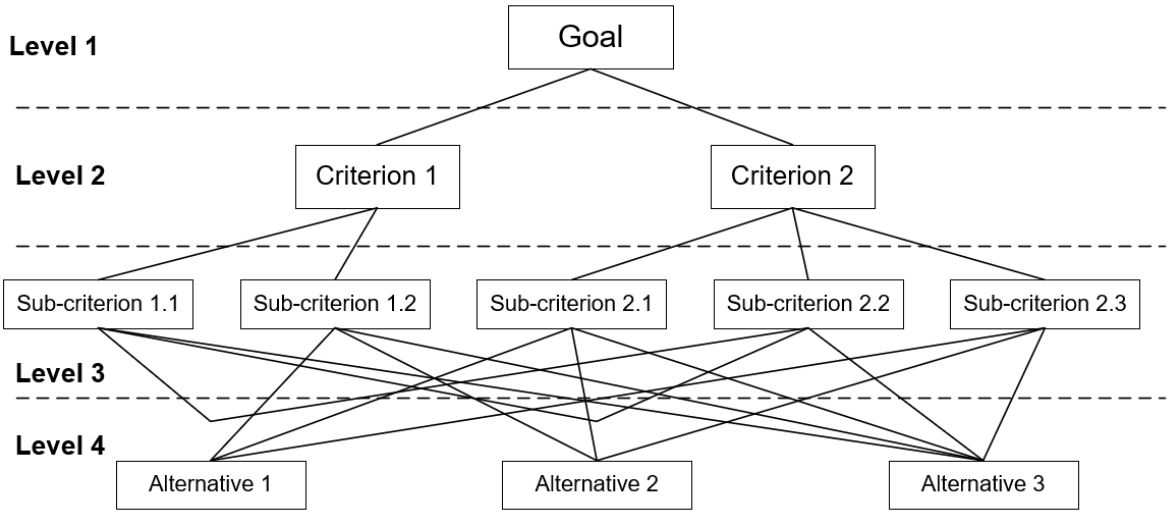


Figure 28: A standard hierarchical structure in AHP

Additionally, AHP has the advantage of transparency of factors significance. Through the comprehensive weighting methodology by comparing all criteria against each other, it is possible to understand the relative priorities of factors compared to each other and therefore derive relations between factors.

However, AHP has some disadvantages and limitations too. For example, the weighting process is completely reliant on the judgement of experts. Therefore, it is highly influenced with the number of experts selected for performing the pairwise comparisons and their level of experience. The results of AHP technique could be unreliable if the experts did not have the required level of knowledge. Therefore, the selection of experts is an extremely important stage in the AHP methodology.

AHP has been used in the field of railway systems evaluation and level crossing risk assessment for years. Wang and Cui developed a safety assessment model based on AHP for level crossings in China. Their model compared 21 influencing factors and produced the following weights of criteria [95]:

Table 33: Weights of factors of the Chinese AHP model [95]

Main criteria	Sub-criteria	Weight
Crossing factors	Intersection angle	0.1627
	Number of tracks	0.0990
	Crossing width	0.0653
	Crossing slope	0.2675

Main criteria	Sub-criteria	Weight
	Road types	0.4055
Safety device factors	Guardrail, door	0.0939
	Flash, sirens	0.1517
	Obstacle Detection	0.2521
	Road sign	0.3826
	Road lights	0.0264
	Vehicle monitors	0.0537
	Safety device position	0.0396
Other factors	Bad weather	0.1770
	Visibility	0.2639
	Traffic density	0.3863
	Traffic chaos	0.0257
	Accident emergency	0.0989
	Road safety education	0.0482
Crossing managing factors	Crossing management modes	0.6371
	Financing source	0.1052
	Policies and laws	0.2582

Bureika et al. proved that applying AHP assessment of railway infrastructure in Lithuania can help improve the safety situation on the long-term. The research performed in 2013 included a case study of 25 risk factors that contribute to a higher risk of human injury, derailment, or a collision of rolling stock. A railway line was evaluated then based on the weights developed from the AHP method according to those risk factors identified [96].

Hans et al. developed a consolidation rating formula in 2015 for level crossings in the state of Iowa in USA. The formula was developed based on a methodology similar to AHP as 9 selected criteria were compared against each other, and two weighting matrices were developed for urban and rural crossings. The factors comparison was completed by a Technical Advisory Committee that involved city and county engineers, agricultural industry representatives, railroad representatives, and Iowa Department of Transportation representatives. The developed model ranks all the crossings of the state for consolidation based on the weighted factors and an Excel sheet was created for the purpose. The results of the project produced the following weighting model [78]:

Table 34: Factor weights of Urban and rural crossings in the Iowa consolidation model [78]

Criteria	Weight (Urban)	Weight (Rural)
AADT	0.16185	0.16185
Out of distance travel	0.17341	0.17341
Trucks volume	0.04624	0.04624
Roadway system	0.08671	0.12139
Number of emergency medical services within 3 miles radius	0.12717	-
Number of emergency medical services within 6 miles radius	-	0.12717
Distance to closest emergency medical service	0.12717	0.12717
Number of schools within 2 miles radius	0.08671	-
Number of schools within 6 miles radius	-	0.06936
Distance to closest school	0.08671	0.06936
Alternate route crash rate	0.10405	0.10405

Recently, Barić and Džambo developed a model to evaluate level crossing design alternatives in congested urban area. The developed model considered 6 main criteria and 15 sub-criteria and was tested for a level crossing in Zagreb, Croatia. Table 35 summarized the criteria selected for the model and their respective weights that were derived through AHP methodology. However, for this model, the AHP weights were not obtained through a survey for experts as usual but rather derived by comparing various studies [97].

Table 35: Weighted factors of the design alternatives model [97]

Main criteria	Sub-criteria	Weight
Safety factors	Safety of pedestrians and cyclists	0.197
	Traffic accident possibility	0.124
	Number of conflict points	0.078
Traffic factors	Average waiting time	0.070
	Queue length	0.033
	Average speed	0.023
	Throughput capacity	0.117
Costs	Construction costs	0.062
	Maintenance costs	0.008
	Land acquisition costs	0.017
Social benefits	Mobility of pedestrians and cyclists	0.014
	Influence on traffic culture of LC users	0.058
Ecological factors	Noise	0.024
	Exhaust gases	0.056
	Area occupancy	0.015
Time for LC reconstruction	-	0.106

In Germany, the AHP methodology was previously used by Mühlbacher and Kaczynski in the healthcare sector [98].

5.3 Work steps

The first step after identifying the most relevant criteria to be implemented in the model was to group the factors into groups that share similar characteristics and distribute them into three hierarchy levels. the first level of hierarchy are the main criteria of the model; the second and third levels represent the sub criteria on the basis of which the level crossings are to be evaluated and, finally, the fourth level presents the different Alternatives (options) related to the criteria investigated.

The main evaluation criteria that form the core of this model are traffic and operational factors, physical factors, safety factors, social factors, and environmental and economic factors. A list of the selected criteria in the model and their respective levels in hierarchies is presented in chapter 5.4.

After the model´s criteria were selected and distributed to groups in a hierarchy model, a survey was created and distributed to a chosen group of experts. Level crossing Experts, safety experts and traffic engineers were identified as key participants of this study. Experts include those identified as having an extensive knowledge of level crossing safety, level crossing consolidation and level crossing planning. Experts panel included university academics, researchers, professional engineers, planners, etc. Diversity in expertise and fields was taken into account by choosing the experts. The participant experts were from railway, road traffic and traffic safety sectors. The survey was completed by 11 contacted experts.

As part of the survey, the experts were asked to perform a pairwise comparison for criteria against each other in terms of the factor contribution to overall risk, its negative contribution to the environment, economy and the life quality of the surrounding population, and the relative importance of the criteria towards consolidation or upgrade priority. A total of 319 pairwise comparisons were completed by each expert. The comparison is performed by choosing a number of 1-9 as rating of importance of one factor over the other as demonstrated in figure 29. However, the rating must be assigned according to a predefined AHP-scale. Table 36 demonstrates the standard scale for AHP ratings as developed by Saaty [99].

Area classification	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Road type
Road type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Track type

Figure 29 Example of AHP comparison:

Table 36: Standard AHP scale [99]

Intensity of importance	Definition	Explanation
1	Equal importance	Both criteria have the same degree of importance
3	Moderate importance	Experience and judgement slightly favor one criterion over another
5	Strong importance	Experience and judgement strongly favor one criterion over another

Intensity of importance	Definition	Explanation
7	Very strong importance	One criterion is very strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The highest possible difference in significance between two criteria
2, 4, 6, 8	Intermediate values	Can be used as a compromise when factors are close in importance

Experts were asked to keep in mind the following considerations while performing the comparisons:

- **Totality:** It is important that experts keep the overall form of the model in mind while comparing individual criteria. This means that the expert must consider the criteria included in the lower levels while comparing criteria from the upper levels.
- **Consistency:** Experts must strive for consistency in their answers. For example, if criterion A is determined more important than criterion B and criterion B is more important than criterion C, then a decision that criterion C is more important than criterion A would be considered inconsistent.

Saaty proposed a consistency index (CI) and a consistency ratio (CR) to check the consistency of the derived matrices. The consistency checks are considered as a validation of the derived weights of factors. If the comparison matrix fails the consistency checks, the derived weights become unreliable and therefore cannot be adopted. The following is the equation proposed by Saaty to calculate the consistency index [99]:

$$CI = \frac{\lambda_{max} - N}{N-1} \quad \text{(Eq. 39)}$$

where λ_{max} is the matrix maximal eigenvalue and N is the size of comparison matrix

The consistency ratio compares between the obtained consistency index and a random index and is calculated by:

$$CR = \frac{CI}{RI} \quad \text{(Eq. 40)}$$

Where RI is the random index value which could be obtained based on the comparison matrix size (N) (Table 37). Saaty sets the limits of accepted consistency ratio at 10% maximum. This means that if the CR value was calculated to be more than 0.1, the judgement may be random and should be revised.

Table 37: Random index values [98]

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The results of the pairwise comparisons collected from experts were then analyzed using the decision-making software “Super Decisions” that was developed by Saaty as a tool of implementation of AHP. The required consistency checks were then performed on the comparison matrices that were generated from the software. Following the analysis and consistency checks, the final weights of factors were adopted, and a points-based evaluation system of level crossing was developed based on the derived weights.

5.4 The model´s hierarchy

The model consists of 5 main criteria, 21 sub-criteria, 32 sub-sub criteria and 147 alternatives.

Table 38: Hierarchy of the model criteria

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)
Traffic and operational factors	Functional classification	Area classification	Rural
			Urban
		Road type	Federal highways
			State roads
			County roads
			City and municipal roads
			Others (e.g. field and forest roads)
		Track type	Main track
			Side track
	Traffic Exposure	Average daily road traffic volume	Weak: ≤100 vehicles/day
			Moderate: 101-2500 vehicles/day
			Strong: >2500 vehicles/day
		Train volume	≤ 20 Trains/day
			21-40 Trains/day
			41-60 Trains/day
			>60 Trains/day
	Road users factor	Pedestrians and cyclists %	<5%
			5-20%
			>20%
		Trucks %	<5%
			5-20%
			>20%
		Presence of buses and school buses	Present
			Not present
	Train characteristics	Train types	With passenger traffic
			Only freight traffic
		Train length	≤ 100m
			101-200m
			>200m
	Speed factor	Train speed	≤20 km/h
			21-40 km/h
			41-60 km/h
			61-80 km/h
			81-100 km/h
			101-120 km/h
			121-140 km/h
			141- 160 km/h
		Maximum road speed	≤ 10 km/h
			11-30 km/h
			31-50 km/h
			51-70 km/h
			>70 km/h
	Waiting time (Delay)	-	≤30s
			31-60s
			61-90s
			91-120s
			121-150s

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)
			151-180s
			181-210s
			211-240s
Physical factors	Geometrical factors	Angle of intersection	61°-90°
			31°-60°
			0°-30°
		Approach grade (AG)	<3%
			3% ≤ AG < 6%
			6% ≤ AG < 9%
			9% ≤ AG < 12%
			AG ≥ 12%
		Track curvature	R < 250m
			250m ≤ R < 500m
			500m ≤ R < 750m
			R ≥ 750m
		Road curvature	<0.25 gon/m
			0.25 - 0.5 gon/m
			0.5 - 0.75 gon/m
			0.75 - 1 gon/m
			> 1 gon/m
		Road width	< 4.75m
			4.75 – 5.5m
			5.5 – 6.35m
			≥ 6.35m
		Number of tracks	1
			2
			3
			≥4
		Number of lanes	1
			2
			≥3
		Distance to nearby intersection (DNI)	In clearance section (≤27m)
			27 < DNI ≤ 50m
			50 < DNI ≤ 100m
			100 < DNI ≤ 150m
			>150m
	Visibility	Sight distance	>400m
			200-400m
			<200m
		Sight obstructions	No obstructions
			Obstructions exist
		Illumination	Sufficient
			Insufficient
			No illumination
	Pavement	Type of crossing surface	Rubber
			Concrete
			Asphalt
			unpaved
		Type of road pavement	Paved
			Unpaved
		Condition of crossing and road pavement	Good condition
			Poor condition
Safety factors	Type of protection	-	Full barriers
			Half barriers
			Light signals / Flashing lights

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)
			Passive
	Accident history	Number of accidents	0
	Accident history	Number of accidents	1-2
	Accident history	Number of accidents	3-4
	Accident history	Number of accidents	>4
	Accident history	Number of fatalities	0
	Accident history	Number of fatalities	1-2
	Accident history	Number of fatalities	3-4
	Accident history	Number of fatalities	>4
	Accident history	Number of severe injuries	0
	Accident history	Number of severe injuries	1-2
	Accident history	Number of severe injuries	3-4
	Accident history	Number of severe injuries	>4
	Accident history	Number of slightly injured	0
	Accident history	Number of slightly injured	1-2
	Accident history	Number of slightly injured	3-4
	Accident history	Number of slightly injured	>4
	Road markings	-	Exist
	Road markings	-	No road markings
	Traffic safety devices	-	Exist
	Traffic safety devices	-	No traffic safety devices
	Hazardous material transportation	-	No regular hazardous material transportation
	Hazardous material transportation	-	Regular hazardous material transportation
Social factors	Emergency services	-	None exist within a radius of 500m
Social factors	Emergency services	-	Exist within a radius of 500m
Social factors	Schools	-	None exist within a radius of 500m
Social factors	Schools	-	Exist within a radius of 500m
Social factors	Vulnerable population and sensitive facilities	-	None exist within a radius of 500m
Social factors	Vulnerable population and sensitive facilities	-	Exist within a radius of 500m
Social factors	Special social and event venues	-	None exist within a radius of 500m
Social factors	Special social and event venues	-	Exist within a radius of 500m
Environmental and economic factors	Noise	No train whistle or pedestrians audible warning signal required at LC	Industrial areas
Environmental and economic factors	Noise	No train whistle or pedestrians audible warning signal required at LC	Commercial and agricultural areas
Environmental and economic factors	Noise	No train whistle or pedestrians audible warning signal required at LC	Residential areas
Environmental and economic factors	Noise	No train whistle or pedestrians audible warning signal required at LC	Near hospitals, schools, health resorts and retirement homes
Environmental and economic factors	Noise	LC secured by train whistle or pedestrians audible warning signal	Industrial areas
Environmental and economic factors	Noise	LC secured by train whistle or pedestrians audible warning signal	Commercial and agricultural areas
Environmental and economic factors	Noise	LC secured by train whistle or pedestrians audible warning signal	Residential areas
Environmental and economic factors	Noise	LC secured by train whistle or pedestrians audible warning signal	Near hospitals, schools, health resorts and retirement homes
Environmental and economic factors	Vehicle emissions	-	Low emissions
Environmental and economic factors	Vehicle emissions	-	Moderate emissions

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)
			High emissions
	Operating costs	-	Low costs
			Moderate costs
			High costs

5.5 Description of the model´s criteria

The main criteria of the model were divided into five categories:

- **Traffic and operational factors:** Factors that are related to traffic situation at the level crossing. These factors simulate the exposure to risk of all users and the characteristics that are significant in determining the consequences of accidents.
- **Physical factors:** These factors are related to the geometrical design of the level crossing. The factors in this category relate to the risk imposed by the crossing on its users and the ability of users to identify the risk and react to it.
- **Safety factors:** this category of factors relate to the historical risk of the crossing and safety measures applied at the crossing to improve safety.
- **Social factors:** This category of factors relate to the special risk imposed on vulnerable groups in society that needs a special elevation in safety and risk elimination measures.
- **Environmental and economic factors:** Factors that are non-safety related but deal with the quality of life of the population that inhabits the area surrounding the level crossing. In addition to the economic factor that could incentivize the removal of the crossing.

5.5.1 Traffic and operational factors

The traffic and operational factors were classified into 6 sub-categories:

- Functional classification
- Traffic Exposure
- Road users factor
- Train characteristics
- Speed factor
- Waiting time (Delay)

5.5.1.1 Functional classification

This category relates to classifications that indicate the intensity of level crossing users. There are three sub-sub criteria in this sub-category which are:

- Area classification
- Road type
- Track type

5.5.1.1.1 Area classification

The presence of a level crossing inside or outside a city is an important factor that also have a high influence on other factors. Traffic volumes and concentration of nearby schools, emergency services and populations are significantly different in urban or rural areas. Also, the type of road users distribution is different between Urban and rural crossings. For example, the percentage of trucks and agricultural vehicles would be naturally higher at rural areas, but buses are expected to be higher in urban areas. On the other hand, removing a level crossing in a rural area can significantly increase the travel time for road users since less alternative roads exist. Some countries use different models for urban and rural areas [78].

To answer the question of whether the highest risk lies at rural or urban crossings, Saccomanno et al. investigated 5-years of accidents at Canadian level crossings and created a risk-based model that is based on accidents frequency and consequences. The researchers concluded that urban crossings with high AADT had the highest risk in terms of frequency while rural crossings with high train speeds had the highest accidents severity [74].

The factor of whether the level crossing is located at Urban or rural location is not only important on its own but can also play a role in determining the significance of other factors. For example, Johnson found that the road system, distance to nearest school and percentage of trucks are more sensitive for urban crossings. Meanwhile, the number of schools within 6 miles radius had a higher sensitivity as a factor for rural crossings. AADT, out of distance travel and distance to nearest emergency service were found to be sensitive for both [100].

In previous research in Canada, Zalinger et al. reported that the factors of train and road vehicles speed, sight distance and road pavement were significant for rural crossings only [73].

The main alternatives of this sub-sub-criterion are:

- Rural
- Urban

5.5.1.1.2 Road type

The road class is an indication to several factors that are highly significant for each crossing. For example, each highway class suggests a different traffic volume and maximum allowed speeds for road users. Moreover, other factors like pavement type and lane width can also be related to the designated road type.

Highway class can also be an influencing factor on the effectiveness of other factors on safety. To study the effects of highway class in addition to number of tracks on various countermeasures for the purpose of accidents reductions at Canadian crossings, Park and Saccomanno applied recursive partitioning method (RPART) and found that accidents are reduced by 78.4% when protection type is upgraded from passive to flashing lights at arterial or collector roads. Reduction rate is similar at local roads with single track (78.8%) but is less if the local road intersects with multiple tracks (68.8%). Table 39 summarizes the findings of Park and Saccomanno [101].

Table 39: Accidents reduction for countermeasures by highway class and number of tracks [101]

Countermeasure	Arterial or collector	Local or other (Multiple tracks)	Local (Single track)	Other (Single track)
upgrading passive to flashing lights	78.4%	68.8%	78.8%	74.0%
Paving an unpaved crossing	0.0%	48.8%	61.7%	0.0%
Reducing Max allowed speed for road vehicles by 10%	4.7%	0.0%	0.0%	0.0%

EBO and Ril 815 use certain road types such as field and forest paths, and private roads in the selection process of the type of security of the level crossings [1,102].

Public highways and roads in Germany are classified by German regulations into five categories. The model adopted the same classification of roads:

- Federal Highways (Bundesstraßen)
- State roads (Landes-(Staats)-straßen)
- County roads (Kreisstraßen)
- City and municipal roads (Stadt und Gemeindestraßen)
- Other public roads (e.g. field and forest paths)

Figure 30 compares between the number of level crossings for each road class, the type of protection and number of accidents according to data collected in 2020 [2]. The data shows that crossings located at Municipal roads dominate the total share of German level crossings with a percentage of 61.6% with a huge gap with the type with the second highest share which is county roads that has a share of 10.6%. Accordingly, the number of accidents at municipal crossings is the highest with a share of 68.4%. The share is logical if taken in context with the share of crossings. Federal highways are the riskiest as they have a high share of accidents that amount to 9.6% despite their low quantity with only 3.9% of the overall number of crossings. This indicates that a higher priority must be given to eliminate crossings at federal roads.

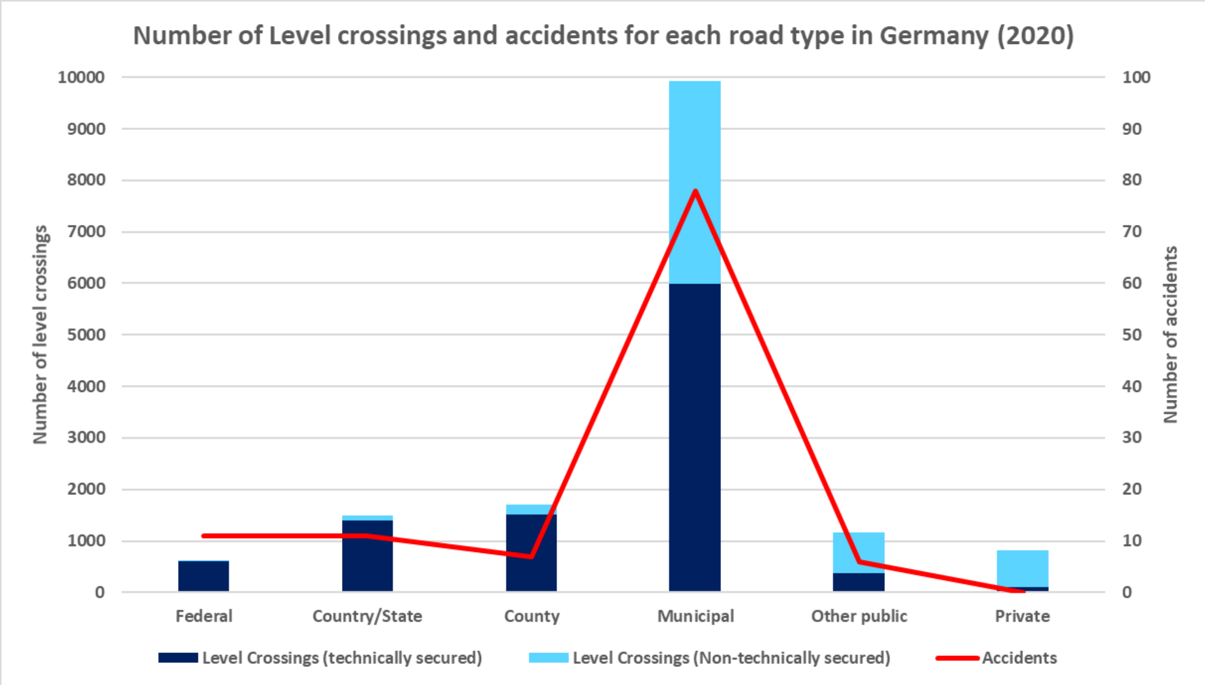


Figure 30: Number of level crossings and accidents for each road type in Germany 2020 [2]

5.5.1.1.3 Track type

Most models differentiate between mainlines and non-mainlines as one of the main criteria for consolidation and prioritization. This is because the type of tracks is connected to other very important criteria. For example, Tracks are usually assigned as main tracks when a high volume of daily trains operate on them, while side tracks usually serve fewer daily trains.

In addition, Track type according to the German regulations have an influence on many physical features of the railway infrastructure. Table 40 demonstrates the main differences in physical features between mainlines and non-mainlines according to EBO [1].

Table 40: Physical features comparison between Mainlines and non-mainlines according to German regulations [1]

Feature	Mainline	Non-mainline
Maximum track gauge	1465 mm	1470 mm
Minimum track radius	300 m	180 m
Maximum gradient	12.5 ‰	40 ‰
Minimum axle load	18 t - 5,6 t/m 20 t (new constructions)	16 t – 4,5 t/m 18 t (new constructions)
Maximum permitted train speed at level crossings	160 Km/h	-
Installing pedestrian barriers at passive crossings with separate pedestrian or cyclist lanes	Compulsory	Optional
Maximum permitted train speed for passenger trains	250 Km/h	100 Km/h

Feature	Mainline	Non-mainline
Maximum permitted train speed for freight trains	120 Km/h	80 Km/h

Track type is one of the four main factors adopted by EBO and Ril 815 for the selection of level crossing protection type. Railway tracks in Germany are classified into two categories in which a different set of rules apply to each track type category according to EBO [1] [102]:

- Main tracks (Hauptbahn)
- Side tracks (Nebenbahn)

5.5.1.2 Traffic exposure

There is a consensus in most presented models that traffic volumes of both trains and vehicles are the most dominant factors of accidents frequency. Accidents data of many studies support this claim [62]. Oh et al proved that higher AADT significantly increases level crossing accidents with undeniable statistical t-ratio of 3.01. The findings for train volumes were similar but not as significant with a t-ratio of 1.66 [103].

These findings support the conclusion of Saccomanno et al. in 2006, that the most important factor for the predicted collision frequency at level crossings of all types is the traffic exposure which is the product of AADT and daily number of trains [74].

The significance of traffic exposure was also tested by Heydari and Fu who studied the statistical significance of various factors on level crossings accidents in Canada by using the negative binomial model, the hierarchical Poisson-gamma model, and the hierarchical Poisson-Weibull model. The researchers found that traffic exposure was the most influential factor for all types of crossings [104].

In a similar study in Hungary, Borsos et al. studied the significance of various factors found that road and rail AADT have the highest significance amongst factors on the safety of Hungarian railway crossings. Based on the statistical findings of the study, it was recommended to raise the weight of traffic exposure from 25% to 30% in the Hungarian model. However, the same study deduced that many other factors that were considered as significant in other models were rather insignificant for the Hungarian study such as crossing angle, track alignment, number of tracks and sight distances [86].

Although higher traffic volume has negative impact on accidents frequency since the exposure and likelihood of a crash increases, it is not necessary that accidents severity gets negatively impacted as well. Fan et al. classified AADT into 4 categories (<10,000, 10,000-20,000, 20,000-30,000, >30,000) to investigate the crash severity at each category using a multinomial logit model. Results shown that highest crash severity was when the AADT was the least (<10,000). The three other AADT categories were found to be less likely to result in injury and fatal crashes. The researchers suggest that drivers drive more cautiously in higher traffic volume conditions which lowers the severity of any possible crash [105].

Despite being a dominant factor in all reviewed models, it is important that the traffic volumes do not get overweighted and allow a fair representation of other factors.

Khattak and Liu argue that using a modified AADT in models can improve the accuracy of prediction. The authors propose an $AADT_{TP}$ factor that “measures the portion of AADT that actually encounters trains”. The idea is to eliminate the AADT that crosses the crossing at times of train absence [106].

Based on the reviewed literature and international models, this sub-criterion involves the two factors that were found to be the two most-used factors in the reviewed international models for prioritization, risk assessment or accident prediction with a presence rate of 91% of all models:

- Average daily road traffic volume
- Daily train volume

5.5.1.2.1 Average daily road traffic volume

EBO and Ril 815 determine the type of security to be installed at German level crossings based on the average daily road traffic volume as acritical factor amongst four factors. The classification of road traffic volumes to select the type of protection stated in EBO was adopted in this model to fit the German standards and be easily compatible with the LC evaluation reports created by DB engineers [1,102]:

- Weak: ≤100 vehicles/day
- Moderate: 101-2500 vehicles/day
- Strong: >2500 vehicles/day

5.5.1.2.2 Daily train volume

Although EBO and Rail 815 do not consider the volume of trains with the selection of protection type at level crossing, this factor remains one of the most significant factors in determining the risk since it is directly involved with the increased chances of accidents following the growing potential of train existence in LC danger zone. Therefore, it is not strange that this factor was found to be included in 91% of all reviewed models in this study. The train volume alternatives included in this model are:

- ≤ 20 Trains/day
- 21-40 Trains/day
- 41-60 Trains/day
- >60 Trains/day

5.5.1.3 Road user factor

The factor of type of level crossing road users is highly important in determining the consequences of a possible crash. For example, a level crossing that have a higher percentage of pedestrian and cyclists users have naturally higher consequence in case of accident since non-motorized users rarely survive an accident with a rail vehicle.

Some studies attempted to find the differences between different types of motorized road users in terms of their contribution to crash severity. By setting automobiles as a reference, Fan et al. found interesting relationships between different types of vehicles. For example, truck trailers were less likely to get involved in injury or fatal accidents than automobiles, but pick-up trucks had on the contrary higher chances. Vans, buses, and school buses showed similar attitude in reference to automobiles as all were found to be more likely to get involved in injury accidents but less likely to get involved in fatal ones [105].

It is assumed that the percentage of trucks have a direct influence on risk at any level crossing. Therefore, the topic of trucks accidents risk and its influencing factors has been studied thoroughly. Khan and Khattak researched the most influencing factors that contribute to the highest severity of accidents for truck drivers at level crossings and found that high train and vehicle speeds, older drivers, crashes at rural roads, and at crossings with an angle of intersection between 60° to 90°, the presence of intersections within 500 ft and the presence of sight obstructions. The study has also concluded that the presence of gates reduces the probability of severe accidents involving trucks. In addition to the vehicle and geometric characteristics, the study also took into account the driver characteristics and found that older drivers (>55 years old) were more likely to get involved in severe accidents. The researchers have identified reducing allowed vehicle speeds, ensuring that trucks are easier to spot by train drivers and applying four quadrant gates and other physical barriers as solutions to improve safety for trucks using level crossings [107].

A similar study was conducted recently and involved many more factors including driver, crash, vehicle, environmental and roadway attributes. Factors found to be significant on the severity of crashes involving trucks are listed in Table 41 [108]

Table 41: Factors leading to higher crash severity for injury crashes involving trucks and percentages of probability increase [108]

Driver attributes	Crash attributes	Vehicle attributes	Environmental attributes	Roadway attributes
Gender: Male (2.5%)	Driving speed: >76 mph (11.8%)	Truck type: truck tractor (2.3%)	Cloudy (2.2%)	Approach grade: downhill (2.6%)
Actions: Running a red light (14.5%)	Over speeding (4.2%)	Vehicle defects: Tire defects (3.6%)	Dawn (3.8%)	Number of ways: two ways (4%)
Actions: Wrong way driving (29.8%)	Airbag deployment (27.3%-33.4%)	Vehicle defects: Brake defects (8.2%)	Darkness with no sufficient illumination (1.4%)	Presence of traffic controller (3.4%)
Actions: Failing to yield the right of way	Unbuckled seatbelts (18%)	-	-	-

Moreover, trucks are accused of increasing the likelihood and severity of derailments at level crossings. Chadwick et al. tested this hypothesis and found that it is only partly true. The researchers observed that trucks were four times more likely to cause a derailment than other vehicle types. However, there was no evidence that trucks cause more severe accidents since the data of accidents involving trucks showed similar derailment severity compared to data of accidents not involving trucks [109].

Figure 31 compares the number of accidents, fatalities, and injuries from each category of road users as per data collected in 2020 for German level crossing accidents [2].

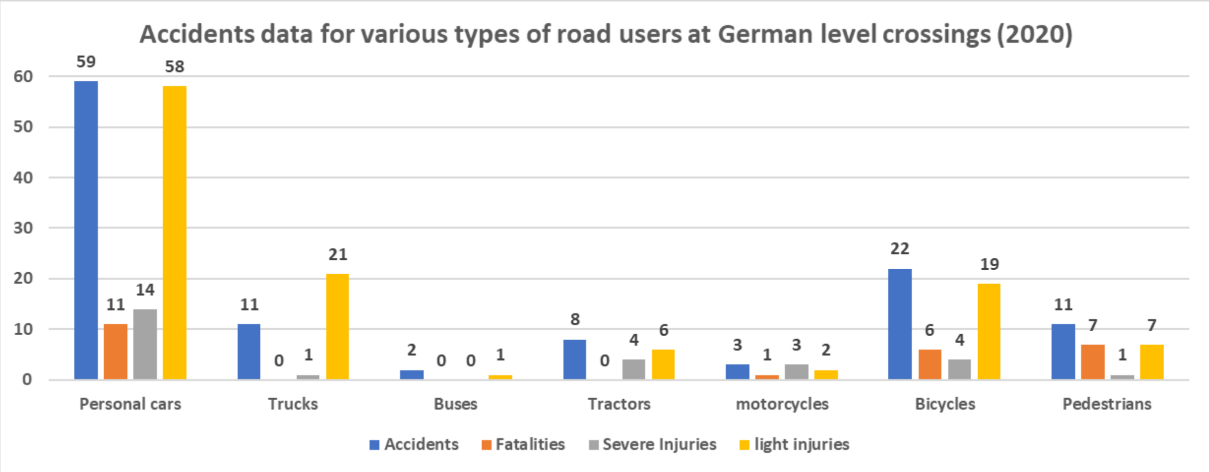


Figure 31: Accident data for various types of road users at German level crossings in 2020 [2]

As expected, Personal cars have the highest share since they are the main users of level crossings. It is also not surprising that vulnerable users such as cyclists and pedestrians have high accidents rates too. This indicates a demand for special attention to be given for special improvements to those two categories. Trucks, although involved in slightly high number of accidents, have no fatalities and very low severe injuries. However, they make the second highest number of light injuries after personal cars. This could be due to the large vehicle size which provides a better protection for the passengers when it collides with a train which minimizes the accident´s consequences. On the other side, motorcycles have the exact opposite effect as they often lead to very high consequences when they get involved in accidents because of the absence of any protective vehicle body. Buses performed fairly good in regard to share of accidents in 2020. This might be an indication of a good quality of training that bus drivers receive which helps them make safer decisions at level crossings.

In this model, this factor is used to account for road users that are exposed or expose the public to higher-than-usual levels of risk:

- Pedestrians and cyclists %: the percentage of pedestrians and cyclists combined from the total number of LC road users.
- Trucks %: the percentage of trucks from the total number of LC road users.
- Presence of buses and school buses: whether public transport bus lines or school buses use the LC frequently.

5.5.1.3.1 Pedestrians and cyclists %

Based on reviewed literature, it was proven that the percentages of pedestrians and cyclists are significant factors of risks at level crossings since the accident consequences for these two road user groups are much higher than accidents that involve personal cars.

Alternatives of this sub-sub-criterion are:

- <5%
- 5-20%
- >20%

5.5.1.3.2 Trucks %

Trucks increase the potential accident consequences for the colliding train because of its size. The size of the truck increases potential of special consequences such as derailment. Therefore trucks lead to higher likelihood of train passengers injuries and fatalities.

Alternatives of this sub-sub-criterion are:

- <5%
- 5-20%
- >20%

5.5.1.3.3 Presence of buses and school buses

Public transport buses and school buses impose higher-than-usual levels of risk because of the larger number of users involved in any potential accident. However, since buses or school buses exact numbers are difficult to obtain from the current standard methodology of traffic counts performed in Germany, it was decided to include this factor to account for the presence of frequent bus lines that uses the level crossings. This factor could be further improved by separating school buses from public transport buses and including a special count for both types in the standard traffic count procedure.

Alternatives of this sub-sub-criterion are:

- Present: Bus lines passing the level crossings are present. Buses and school buses frequently use the crossing.
- Not present: No Bus lines passes the level crossings. Level crossing is not used frequently by buses and school buses.

5.5.1.4 Train characteristics

There are two train characteristics identified as significant based on reviewed literature and selected for this model:

- Train types
- Train length

5.5.1.4.1 Train types

The factor of type of train types is highly important in determining the consequences of a possible crash. For example, a track where more freight trains operate than passenger trains have less consequences and therefore level crossings that it passes are considered less hazardous.

More developed models can take into consideration not only the type of train (passenger or freight) but also consider factors such as the number of passengers for passenger train and the money value of transported goods for freight trains.

The consequences of a level crossing accident involving a passenger train are not the same as freight train. Naturally, the value of human lives that could be lost as a consequence of a potential accident is more valuable than the value of goods. Since both freight and passenger trains can travel on most existing German lines, this model differentiates between lines where shared operation takes place and lines which only freight trains operate in.

- With passenger traffic: Level crossings that exists on rail lines which passenger trains are allowed to use.
- Only freight traffic: Level crossings that exists on rail lines which passenger trains are not allowed to use.

5.5.1.4.2 Train length

The length of train is the factor that is involved the most in determining the duration of LC closure. Longer trains mean longer closure times, and this leads to higher delays and more wasted energy. Also, longer delay times encourage more risky driver behavior, especially for drivers familiar with the level crossing. Many drivers would attempt to race and beat the crossing before it closes in order to avoid waiting for a long train to pass.

Moreover, lengthier trains mean that the crossing area will be occupied for longer time which increases the risk of all crash types.

Train length contributes to the total delay time at level crossing since longer trains take more time to evacuate the area of the level crossing and thus increases the waiting time of the road vehicles. Additionally, when the time of crossing area occupancy increases, the risk of collision increases accordingly.

Schöne found that the length of train has an influence on individual risk for most road users until 200 m train lengths only. Train lengths less than 100 m have a slightly different influence on risk than length between 100-200 m. For values beyond 200 there is no influence on individual risk at all [30].

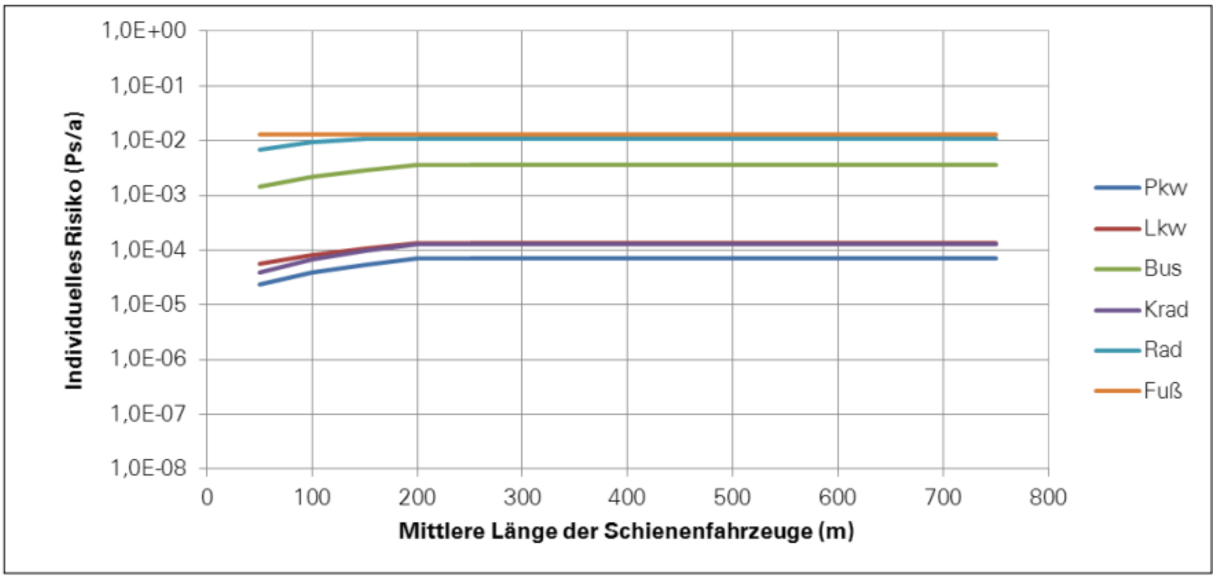


Figure 32: Influence of train length on individual risk for different road users [30]

The alternatives chosen for train length criterion are based on the findings of Schöne [30]:

- ≤ 100m
- 100-200m
- >200m

5.5.1.5 Speed factor

The particular significance of train speeds as a factor stems from the very high stopping distances that trains require to perform full stop. The higher speeds that trains are allowed to travel, the higher distances they need to stop and less possibility for train drivers to spot dangers and react accordingly. This explains why Germany bans trains that travel with a speed exceeding 160 km/h from driving on tracks that pass through level crossings.

The rail speed limit of 160 Km/h in Germany is considered usual in comparison to other nations. In Norway the speed limit is set to 160 Km/h just like in Germany ([110]. The maximum speed in Sweden is higher than the limit in Germany as trains are permitted to drive up to 200 Km/h at tracks with level crossings [111]. Its Scandinavian neighbor Finland on the contrary has a lower maximum limit of 140 Km/h for both active and passive crossings [112]. Netherlands also has disallowed level crossings to be built at tracks with train speeds more exceeding 140 Km/h [113].

In North America, Level crossings are allowed to exist on tracks with slightly higher maximum speeds than in Europe. Canada permits rail traffic to operate at tracks containing level crossings with speeds up to 200 Km/h [114]. In the United States, level crossings at Interstate highways are not allowed and a grade separation or closure is always required. Otherwise, crossings at other road classes that are equipped with passive protection may travel up to 80 mph (128.75 Km/h) and 110 mph (177 Km/h) for active crossings. However, level crossings can host train speeds up to 125 mph (201.17 Km/h) after obtaining a special permit from the Federal Railroad Administration

(FRA). Grade separation or closure is necessary for any speed exceeding 125 mph [31].

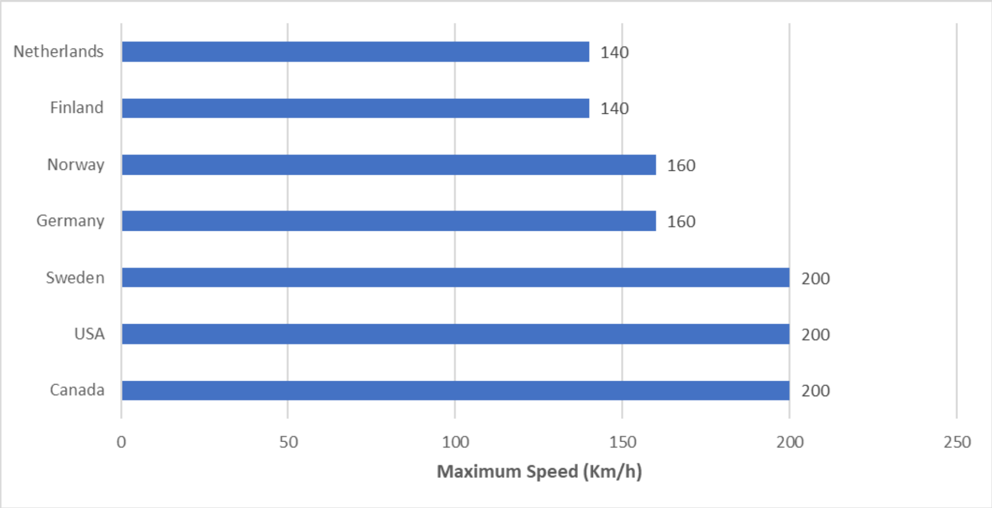


Figure 33: Maximum allowed rail speed at level crossings comparison by country

Higher allowed driving speeds for road vehicles may increase the risk of losing control while approaching the crossing and shortens the sight distances lowering the chance of spotting the crossing in the right time and taking the right decision. In case of rail vehicles, studies show that lower operating speeds increase the likelihood of a derailment at level crossings. The study concluded that the highest probability of a derailment to happen occur when a road vehicle with high speeds crash with a train with low speed. The authors explain the surprising findings by that trains with high speed would knock the road vehicle out of its way when driving at higher speeds while it would not have sufficient power to do so at lower speeds leading it eventually to a derailment [109].

The findings of Heydari and Fu suggest that road speed has higher influence than train speed at passive crossings and therefore it can be more beneficial to attempt reducing road speed by utilizing traffic calming devices at crossing of that type. The results of study have further showed that train speed have influence on all crossing types except those protected with barriers. Meanwhile, road speed has influence only at passive crossings [104].

Higher speeds at road and rail significantly affect not only the crash frequency but the severity as well. Fan et al. demonstrated that crash severity is higher when the vehicle speed exceeds 72 km/h than speeds in the range of 40-72 km/h. The study also found that vehicle speeds below 40 km/h are insignificant to crash severity at level crossings. The study found that train speeds function in the exact same way too [105].

In this model, two speed factors are considered:

- Train speed
- Maximum road speed

5.5.1.5.1 Train speed

This factor accounts for the risk imposed by high train speeds. The regulations of Germany state that level crossings cannot exists at tracks with speeds higher than 160 km/h.

Schöne proved that the individual risk increases with higher train speeds as demonstrated in figure 34. From the figure, it can be observed that fine increments of speed always lead to higher risk. Therefore, it can be concluded that the more speed ranges included in any prioritization model, the more accurate risks will be produced [30].

Accidents statistics at German level crossings for each train speed range are demonstrated in figure 35.

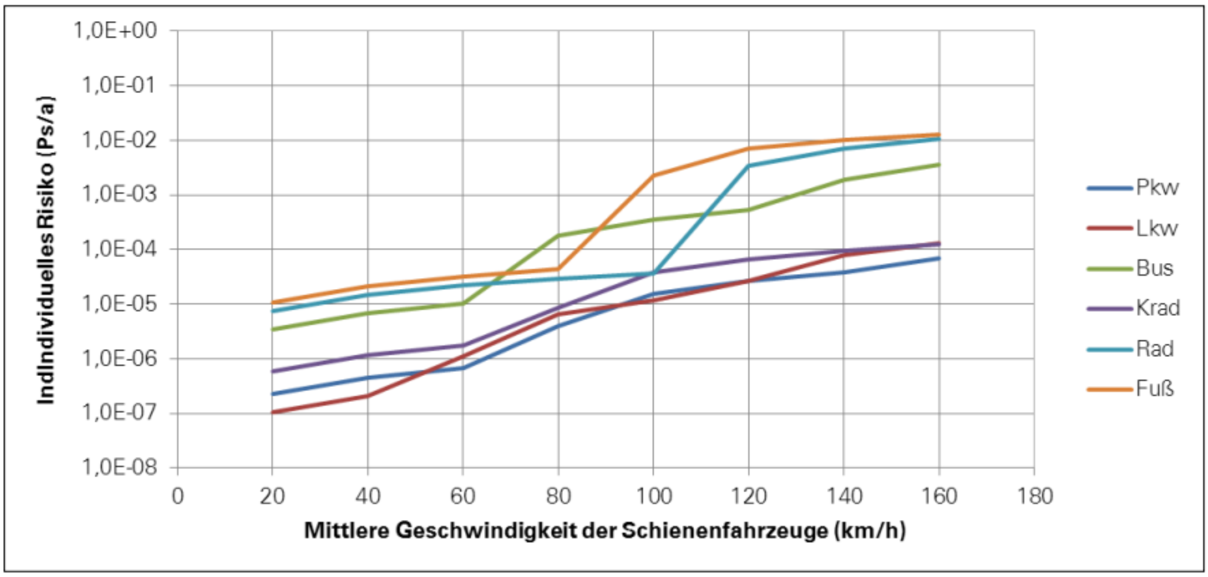
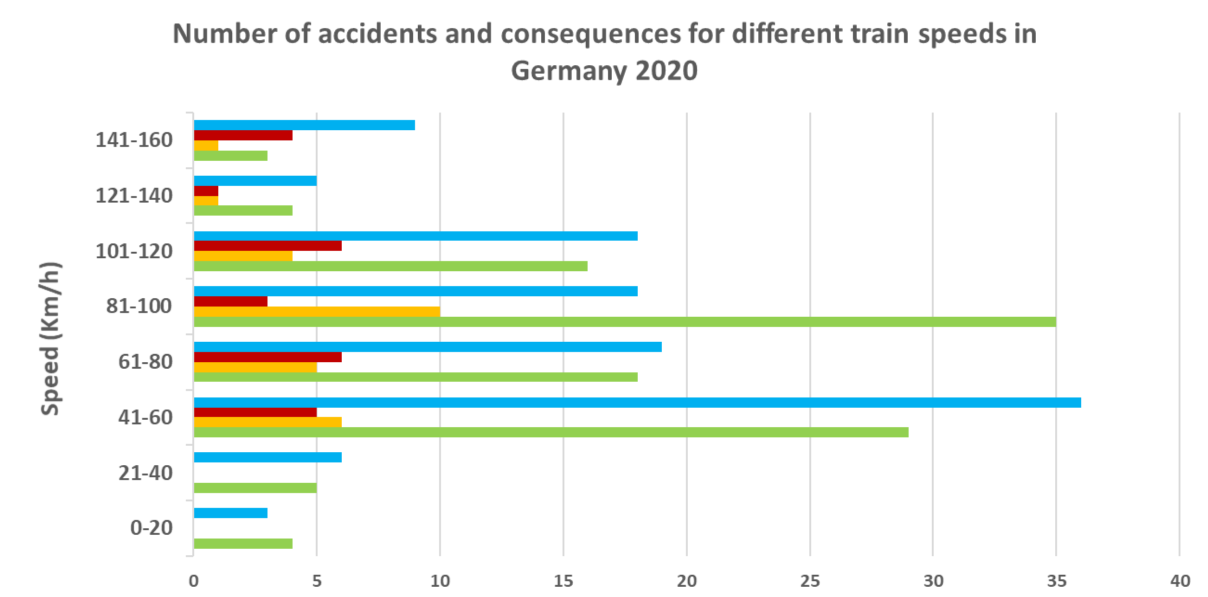


Figure 34: Influence of train speed on individual risk for different road users [30]



	0-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160
Accidents	3	6	36	19	18	18	5	9
Fatalities	0	0	5	6	3	6	1	4
Severe Injuries	0	0	6	5	10	4	1	1
light injuries	4	5	29	18	35	16	4	3

Figure 35: Accident statistics for different train speeds in Germany in 2020 [2]

Based on that, 8 speed ranges were selected for the development of this model:

- ≤20 km/h
- 21-40 km/h
- 41-60 km/h
- 61-80 km/h
- 81-100 km/h
- 101-120 km/h
- 121-140 km/h
- 141- 160 km/h

5.5.1.5.2 Maximum road speed

Schöne measured individual risk with regard to speed of road users. It can be observed from the findings that the slope of risk to speed is different at every 20 Km/h benchmark approximately.

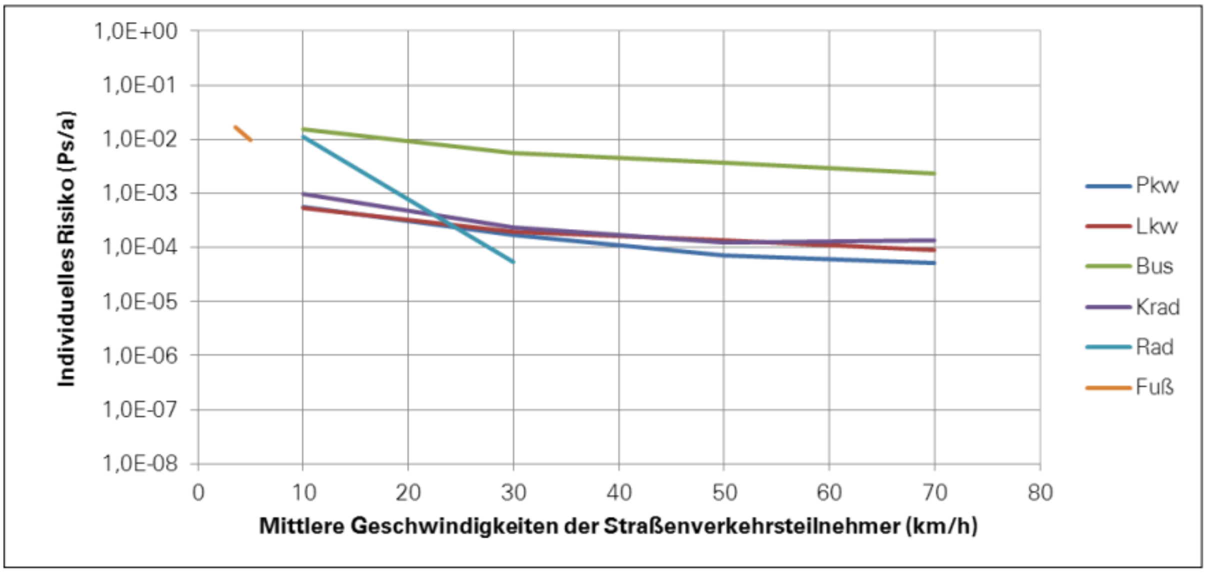


Figure 36: Influence of vehicles speed on individual risk for different road users [30]

Therefore, maximum road speeds were classified into five groups:

- ≤ 10 km/h
- 11-30 km/h
- 31-50 km/h
- 51-70 km/h
- >70 km/h

5.5.1.6 Waiting time (Delay)

An important factor that has an impact on safety levels at active crossings is the waiting time. Laure et al defines the waiting time as “the time road users have to wait before being able to proceed through the crossing” [115].

Many studies researched the drivers behavior at crossings in regard to different waiting times including the work of Laure et al. which concluded that more waiting time leads to higher frustration levels for the drivers and increase the likelihood of risky behavior, especially for waiting times that exceed 3 minutes. The study recommended keeping the waiting time at level crossings below 3 minutes to achieve a good level of safety [115].

It must be noted that patience levels are significantly less for pedestrians and cyclists. Beard and Melo report that pedestrians start ignoring traffic lights and cross based on their judgements when the waiting time exceeds 30s [116].

The maximum waiting time in the German standard Ril 815 allowed for light signals is 90s and 240s for light signals with half barriers. Ril 815 does not have a limit for the waiting time at full barriers [102].

Schöne measured the influence of “pre-blocking time” factor which the author defines as the time period from the activation of the level crossing safety device until the arrival of the rail vehicle at the level crossing. It was found that for non-motorized traffic, the risk remains constant until the impatience threshold is exceed, then the risk start increasing linearly. Meanwhile, the risk initially decreases due to the “Stott effect” (figure 25) then starts increasing as the impatience threshold is crossed before the risk level becomes constant [30].

Impatience threshold determined by Schöne are demonstrated in Table 42:

Table 42: Impatience threshold values [30]

	Non-motorized road users	Motorized road users
Light signals	30s	60s
Half barriers	60s	120s
Full barriers	120s	-*

* No value due to absence of possibility to commit a violation

In addition to the safety risks that high waiting times poses, there are huge economical losses that result from delay. Level crossings are a reason of huge collective loss in time and money for a wide segment of road users. Arguably, the consolidation of level crossings can save the society significant amount of money and improve the community´s economy in general. Protopapas et al. predicted the economic and environmental losses resulting from delays at 1200 level crossings in Houston, Texas and estimated the total public cost of delay at $907 million in 10-years period and more than $2.6 billion in 20-years period. Approximately 7.5% of those losses are the costs of emissions and wasted fuel. The authors report that the 1200 level crossings studied cause almost 2 million unproductive hours per year and 584 tons of additional emissions [117].

It is worth mentioning that the state of Illinois adopted a benefit-cost methodology in 2002 to prioritize crossings based solely on user delay costs after estimating that delays cost the region $74-120 million annually [118].

Waiting time at a level crossing impacts the level of frustration of drivers and can increase the number of violations committed at a level crossing. Additionally, the more time vehicles spend idle at a crossing, the more fuel is wasted and vehicle emissions are discharged. This model uses the value of approach time (Annäherungszeit) as an indicative of the delay time.

Based on the reviewed literature, this model assigns different risk value for the following ranges of waiting times:

- ≤30s
- 31-60s
- 61-90s
- 91-120s
- 121-150s
- 151-180s
- 181-210s
- 211-240s

5.5.2 Physical factors

The physical factors were classified into 3 sub-categories:

- Geometrical factors
- Visibility
- Pavement

5.5.2.1 Geometrical factors

There are 8 sub-sub-criteria considered within the geometrical factors category:

- Angle of intersection
- Approach grade
- Track curvature
- Road curvature
- Road width
- Number of tracks
- Number of lanes
- Distance to nearby intersection

5.5.2.1.1 Angle of intersection

Angle of intersection plays a role in determining the visibility of the level crossing. It is always recommended to have intersections with 90° as it provides the best visibility and highest level of comfort for users. The furthest the angle gets from 90 the less visibility will the drivers have and the less safe will the level crossing be to use. Also, some drivers especially older drivers have physical limitations that prevents them from turning too much while checking the level crossing clearance. This may lead to a hazard if a train was approaching from the difficult angle.

The risk analysis for the factor of angle of intersection performed by Schöne proves that individual risk increases with the increase in deviation from 90°. The sharpest increase in risk for most road users is at angles between 30°-60° and 120º-150°. Since no difference in risk can be observed between acute and obtuse angles, this model considers angle groups deviating from 90º to be identical. For example, if a level crossing has angle of 130º, it would be considered same as 50º and will get risk score of the 31°-60° category [30].

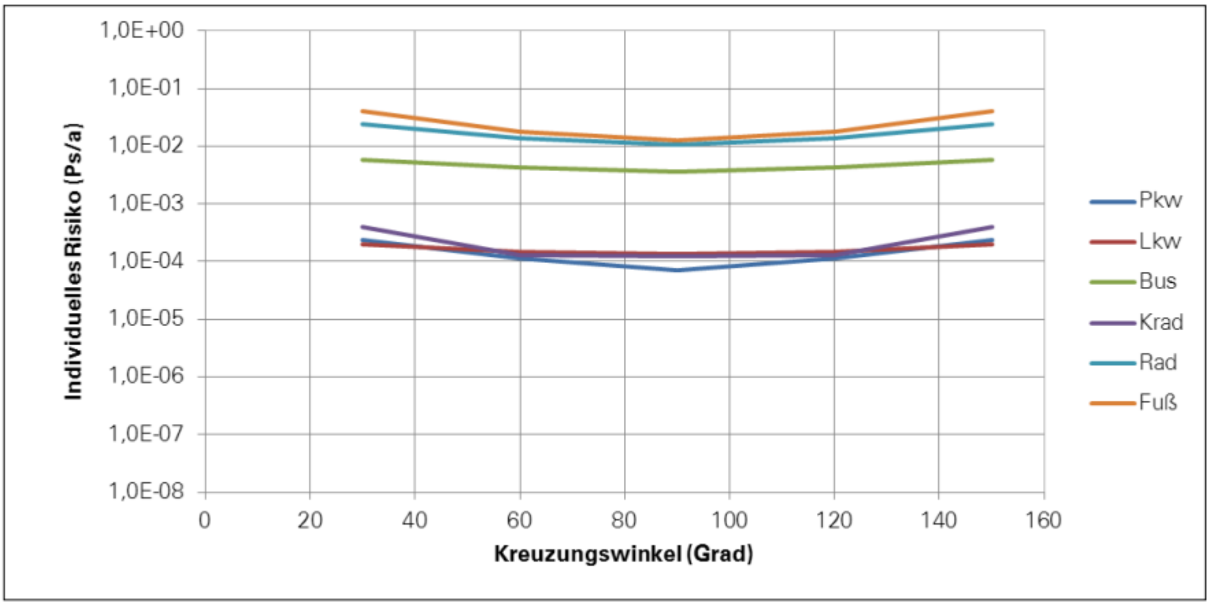


Figure 37: Influence of angle of intersection on individual risk for different road users [30]

As a result, this model gives a different risk score for 3 categories of angles:

- 61°-90°: also refer to angles 90°-119°
- 31°-60°: also refer to angles 120°-149°
- 0°-30°: also refer to angles 150°-180°

5.5.2.1.2 Approach grade

The factor of approach grades contributes highly to the sight distance at any level crossing. In addition, it can influence the speeds of approaching car depending on whether the approach grade is an uphill or downhill. High approach grades could also be a risk factor in poor weather conditions such as snow or ice as drivers often find it harder to control their cars on such conditions which may increase the risk.

Based on literature review the following alternatives were selected for approach grade (SLN):

- <3%
- 3% ≤ SLN < 6%
- 6% ≤ SLN < 9%
- 9% ≤ SLN < 12%
- SLN ≥ 12%

5.5.2.1.3 Track curvature

The curvature of the railway track influences the visibility and sight distance for road users which impacts the distance road users need to be away from the level crossing to make a crossing judgement. Based on literature review, the following alternatives were identified as significant for track radius (GBR):

- GBR ≥ 750m
- 500m ≤ GBR < 750m
- ≤ GBR < 500m
- GBR<250m

5.5.2.1.4 Road curvature

Road curvature has an influence over vehicles speeds, visibility, and imposes an increased risk in bad weather conditions in case of C-shaped or S-shaped roads. This model uses five different alternatives to determine the risk score resulting from road curvature. The unit gon/m was decided to be used instead of grad/m to better fit the standards in Germany.

- <0.25 gon/m
- 0.25 - 0.5 gon/m
- 0.5 - 0.75 gon/m
- 0.75 - 1 gon/m
- 1 gon/m

5.5.2.1.5 Road width

Level crossings with insufficient lane widths form a hazard of congestion in the crossing area if two vehicles crossed at the same time from opposite directions, especially if no proper “priority to incoming traffic” rule was installed.

The width of the road along with the angle of intersection usually determine the width of the level crossing. Wide roads can increase the risk at crossings secured with barriers if the barrier length was not sufficient to cover the full length of the road. Some drivers will feel tempted to maneuver the barriers by zigzagging if the road width and barrier length allows such a movement. On the other hand, very narrow roads usually force car drivers to approach the crossing with slower speeds which may lead them to need longer time to clear the crossing and thus be exposed to higher risk.

Since the potential of road users committing violations such as zigzagging is closely tied to the road width particularly at crossings secured with barrier arms that do not cover the full width of road, it is recommended for the upgrade of this model or for any models created in the future to include a factor that measures the difference between barrier arm length and road width as an indicator to zigzagging risk.

German standards set the minimum width of road to be provided at level crossings as 3 m per lane. The same crossing width should be guaranteed to allow safe clearing of the crossing. However, the widths could vary at roads where trucks are not allowed. The factor of lane width is also used in determining the minimum barrier length for technically secured level crossings [102].

Ril 815 sets the rules for design of the road width at level crossings based on possible encounter cases. The following are the minimum road widths stated in Ril 815:

Case 1: truck-truck encounter = 6.35 m
Case 2: truck-car encounter = 5.55 m

Case 3: car-car encounter = 4.75 m

Based on that, the following alternatives were selected in this model to reflect the limits stated in Ril 815:

- < 4.75m
- 4.75 – 5.5m
- 5.5 – 6.35m
- ≥ 6.35m

5.5.2.1.6 Number of tracks

Number of tracks factor is not an independent factor as it is often related to higher traffic volumes. However, this does not cancel its own significance.

The number of tracks as it gets higher increases the risk as well. The reason is that the higher the number of tracks that pass within the level crossing, the higher the time road users will need to clear out the danger zone.

Another risk arises in the cases when multiple tracks with two directions of travel exist. Road users might only overview one direction and proceed without making sure that the opposite direction is clear as well. This driver´ behavior could lead to more accidents.

The difference in effects of some countermeasures in terms of accidents reduction for single track and multiple tracks is demonstrated in Table 39.

Even though most level crossings in Germany exist at roads that cross one railway track only, there are crossing that exist at railways with 4 or more tracks in some cases based on the LC statistics collected by Hantschel et al [94].

Therefore, the following alternatives were adopted in this model for number of tracks:

- Number of tracks = 1
- Number of tracks = 2
- Number of tracks = 3
- Number of tracks ≥4

5.5.2.1.7 Number of lanes

Number of highway lanes is also not an independent factor as it is related to higher traffic volumes too.

More road lanes mean more collision points at the crossing which also means higher risk and exposure. A level crossing with two lanes gives the opportunity for two cars to exist within the LC area at the same time which doubles the risk.

Heydari and Fu found that the factor of number of lanes is influential only at passive crossings with STOP sign and at active crossings equipped with flashing light although the significance at passive crossings was found to be higher than at the active ones [104].

According to Hantschel et al., only a small number of level crossings in Germany exist at roads with more than two lanes. The majority of crossings are at one-lane or two-lane roads [94].

Therefore, the following alternatives were adopted in this model for number of lanes:

- Number of lanes = 1
- Number of lanes = 2
- Number of lanes ≥3

5.5.2.1.8 Distance to nearby intersection

The distance from the level crossing to the nearest intersection could be considered as a risk factor if the distance was too short because it directly affects other factors such as sight distance and could lead to problems of level crossing clearance.

If the distance between the LC and the closest intersection was too short, a car using the intersection to turn towards the crossing would have a shorter sight distance and thus a shorter reaction time. For cars leaving the crossing towards the intersection, if the traffic flow was too high and the distance until the intersection was too short, a tail-back (queue) could occur leading to a blockage in the level crossing.

However, Austin and Carson found in their work that vicinity intersections as a factor is statistically insignificant and thus cannot be considered as a criterion for consolidation [62].

Also, Keramati et al. created a mathematical model after investigating the accidents data at US level crossings of 30 years and ranked factors based on the model. Out of 13 factors studied, only Nearby intersections and angle of intersection were found to be statistically insignificant. Nearby crossings factor was ranked at 12 according to impact on number of crashes [47].

A German research conducted in 2016 found that the accident rates at level crossings, that are located in the vicinity of intersections at a distance less than 50 m, are significantly higher compared to other level crossings [94]. By investigating the number of accidents that occurred at German level crossings against the distance to nearest intersection of each LC, the numbers showed that accidents rate decrease as the distance to nearest intersection increases. These results support the findings of a Japanese study that compared the average number of accidents at level crossings at different distances from the closest intersection (<10m, 10-20m,20-50m, >50m). The results showed significantly higher accidents rate when the distance is less than 10 m. And similar to the German study, the accidents decreased by the increase of intersection distance [119].

Since Ril 815 gives a special consideration for intersections within the clearance section (≤27m) in its risk points evaluation particularly if the intersection was not controlled by a traffic signal. Therefore, a special alternative category for nearby intersections with the clearance section was included in this model.

These are the alternatives selected for ´Distance to nearby intersection´ sub-sub-criterion:

- >150m
- 100 - 150m
- 50 – 100m
- 27 – 50m
- In clearance section (≤27m)

5.5.2.2 Visibility

In this model, visibility was assumed to be a result of sufficient sight distance, absence of any permanent or temporary sight obstructions, and presence of good illumination to ensure good visibility during night hours. Sight distance and sight obstructions can highly affect the quality of judgement of the driver and therefore the reaction.

The visibility criterion contains the following sub-groups:

- Sight distance
- Sight obstructions
- Illumination

5.5.2.2.1 Sight distance

Sight distance is the total visible length of the road and along the track that is visible to the driver. Many models considered sight distance as a primary criterion since the quality of observation can highly affect the quality of judgement of the driver and therefore the reaction.

Highway-Rail Crossing Handbook divides sight distance into three major types [31]:

- Approach sight distance: It is the distance from the driver of the vehicle to the closest track. This distance represents the length that the road user can spot the crossing from to react accordingly.
- Corner sight distance: it measures the visibility in the quadrants and checks the ability of the driver to normally perceive the approach of a train without obstruction to his left or right.
- Clearing sight distance: It is the distance visible ahead of the driver when stopped at the crossing

Sight distance triangle formulas in the United States are calculated based on the train and car speeds according to the following table:

Table 43: Sight distances in the American standards [31]

Train Speed (MPH)	Case B Departure from Stop	Case A Moving Vehicle							
		Vehicle Speed (MPH)							
—	0	10	20	34	40	50	60	70	80
Distance Along Railroad Crossing from d_T (ft)									
10	255	155	110	102	102	106	112	119	127
20	509	310	220	203	205	213	225	239	254
30	794	465	331	305	307	319	337	358	381
40	1,019	619	441	407	409	426	450	478	508
50	1,273	774	551	509	511	532	562	597	635
60	1,528	929	661	610	614	639	675	717	763
70	1,783	1,084	771	712	716	745	787	836	890
80	2,037	1,239	882	814	818	852	899	956	1,017
90	2,292	1,394	992	915	920	958	1,012	1,075	1,144
Distance Along Highway from Crossing, d_H (ft)									
—	—	69	135	220	324	447	589	751	931

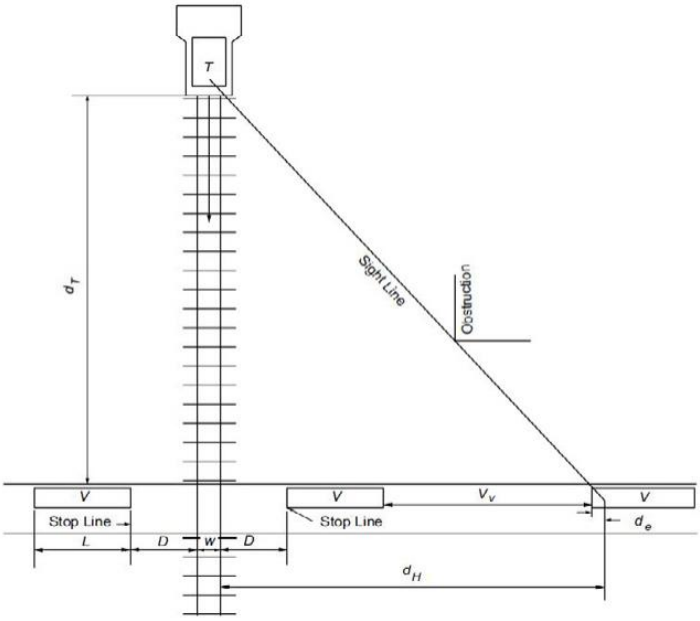


Figure 38: Sight distances in the American standards

Although bad sight distance can hinder the judgement of drivers, but there is no proof that it contributes effectively to higher accidents rate. Messick concluded that there is no correlation between number of accidents and sight distance after examining 81 level crossings´ accidents data against their available sight distances [120]. This might be explained as that drivers recompensate for sight deficiencies with being more cautious as they approach the crossing.

In Germany, sight distance triangle is calculated by determining the following values [27]:

Road sight point (*Sehpunkt*): it is the point at road from which the road user is able to spot the rail vehicle until the location of St. Andrew´s Cross (Stop line) and is measured by calculating the breaking distance (*Anhalteweg l_a*) based on car speed, breaking delay, and reaction time.

Clearance time (*Räumzeit*): The time needed by the vehicle to clear the level crossing area from the Road sight point.

Approach time (*Annäherungszeit*): a time value calculated to measure the time the train takes to arrive at the level crossing after clearance time plus a safety margin is over.

Rail sight point (*Sichtpunkt*): It is the point at rail track where the rail vehicle becomes detectable for the road user and is measured by calculating the approach distance (*Annäherungsstrecke*) based on approach time and train speed.

Figure 39 demonstrates the locations and distances of Road sight point, Rail sight point, breaking distance, and approach distance [27]:

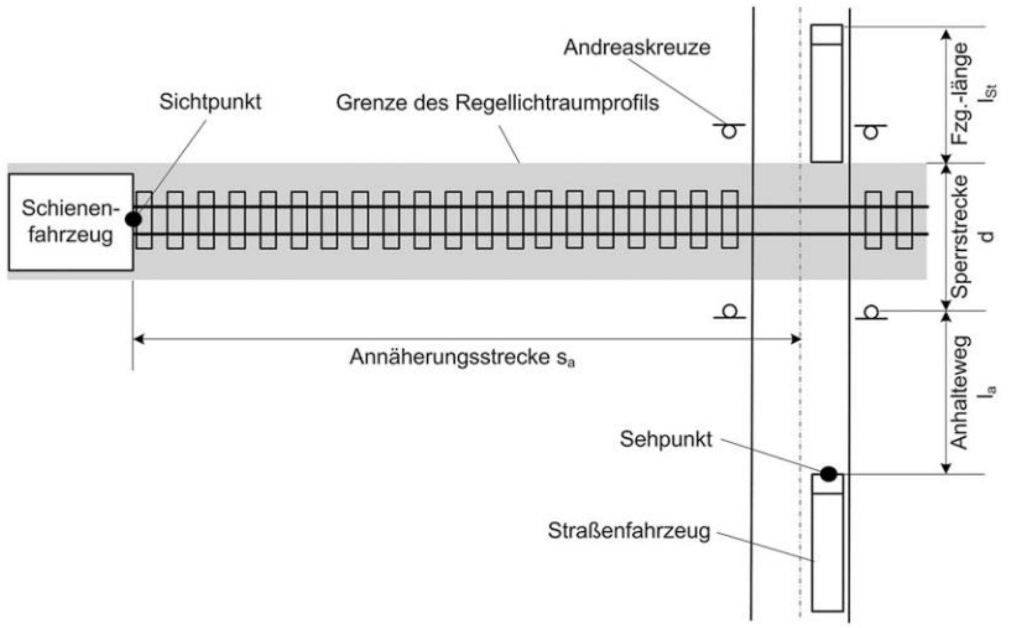


Figure 39: Sight distance triangle according to German standards [27]

Visibility depends highly on geometrical factors like horizontal and vertical alignments and angle of intersection.

Not only the visibility of the level crossing needs to be ensured but also the visibility of all level crossing components such as signals, the St. Andrew's Cross, and any traffic signs. National standards contain specific dimensions of all components to ensure their visibility to all users from safe distances. There are laws that prohibit blocking the visibility of level crossings or some of their components by parking. For example, it is not allowed to park in front of or behind a St. Andrew's Cross up to 5 m at urban areas or 50 m at rural areas.

In this model, Level crossings are rated based on these sight distance ranges:

- >400m
- 200-400m
- <200m

5.5.2.2.2 Sight obstructions

Sight obstructions are all objects and factors that lead to a temporary full or partial loss of sight and limits the sight distance while approaching the level crossing.

Sun glare effects must be considered by planning engineers in the design phase of any level crossing while planning the geometrical factors such as the horizontal and vertical alignments of both the road and track. After construction, it is usually very hard to make adjustments to the geometrical elements to eliminate sun glare and therefore an elimination of the level crossing could be the only solution if the problem is confirmed as a safety threat. In some cases, sun glare can cause a temporary vision loss for seconds which increases the risk of an accident.

Another temporary sight obstructions are the plants and trees near the level crossing. Plants and trees grow and vary in their size and density at certain times or seasons. In some cases, the level crossing might be inspected at a season when the surrounding vegetation is short and do not obstruct the vision. Few months later, it becomes a sight obstruction problem after growing. This can be an issue especially for rural crossings located close to farms where long crops or trees are planted. However, the elimination of such problem is often not complicated unlike sun glare.

Sight obstructions was also one of the factors that Austin and Carson rejected from their model due to its statistical insignificance. Only 10% of the studied crossings had obstacles existing blocking the view of drivers and therefore was decided to be an undecisive factor [62].

Objects considered as sight obstructions in this model include trees and plants, advertisement boards, structures and buildings, rail equipment and traffic safety devices. In addition, any temporary visual impediments such as sun glare are considered as sight obstructions.

In this model, a risk score is only given to the level crossing for this sub-sub-criterion if sight obstructions were deemed present by the evaluator. Therefore, the alternatives of this category in the model are:

- No sight obstructions
- Sight obstructions exist

5.5.2.2.3 Illumination

Ril 815 states that non-technically secured crossings must be illuminated if they are occupied by unlit rail vehicles for long periods. It also states that sufficient lighting should be provided for technically secured crossings with light signals and barriers to aid the operator´s view of the level crossing or when the LC is supervised through camera.

Illumination can be a big safety factor for level crossings at night since visibility is reduced to the minimum particularly at rural crossings where there is no enough surrounding illumination.

Researchers attempted to answer whether the factor of illumination makes a difference in significant factors towards accidents severities. The study included 10 years of accidents data from US crossing and created two mixed logit models in terms of existence of lighting. The results proved that there are massive differences between illuminated and non-illuminated level crossings. Table 44 summarizes the main findings of the study [121].

Table 44: most significant factors according to illumination conditions [121]

Factor	Fatality probability increase with sufficient lighting existing	Fatality probability increase with no illumination
Vehicle speed: ≥ 50 mph	56%	87%
Train speed: ≥ 50 mph	37%	68%
Age: ≥ 65 years	20%	58%
Gender: Female	3.7%	4.9%
Weather: cloudy	6%	13%
Weather: fog	9%	17%
Weather: snow	12%	25%
Weather: rain	4%	9%
Weather: sleet	15%	32%
Area type: open space	8%	18%
Pavement: non-paved	5%	12%

In this mode, three alternatives for the presence of illumination exist:

- Sufficient: Illumination is present at the level crossing and the intensity of illumination is sufficient for safe visibility of the crossing during night hours.
- Insufficient: Illumination is present at the level crossing, but the intensity of illumination is not sufficient for safe visibility of the crossing during night hours.
- No illumination: No illumination available at the level crossing. The crossing is very dangerous to use during night hours.

5.5.2.3 Pavement

The pavement factor consists of three sub-factors:

- Type of crossing surface
- Type of road pavement
- Condition of crossing and road pavement

5.5.2.3.1 Type of crossing surface

The type of crossing surface is a significant when studying level crossings since it contributes to the time the vehicle needs to clear the crossing. Also, when the crossing is not paved, the danger of a vehicle getting stuck on the rails increases.

Ril 815 regulates the allowed types of crossings coatings in Germany. The majority of approved systems are either made of rubber or concrete (Figure 40). The conditions of selecting a coating are that it fulfills the safety requirements, traffic volumes and speeds and be economical. The guideline also allows level crossings to be coated with asphalt (Figure 41) or mineral mixture (i.e., gravel) on crossings that have low road traffic density (<100 vehicles per day) and low train speeds (max 80 km/h). crossings that are exclusive for pedestrians and cyclists are allowed to be coated with asphalt or mineral mixture (gravel) as well.

Figure 40: A level crossing with a rubber coating in Regen

Figure 41: A level crossing with an asphalt coating in Regen

Austin and Carson found that using wood planks as crossing surface leads to higher crash risk despite the fact that they are mostly used at crossings with low traffic volumes [62]. These findings support the decision of not including wood planks as a surface possibility for German level crossings.

The different crash severity rates for each type of level crossing surface were studied by Fan et al. The results however were surprising. It was found that rubber and concrete level crossings has the highest likelihood of injury and fatal crashes while asphalt and unpaved crossings had the lowest. The researchers explain the results by arguing that drivers tend to be more careful when the type of level crossing coating is of lower quality [105].

Crossing surface type is also a contributing factor to delay time and money loss at level crossings. After drivers come to a complete stop or slow their speeds down, the friction between tires and crossing type determine the speed that they reach while crossing. A study performed in Thailand found that the average speed of cars on asphalt crossings were 25.91 Km/h, while concrete and timber crossings recorded 19.41 Km/h and 16.37 Km/h respectively. The difference in speed could be translated to economic losses in terms of delay [122].

This model gives a different risk score to each type of crossing surface available in Germany:

- Rubber
- Concrete
- Asphalt
- Unpaved

5.5.2.3.2 Type of road pavement

The work of Austin and Carson proved that the type of highway pavement influences the accidents rate. It was found that more accidents happen on paved roads than gravel roads. The authors suggested that these factors are also correlated with traffic volumes as road pavement usually indicates high AADT. However, those factors were still considered in their suggested model due to the high t-ratio and low standard errors [62].

In this model, level crossings that are located at unpaved roads have a different risk score than those located at paved crossings. Therefore, the two alternatives for this category are:

- Paved
- Unpaved

5.5.2.3.3 Condition of crossing and road pavement

Not only the type of pavement used, but also the condition of the pavement can be a big factor of risk. Poor pavements hinder the movement of road users and slows them down which results in a larger needed clearing time. Additionally, severe defects in pavement inside the level crossing can cause the vehicles drivers to stop or significantly reduce their speed in the middle of the crossing which may lead to rear-end collisions.

Examples of defects that will result into a poor condition classification in this model are based on Ril 815 and they include ruts (Spurinnen), net and single cracks (Netz und Einzelrisse), and patches (Flickstellen).

This model evaluates level crossings according to two alternatives regarding condition of pavement:

- Good condition: Both crossing and road pavements are in good condition.
- Poor condition: Both crossing and road pavements are in poor condition.

5.5.3 Safety factors

This category calculates a risk score for the level crossing based on the following sub-criteria:

- Type of protection
- Accident history
- Road markings
- Traffic safety devices
- Hazardous material transportation

5.5.3.1 Type of protection

Caird et al. summarized the findings of various studies that measured the effectiveness of level crossing safety devices between 1975 and 2002. It was reported that flashing lights reduce accidents by 64% in accidents, 84% in injuries and 83% in fatalities over crossbucks. While combining the flashlights with lights and gates manages to reduce accidents by 88%, injuries by 93% and fatalities by 100% over crossbucks and accidents by 44% over flashing lights only. As for the effectiveness of systems to stop driver violations, the authors compared the efficiency of different systems against the half barriers and concluded that median barriers can reduce 80% more violations than half barriers, long arm gates (3/4 the length of full barriers) reduce 67-84% of violations. Full barriers reduce 82% while combining median barriers with full barriers eliminates 92% of drivers violations. Additionally, monitoring the crossing with video/photo surveillance was found to reduce 34-94% of violations. Finally, the option of closure logically eliminates 100% of violations, accidents, injuries, and deaths [123].

In a study performed by Saccomanno and Lai on 10449 level crossings in Canada using factor analysis to evaluate the performance of countermeasures at level crossings, the authors found that an accident reduction of 58% can be achieved when passive protection is upgraded to active protection using flashing lights and 63% when upgraded to active protection using barriers. This means that adding barriers to passive crossings can only improve the accidents situation by a small rate of 5%. The study concluded that an upgrade of passive to active (flashing lights only) can be more cost-effective than installing barriers. However, the addition of barriers to crossings equipped already with flashing lights was found to improve the safety by 13%. [76].

In another study performed using propensity score method, the authors suggested that limiting treatment selection biases that can be the result of dominant criteria can produce misleading improvement rates. Their work indeed resulted in less safety improvement rates to Saccomanno and Lai with percentage reduction of 31.7% for passive to flashing lights, 47.6% for passive to barriers and 24.4% for flashing lights to barriers [124].

Elvik et al. studied several studies and accident prediction models between 1987-2009 that controlled the different potential biases and selected the best estimates based on the collected results. Their best estimates show that accidents can be reduced by 26% when a whistle blow is used to announce train approaching, 23% when signs only are used and 65% when a Stop sign is used. Improvements data at level crossings were also similarly studied and show that upgrading passive crossings (signs only) to flashing lights and sound signals reduce the accidents by 51%, improving flashing lights and sound signals to barriers reduce the accidents by 45% while going from passive to active with barriers improves the safety by 68%. Additionally, they report that improving sight conditions can lead to a 44% less accidents [125].

The variance of influential factors to safety in regard to the type of crossing protection type was later demonstrated by Heydari and Fu in 2015 as they investigated statistically significant factors for accidents at Canadian level crossings. Their findings showed that traffic exposure was the most influential for all types and it was the only influential factor for crossings equipped with barriers. The researchers attribute that to the high influence of barriers on drivers behavior. Crossings equipped with flashing lights only were found to be influenced by train speed, number of lanes and whistle prohibition. Finally, passive crossings were found to be influenced traffic exposure and speeds of road and train. However, if a passive crossing is equipped with a STOP sign, the study shows that the influencing factors turn to be exactly as an active crossing equipped with a flashing light [104].

Active protection methods are affected with the factor of waiting time. Road users tend to commit more violations and cross the level crossing without authorization the more they wait. Various researches have been conducted to study the impatience limits for road users that are discussed in chapter 5.1.

Examples of different types of warning lights used worldwide are shown in figure 42.

Figure 42: Examples of different types of flashing lights used worldwide

Accident statistics for various types of protection in Germany are presented in figure 14.

This model uses the four most popular types of protection in Germany as alternatives for Type of protection sub-criteria:

- Full barriers
- Half barriers
- Light signals / Flashing lights
- Passive

5.5.3.2 Accident history

Accident history reflects clearly how the crossing is performing in terms of safety. The duration of accident records is also a factor. Most models take 5-10 years of accident records. However, it must be also considered that the duration correctly reflects the real situation in case the crossing protection type was upgraded. For example, it makes no sense to consider 5-years of accident data for a crossing that was upgraded from Passive to active 2 years ago.

Most models do not consider the number of accidents only but have a different weight for accidents of different severities. It is very logical that a crossing that causes high fatality accidents but low overall accidents rates to be considered as a higher priority than a level crossing with more overall accidents but with a majority of material damage only accidents.

Accidents data help researchers identify hazards in level crossings. To achieve better safety situation and accurate research results, it is crucial that countries collect and record accident data in a systemized way with a high level of detail and accuracy. In Germany, the Federal Authority for Railway Accident Investigation (BEU) is responsible for investigating all significant railway accidents including level crossing accidents. However, most non severe accidents or material damage only accidents are only investigated by local police. It is advisable to create a national database for level crossing accidents for an easier access for researchers to data related to safety at level crossings.

The main advantage of including the accidents history factor is to measure how the level crossing has performed in recent years. This is considered a very powerful raw indicator of risk.

This model considers the accident history for the level crossings in the last 5 years. However, if the type of protection at the crossing was changed during the last 5 years, only the years after the change will be taken into account.

This sub-criterion could be further improved in the future by adding two extra factors that were not considered in this model which are the number of accidents with material damage only and the number of near misses. These two factors were not adopted in this model because they were deemed not significant during literature review and because it is difficult to obtain data for them particularly with the absence of an advanced German level crossing accidents database.

In this model, the weight of accident history is distributed to the following sub-criteria based on number and consequences of accidents:

- Number of accidents
- Number of fatalities
- Number of severe injuries
- Number of slightly injured

For each of these sub-criteria four alternatives are available to determine the risk score:

- 0
- 1-2
- 3-4
- >4

5.5.3.3 Road markings

Road markings are applied on paved road surfaces to improve the driving conditions, improve the attention of the drivers, and communicate information to the drivers. Whenever road markings are used, drivers have less confusion while approaching and crossing and can position their vehicles better. Crossing markings can also help the drivers evaluate the crossing decision better in case of the existence of an intersection nearby. In Germany, Road markings at level crossings are the responsibility of DB Netz AG [102].

The significance of applying road markings at level crossings was proven by Hu et al. as they used a logit model to measure the significance of 35 factors on accident severity at level crossings in Taiwan. Crossing markings had the highest statistical significance on accident severity while road separation through markings were also found to be significant [126].

Khan et al determined that road markings have a negative relationship with accident probability and included this factor in their level crossing accident prediction model for North Dakota. Their model takes into account 3 types of crossing markings which are stop lines, RR crossing symbols (X-box markings) and Dynamic envelope [127].

X-box markings are applied to improve the judgement of drivers whether to cross or not when intersections are close to the level crossing and an enough storage space availability is uncertain. In this case, the X-box markings will aid the driver´s vision and ensure better judgement. The improvements caused by X-box markings were measured by Stephens and Long at one urban and one rural level crossings in Florida for 18 months. The study concluded that hazardous stoppage rates declined by more than 60% at the rural crossing while it provided no significant improvement at the urban crossing. Having a lower number of markings, signs, and safety devices or the ´stand out´ effect at rural crossings could be the reason that encouraged the drivers to notice and utilize the X-box markings at the rural crossing more than the urban crossing [128].

Figure 43: X-box marking [128]

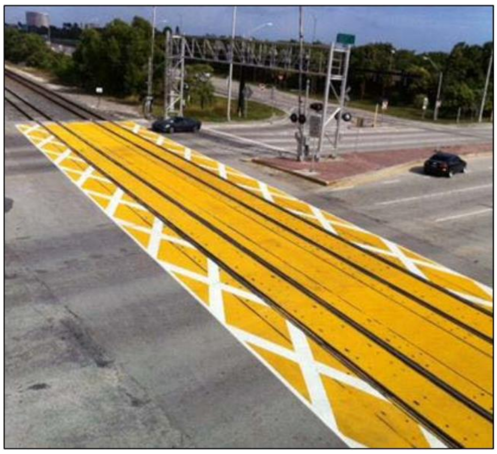


Figure 44: Dynamic envelope [129]

However, some road markings can be also a source of risk for drivers. Researchers have shown that right-turn arrow markings in front of level crossings that are close to intersection can in some cases lead to confusion for drivers as they mistake the level crossing for their intended intersection. A mistaken decision of turning right at the level crossing could take a long time to correct and thus form a great hazard especially that the driver´s stress level normally increases in such situations and the probability of poor judgements increase. Researchers identified proper road markings as one of the cost-effective remedies to prevent this risk beside countermeasures such as advance direction signage, striping, and elimination of potentially misleading pavement markings and signs [129].

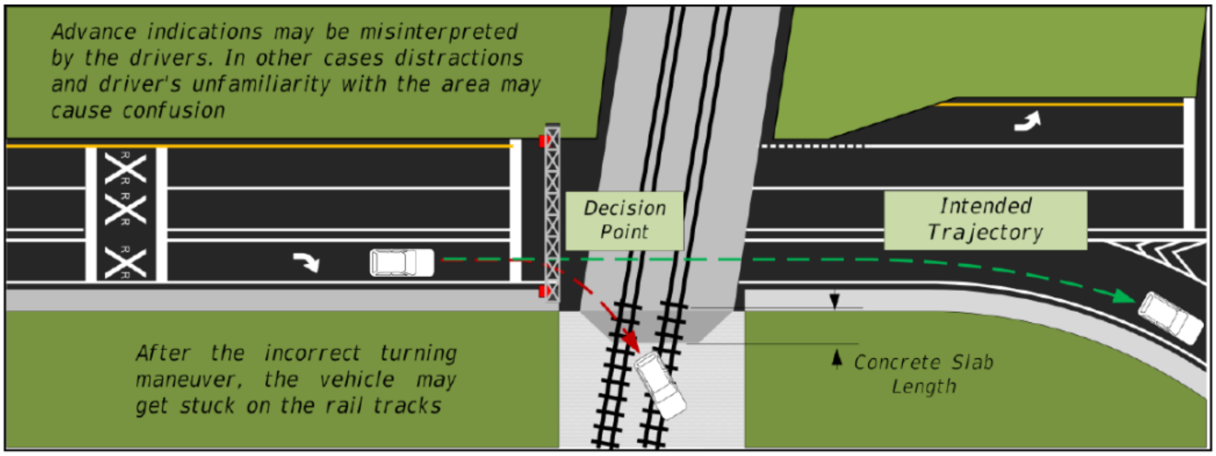


Figure 45: Risk of incorrect turning at level crossings [129]

This model assigns a risk score only for crossings in which road markings are missing and therefore have the following two alternatives for this sub-criterion:

- Road markings exist
- No road markings

5.5.3.4 Traffic safety devices

Overtaking other vehicles or bypassing the level crossing´s barriers are forbidden actions in the German law according to §19 of the Road Traffic Regulation (StVO). However, although the penalties for disobedience are quite severe and could reach up to €700- and 3-months ban, it is sometimes necessary to prevent such behavior through safety devices.

For example, building median barriers proved to be an effective solution to reduce risky driver behavior. Khattak compared the drivers actions at one level crossing in Nebraska for 4 months before and after installing a median barrier (Figure 46) and found that medians successfully reduced the frequency of drivers going through the level crossing barriers. Results also showed a decrease in the number of drivers performing risky actions such as U-turns and gate rushes. However, the study observed that drivers have turned to different kind of risky behavior after the median barriers were installed which was the backing-up. Nevertheless, this kind of behavior was considered mildly unsafe. The positive gains from the installation of median barriers outranks the negative increase in backing-up behavior [130].

Figure 46: Mountable Raised Curb System with Vertical Panels in USA [130]

The findings were proven further as Khattak and McKnight reported that violations related to drivers rushing through closed or closing level crossing barriers as trains approaches get reduced by 37% after median barriers are installed. The study also showed that barriers do not necessarily need to extend up to crossing barriers to be effective. Two scenarios where a gap of 12 ft (3.66 m) and no gap were studied and both scenarios showed the same effectiveness in decreasing risky driver behavior [131].

One may assume that a traffic safety device that succeeded in positively improving the driver behavior at one city may not necessarily function in the same way somewhere else due to a different driving behavior between cities and countries. This assumption was found to be only partly true by Khattak as he compared the effectiveness of median barriers between two cities in the same state. His results show that although the driver behavior was indeed different, the magnitude of reduction in violations after installing the median barriers was similar. Therefore, it could be safely assumed that applying such traffic safety devices in Germany as cheap and easy methods to improve safety at level crossings could generate comparable safety improvements [132].

In the United States, five different types of median barriers are used [31]:

- Wide Raised Medians
- Barrier Wall Systems
- Non-mountable Curb Islands
- Mountable Raised Curb Systems (Figure 46)

In addition to median barriers, various traffic calming devices are used in the US to control the drivers behavior while approaching the level crossing such as speed humps, curb extensions, pavement markings, and textured pavement [31].

The expected deduction that installing speed humps in front of the level crossings improve the safety conditions and reduce the probability of accidents was proven by Oh et al as they measured the significance of the presence of speed humps amongst 55 other factors at 162 level crossings in South Korea [103]. Washington and Oh also measured the effect of speed humps in addition to 17 other countermeasures on the basis of previous research and found that speed humps improve safety by 36-40%. However, the study found that in-vehicle warning systems, obstacle detection systems, and constant warning time systems are the most effective countermeasures for accident reduction [133].

Similarly, many protective and traffic calming devices are used in Germany. A great amount of such devices do not only attempt to control the behavior of car drivers but all road users including devices designed for pedestrians and cyclists. This model considers the existence of any of the traffic safety devices currently used in Germany. Traffic safety devices currently used in Germany include:

- Guardrails (Geländer): a safety barrier that is often used to separate pedestrians and cyclists lane from cars, to clearly define the crossing path or to protect surrounding objects.
- Protective barriers (Schutzplanken): safety barriers used to protect nearby equipment such as traffic lights and St. Andreas crosses from road vehicles.
- Pedestrian barriers (Umlaufsperren): The idea behind installing pedestrian barriers is to hinder the movement of pedestrians and cyclists and to force them slow their speed down before crossing. This usually encourages them to stop and watch for any coming trains correctly. This type of safety devices is usually used at passive crossings secured by overview to enforce a correct overview process.

Figure 47: Pedestrian barriers (Source: marburg-biedenkopf-mobil.de)

- Barriers skirt (Gitterbehang): a net fixed below level crossing barriers to stop pedestrians from bypassing the barrier by ducking under it. This is particularly used on level crossings with particularly high pedestrians risk or in proximity to schools since the barrier skirt is particularly effective against violations from children pedestrians. Recent studies show that installing a Barriers skirt decreases pedestrians violations by 56% while the barrier is going down and by 19% when the barrier is fully lowered (horizontal) [134].

Figure 48: Barrier skirt (Source: Benjamin Hogl, 2019)

- Audible pedestrians signal (Fußgängerakustik): An alarm sound that warns pedestrians and cyclists that the level crossing is being closed and a train is approaching.

Also, the existence of a speed hump within the clearance section of the level crossing is considered as part of this criteria.

This model assigns a risk score only for crossings in which no traffic safety devices exist to improve the safety situation. Therefore, the following two alternatives were defined for this sub-criterion:

- Traffic safety devices exist
- No traffic safety devices

5.5.3.5 Hazardous material transportation

This model gives a special priority to level crossings located close or at the route of regular hazardous material trucks or freight trains carrying hazardous material. An example would be the level crossing being located in the vicinity of an oil terminal or a factory where multiple hazardous material trucks pass the level crossing regularly.

In this model, a special risk score is given to level crossings located on the path of regular hazardous material transportation. Therefore, the two alternatives of this sub-criterion are:

- No regular hazardous material transportation: The level crossing is not exposed to hazardous material trucks frequently.
- Regular hazardous material transportation: The level crossing is exposed to hazardous material trucks frequently or located in the vicinity of an establishment that requires the delivery of hazardous material frequently.

5.5.4 Social factors

This category of factors relates to the special risk imposed on vulnerable groups in society that needs a special elevation in safety and risk elimination measures.

The four primary sub-criteria included in this category are:

- Emergency services
- Schools
- Vulnerable population and sensitive facilities
- Special social and event venues

5.5.4.1 Emergency services

Emergency services include hospitals and emergency medical services, fire departments and police stations within a radius of 500m of the level crossing. This factor accounts for any possible delays the existing level crossing imposes on the emergency vehicles response time and the time required to reach the medical services by individuals. Also, level crossings close to emergency medical services have a higher risk of collisions as a result of higher percentage of road users willing to violate safety guidelines or driving under stress to reach their destination as fast as possible.

To account for the priority of consolidation and risk increase due to the wasted time of emergency services by waiting at the level crossing, this model considers the existence of emergency services within 500 m from the crossing. Therefore, the two alternatives of this sub-criterion are:

- No emergency services exist within a radius of 500m
- Emergency services exist within a radius of 500m

5.5.4.2 Schools

This factor includes schools and kindergartens within a radius of 500m of the level crossing. It accounts for the higher percentage of vulnerable level crossing users of young age. Level crossings located nearby schools often have more public buses full of school students and school buses at certain times of the day which increases the risk of any possible collision.

To account for the priority of consolidation and risk increase due to the presence of schools in the vicinity of the level crossing, this model considers the existence of schools within 500 m from the crossing. Therefore, the two alternatives of this sub-criterion are:

- No schools exist within a radius of 500m
- Schools exist within a radius of 500m

5.5.4.3 Vulnerable population and sensitive facilities

Vulnerable population and sensitive facilities include Senior and disabled residences, prisons, and city halls within a radius of 500m of the level crossing.

The two alternatives of this sub-criterion are:

- None exist within a radius of 500m
- Exist within a radius of 500m

5.5.4.4 Special social and event venues

Special social and event venues include Pubs, clubs, stadiums, and swimming pools within a radius of 500m of the level crossing. Additionally, any special areas that are popular at special times of the year (i.e. have significantly higher than usual traffic during certain days of the year) such as swimming lakes or ski areas are also included within this factor.

Level crossings close to pubs and clubs have a higher risk than other level crossings due to a higher exposure to users with less surrounding awareness and who are more likely to take poor judgements. Level crossings nearby stadiums and sport venues get significantly higher volume of users during special times within the week and therefore the risk increases significantly within those times. For example, the existing type of security could be enough for regular traffic but not enough for the high traffic within the event hours.

To account for the priority of consolidation and risk increase due to the presence of special social and event venues in the vicinity of the level crossing, this model considers the existence of such venues within 500 m from the crossing. Therefore, the two alternatives of this sub-criterion are:

- None exist within a radius of 500m
- Exist within a radius of 500m

5.5.5 Environmental and economic factors

This main category gathers some of the factors that were identified as most important through literature review.

The sub-criteria included in the risk assessment based on this category are:

- Noise
- Vehicle emissions
- Operating costs

5.5.5.1 Noise

As countries and communities often strive to offer the best quality of life to the residents, Noises that occur from train traffic usually hinders those efforts and become a reason of complaints. It is often reported in the media that level crossings are a source of noise and negatively impacting the quality of life for the surrounding residents. Also, it can be an economic disadvantage for citizens living close to a level crossing since usually a property that is exposed to higher traffic noise have less market value.

On the safety side, level crossings that are secured with whistle blow and located in locations with high noises such in the proximity of construction sites can become dangerous as the chance of the whistle blow going unheard gets higher.

This model differentiates between level crossings that are secured using train whistle and where trains are not obliged to announce their arrival by whistling. In the case of technically secured level crossings, the model takes into account the presence of pedestrian audible warning device.

Therefore, the two sub-sub-criteria under the noise factor are:

- No train whistle or pedestrians audible warning signal required at LC: usually at active crossings where no whistle signal needed or at crossings with no separate pedestrian paths.
- LC secured by train whistle or pedestrians audible warning signal: usually at passive crossings that are secured using whistle signal or at crossings that have separate paths for pedestrians.

The sensitivity to noise is then evaluated using the type of land. Figure 49 demonstrates the noise emissions limit values according to §2 of the 16. BImSchV.

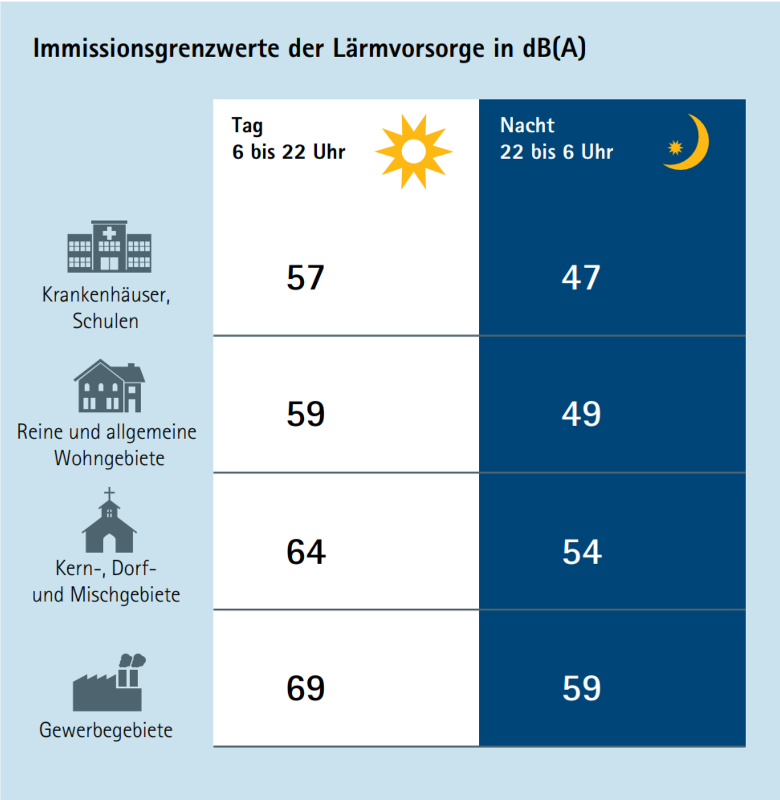


Figure 49: Noise limit values in Germany [135]

The same types of lands that are used to set noise limit values in the German regulations will be used as alternatives for both sub-sub-criteria:

- Industrial areas
- Commercial and agricultural areas
- Residential areas

- Near hospitals, schools, health resorts and retirement homes

5.5.5.2 Vehicle emissions

The amount of emissions discharged from road vehicles and fuel wasted while idle at the level crossing increase proportionally with the average daily traffic, the percentage of trucks and the type of security since waiting times significantly change by changing the type of security. Therefore, the model suggests three different categories to prioritize crossings for consolidation according to the amount of vehicle emissions:

- Low emissions: occurs at weak road traffic volume, low percentage of trucks and non-technically secured level crossings.
- Moderate emissions: occurs at moderate road traffic volume, moderate truck percentage and with light signals/flashing lights type of protection.
- High emissions: occurs at high road traffic volume, large percentage of trucks and at crossings secured by barriers.

5.5.5.3 Operating costs

There were four main criteria related to economy identified in the reviewed literature:

- Financial feasibility: A cost/benefit analysis to determine whether the economic advantages achieved from making the project justify the cost of the project.

- Project cost: Only the factor of cost of construction is considered regardless of the positive economic benefits gained from making the project. In some cases, the costs of annual maintenance or lifecycle costs are also considered in the evaluation.

- Cost of accidents (Safety benefits): This factor calculates the economic benefits of all accidents to be avoided as a result of consolidation per severity type based on the national estimations of human life values, medical expenses, loss of productivity and average material losses.

- Delay: An estimate of the costs and savings resulting from removing the level crossing in comparison to the current situation. The factor measures the savings in time wasted for all road users as a result of level crossing consolidation. Also, it considers the deceleration time and waiting time for all road users at a certain crossing per year for a set amount of years. If the consolidation leads to higher travel times for road users, the delay expenses are calculated as costs. Some prioritization models are based on delay savings such as the benefit-cost methodology utilized by state of Illinois after it was estimated that delays cost the state $74-120 million annually [118].

- Environmental benefits: All the financial benefits gained from improving the environmental situation at the area of the level crossing after consolidation. It considers the reduction in emissions, health improvements of residents in the proximity of the level crossing in addition to air quality improvements. If removing the crossing leads to higher travel distances for users and thus higher emissions, the result will be presented as costs. For example, GradeDec.Net crossing evaluation tool considers saving from three types of emissions which are carbon monoxide (CO), hydrocarbons (HC), and nitrous oxide (NOx) [66]

- Operating costs savings: reductions in wasted fuel and oil for motorized level crossing users that result from the continuous process of deceleration, idling and acceleration. Also, the money costs of additional car maintenance from the deceleration and acceleration processes in addition to level crossing maintenance needed to keep the crossing operational. The costs of maintenance of the level crossing and its surrounding infrastructure include costs of maintenance of protection equipment and signals along with the costs of crossing and road pavement maintenance as a result of cars stopping. Any additional travel distances are counted as costs.

The optimum methodology to include economic factors in a prioritization model is by creating a benefit-cost methodology that takes into account all the mentioned factor. However, a creation of such methodology is deemed very complicated. Therefore, a simplified operating costs factor was adopted in this model to keep the model easy-to-use by all level crossing risk evaluators. Nevertheless, it is advised to develop the model to adopt a benefit-cost methodology as a factor of the economic criteria in later stages. The simplified methodology currently adopted ties operating costs to three basic factors: daily traffic volume, percentage of trucks and type of security.

The amount of emissions discharged from road vehicles and fuel wasted while idle at the level crossing increase proportionally with the average daily traffic, the percentage of trucks because trucks consume more energy and therefore higher trucks percentages means higher amount of fuel wasted at the level crossing. The type of security also influences the amount of fuel wasted since waiting times significantly change by changing the type of security. On these bases, the model suggests three different bands to prioritize crossings for consolidation according to the operating costs:

- **Low operating costs:** occurs at weak road traffic volume, low percentage of trucks and non-technically secured level crossings.
- **Moderate operating costs:** occurs at moderate road traffic volume, moderate truck percentage and with light signals/flashing lights type of protection.
- **High operating costs:** occurs at high road traffic volume, large percentage of trucks and at crossings secured by barriers.

5.6 Criteria not considered in the model

Through the review of literature and international models, there were some criteria identified as candidates for any future upgrade of this model. These criteria were not selected for this model either because of lack of proof of their significance or due to absence of means or available data for a meaningful application of the factors. However, it is recommended that these criteria get investigated thoroughly and evaluated whether they would be useful for a prioritization model of level crossings in Germany for consolidation and upgrade projects. In this chapter, a selection of candidate criteria is presented.

5.6.1 Time (day/night)

USDOT model gives a special significance to the number of day through trains and puts it as an additional factor beside the total daily train volume. On the contrary, Austin and Carson revealed that depending on nightly through trains is more significant and even decided to rely on it in their negative binomial model exclusively without the total daily train volume [62].

Time is strongly connected to other factors like a reduction in both rail and road traffic volumes and a decline in visibility conditions. Illumination of the level crossing can be a decisive factor of safety during night times. Walker and Roberts found that nighttime accidents reduce by 52% when lighting is added to rural highway intersections [136]. However, more studies that measure the effectiveness of lighting in level crossings specifically are yet to performed.

5.6.2 Out of distance travel

It is the additional distance to be travelled as result of closure of the level crossing. The distance is naturally greater in rural areas than urban areas since road intersections are more and closer within cities. Therefore, the removal of a level crossing in a rural area could have greater effects on the surrounding community in terms of distances travelled and time delays which translates into economical disadvantages for the residents.

Moreover, increased out of distance travels can have negative impacts on the overall transportation network, environment, and economy. When distances of travel increase, the fuel usage, pollution, roadway usage, vehicle maintenance costs, and vehicle value depreciation increase as well. And at the same time, more time value is lost [78].

Out of distance travel can be calculated simply by finding the difference in distance between the level crossing path and the alternate path as explained in Figure 50. The alternate route distance is approximately 5.9 km while the normal level crossing path is 300m between the two points. Therefore, removing the level crossing results in a 5.6 km out of travel distance.

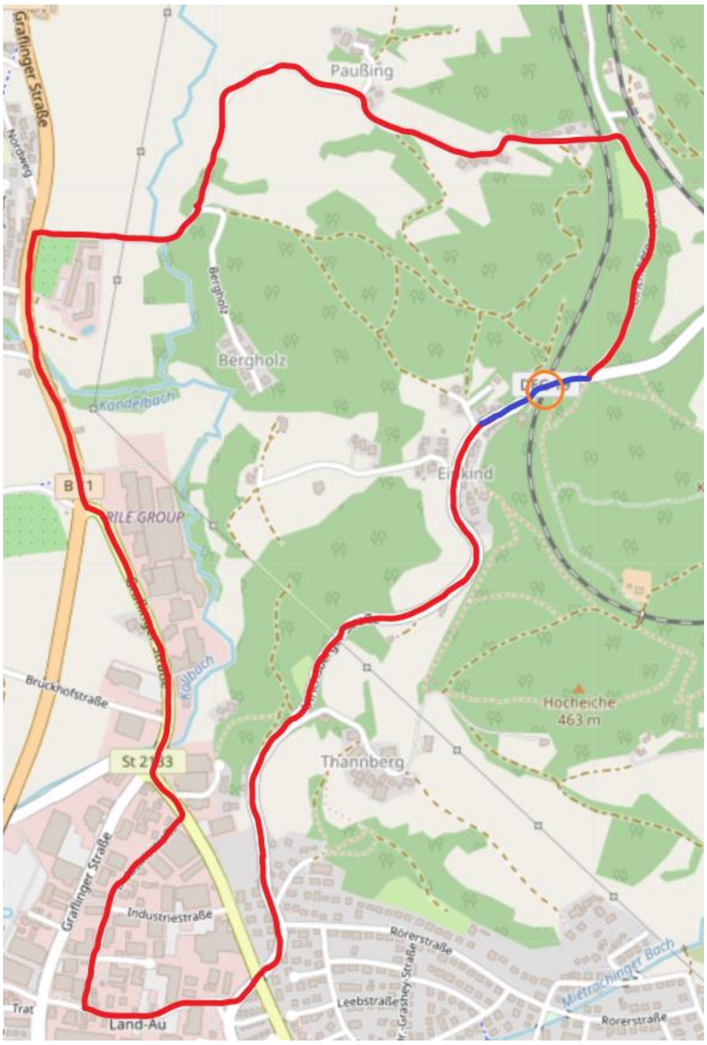


Figure 50: Example for out of travel distance (Source: Openstreetmap.org)

5.6.3 Type of land use

The German standard "Ordinance on the Structural Use of Land (BauNVO)" divides lands into four main categories:

- Residential areas: small settlement areas, purely residential areas, general residential areas, and special residential areas.
- Mixed building areas: Villages, village residential areas, Mixed areas, urban areas, and core areas.
- Commercial building areas: Commercial areas and Industrial areas.
- Special building areas

There were studies to measure the crash severity at level crossings in different kind categories. It was found that level crossings that are located in residential, commercial, industrial, and institutional areas have a higher likelihood of fatal and injury accidents than level crossings in open space areas [105].

5.6.4 Distance to the closest level crossing

Some models measure the distance of the level crossing to the closest neighbor crossing as a factor of elimination since it translates into an availability of alternative options for crossing. Also, in areas where there are level crossings close to each other, the scale of almost all the negative effects that result from the consolidation is less.

5.6.5 Weather

Weather can be an effective factor to determine risk at level crossings. During foggy weather the visibility of drivers decrease, and the risk of accidents becomes high. Drivers will also have difficulties in observing the light signal and barriers in case of active crossings or do a safe overview process for passive crossings. Snow and ice have also bad influence on the friction between tires and crossing surface which increases breaking distances and increase the possibility of occasions where drivers lose control over their vehicles.

In sunny weather, the effects of sun glare discussed in section 5.17 become more severe.

Although, Weather effects could be very severe and play a big role in increasing risk at level crossings, but the inclusion of such factor in any prioritization model is very hard and sometimes have no effect since weather impacts almost all level crossings within huge areas in the same manner. It might make sense to include the weather factor for countries that have huge differences in weather type between its states like the United States for example. In Germany, there is no great contrast in weather between states.

5.7 Survey results

Along with the pairwise comparisons, the experts were asked about their opinion regarding the current level crossing situation in Germany and whether they think applying a model to prioritize and evaluate German level crossings is necessary. In this section, the opinions of the experts are presented in figures 51-55.

Figure 51: Experts opinions regarding safety situation

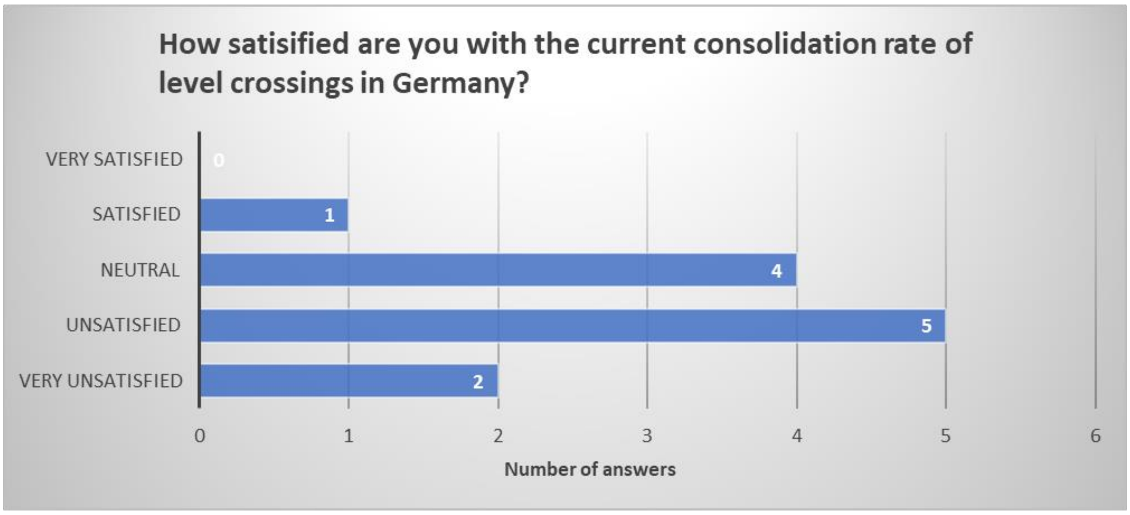


Figure 52: Experts opinions regarding consolidation rate

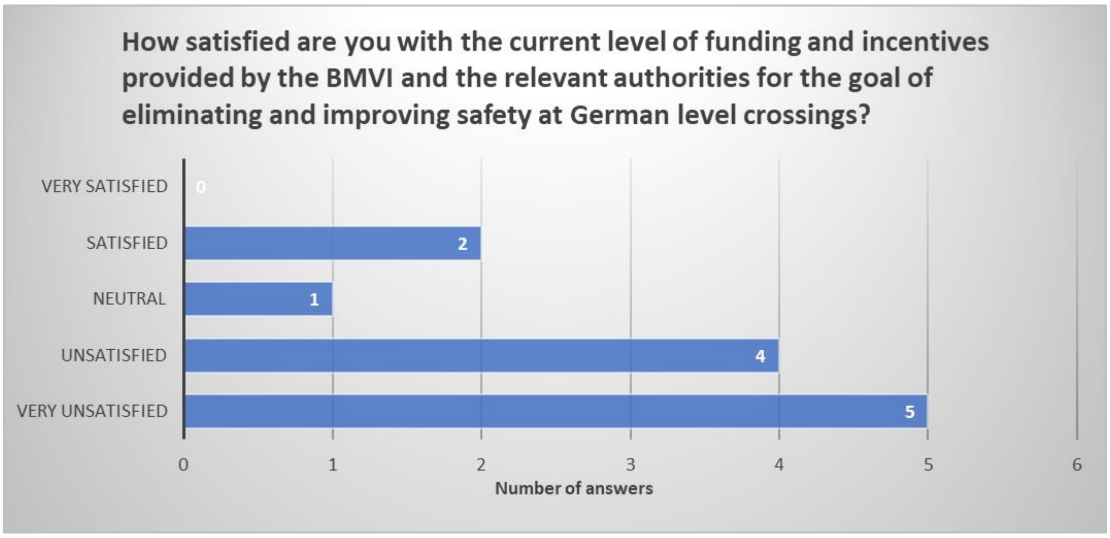


Figure 53: Experts opinions regarding funding of LC projects

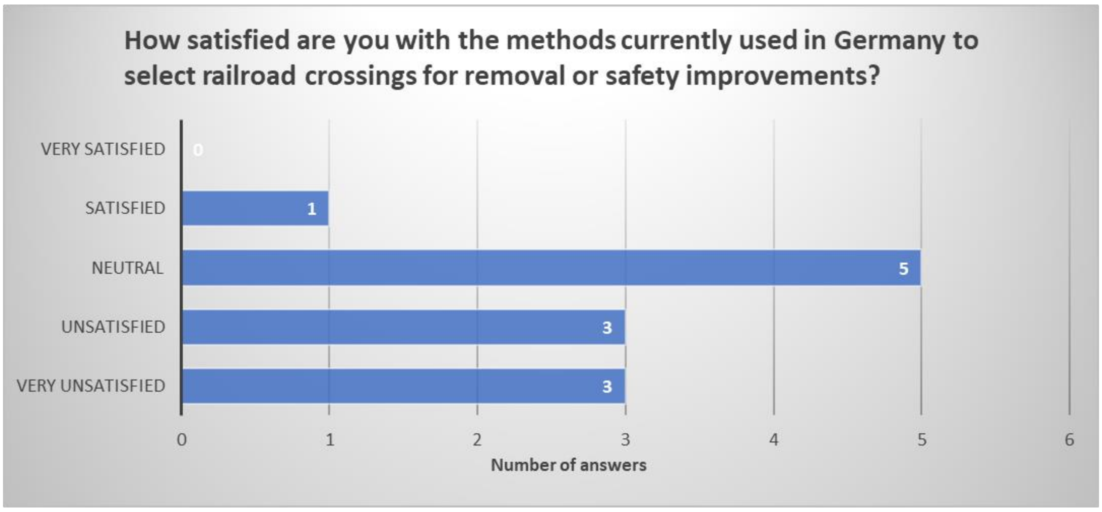


Figure 54: Experts opinions regarding prioritization methods

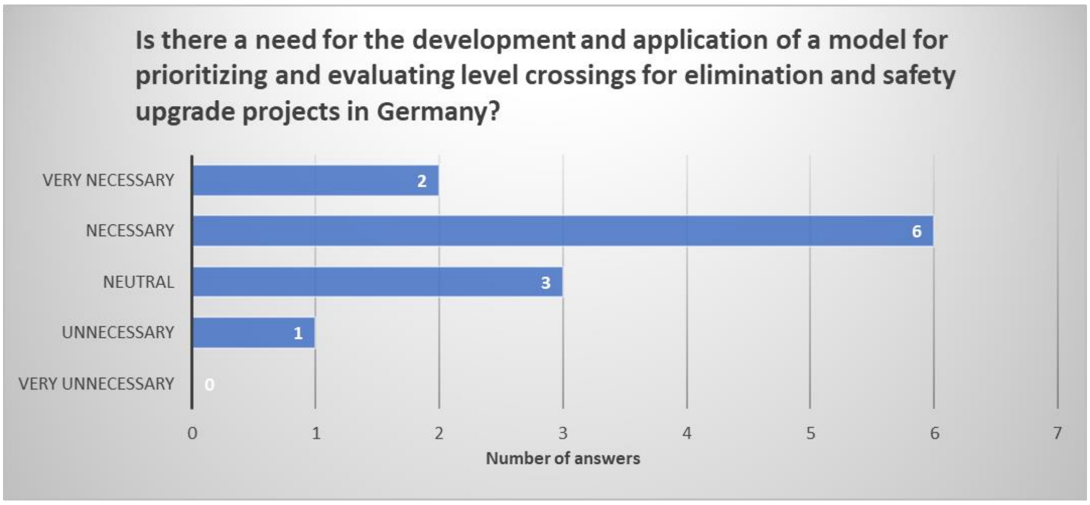


Figure 55: Experts opinions regarding necessity of development of a LC consolidation and prioritization model

When asked about the most important problems with the current way of selecting level crossings in Germany in their opinion, the experts listed the following points:

- Absence of method for the systematic selection of level crossings for elimination
- Lack of funding and financial resources
- Absence of incentives for road authorities to consolidate level crossings
- The full cost bearing by the federal government
- Not relying on low-cost measures to increase LC safety similar to the measures applied internationally
- Diffusion of responsibility between authorities due to the special location of level crossings between road and rail
- Rigidity of rules and regulations regarding level crossings safety in Germany
- Lack of understanding of the legal situation by the municipalities or local authorities
- Lack of planning capacity
- Projects not reaching their target such as the flashing lights program that was originally scheduled to replace flashing lights protection by 1998 but have not achieved its target after almost 25 years of its initiation

After completing the pairwise comparisons, the experts were asked about their opinions regarding the build of the model and the criteria selected. For the purpose of future further development of the model, the experts suggested that the following criteria are missing from the model despite being relevant for the purpose of prioritization:

- Influence on rail operations
- Consequential costs on railway infrastructure
- Connectivity between city districts or to important facilities
- Combined factors rather than absolute factors such as number of accidents per type of protection or number of accidents for a certain road class
- Type of crossing (Public vs private) to cover the funding responsibility
- Access roads to private property

In addition, some of the experts did not find the following criteria adopted in the model as relevant for the situation in Germany:

- Functional classification: Rural vs Urban
- Train characteristics
- Operating costs
- Vehicles emissions due to difficulty of measurement
- Track type: Main or side track

5.8 The points system

5.8.1 Overview of the points system

Based on the weights of criteria obtained from AHP, a points system to rate level crossings was developed. The system gives a priority score for each criterion and the crossing which receives the highest priority score has the highest priority for consolidation or safety upgrade. The system is designed to assign a total of 1000 priority points into the five main criteria. According to their respective weights, the main criteria have the following priority points:

- **Traffic and operational factors:** 221 priority points
- **Physical factors:** 150 priority points
- **Safety factors:** 524 priority points
- **Social factors:** 59 priority points
- **Environmental and economic factors:** 46 priority points

During the analysis of the experts judgements, it was observed that experts rated all alternatives of the ´train length´ criterion equally which makes including the criteria in the model meaningless. Therefore, the priority points of this criterion were transferred to `train types´ criterion. As `train types´ has become the sole sub-sub-criterion of the ´train characteristics´ sub-criterion it was decided to upgrade it to replace the latter as a sub-criterion holding the same weight of ´train characteristics´.

In addition, experts rated all types of crossing surface except ´unpaved´ according to risk influence equally. Therefore, it was deemed more meaningful to replace the categorization by type of crossing surface to the existence of crossing surface. The model now gives a risk score only if the crossing is unpaved.

Table 45 demonstrates the criteria weights and priority points for every alternative.

Table 45: Model´s criteria weights and priority points

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)	Priority points
Traffic and operational factors (Weight=0.22116)	Functional classification (Weight=0.01921)	Area classification (Weight=0.01217)	Rural	3
			Urban	12
		Road type (Weight=0.00369)	Federal highways	4
			State roads	2
			County roads	1
			City and municipal roads	1
			Others (e.g. field and forest roads)	0
		Track type (Weight=0.00335)	Main track	3
			Side track	1
	Traffic Exposure (Weight=0.08934)	Average daily road traffic volume (Weight=0.04467)	Weak: ≤100 vehicles/day	3
			Moderate: 101-2500 vehicles/day	19
			Strong: >2500 vehicles/day	45
			≤ 20 Trains/day	3

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)	Priority points
		Train volume (Weight=0.04467)	21-40 Trains/day	11
			41-60 Trains/day	20
			>60 Trains/day	45
	Road users factor (Weight=0.03067)	Pedestrians and cyclists % (Weight=0.01022)	<5%	1
			5-20%	4
			>20%	10
		Trucks % (Weight=0.01022)	<5%	1
			5-20%	4
			>20%	10
		Presence of buses and school buses (Weight=0.10200)	Present	10
			Not present	0
	Train types (Weight=0.01548)	-	With passenger traffic	16
			Only freight traffic	4
	Speed factor (Weight=0.04103)	Train speed (Weight=0.02735)	≤20 km/h	1
			21-40 km/h	1
			41-60 km/h	3
			61-80 km/h	4
			81-100 km/h	7
			101-120 km/h	11
			121-140 km/h	17
			141- 160 km/h	27
		Maximum road speed (Weight=0.01368)	≤ 10 km/h	1
			11-30 km/h	2
			31-50 km/h	3
			51-70 km/h	6
			>70 km/h	14
	Waiting time (Delay) (Weight=0.02542)	-	≤30s	1
			31-60s	2
			61-90s	3
			91-120s	5
			121-150s	8
			151-180s	12
			181-210s	18
			211-240s	25
Physical factors (Weight=0.15041)	Geometrical factors (Weight=0.06682)	Angle of intersection (Weight=0.01437)	61°-90°	2
			31°-60°	6
			0°-30°	14
		Approach grade (AG) (Weight=0.00686)	<3%	0
			3% ≤ AG < 6%	1
			6% ≤ AG < 9%	2
			9% ≤ AG < 12%	4
			AG ≥ 12%	7
		Track curvature (Weight=0.00437)	R < 250m	4
			250m ≤ R < 500m	3
			500m ≤ R < 750m	1
			R ≥ 750m	1
		Road curvature (Weight=0.00566)	<0.25 gon/m	1
			0.25 - 0.5 gon/m	1
			0.5 - 0.75 gon/m	2
			0.75 - 1 gon/m	4
			> 1 gon/m	6
		Road width (Weight=0.00763)	< 4.75m	7
			4.75 – 5.5m	4
			5.5 – 6.35m	2
			≥ 6.35m	1

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)	Priority points
		Number of tracks (Weight=0.01336)	1	1
			2	2
			3	6
			≥4	13
		Number of lanes (Weight=0.00601)	1	1
			2	2
			≥3	6
		Distance to nearby intersection (DNI) (Weight=0.00855)	In clearance section (≤27m)	9
			27 < DNI ≤ 50m	4
			50 < DNI ≤ 100m	2
			100 < DNI ≤ 150m	1
			>150m	0
	Visibility (Weight=0.01258)	Sight distance (Weight=0.00314)	>400m	0
			200-400m	1
			<200m	3
		Sight obstructions (Weight=0.00747)	No obstructions	0
			Obstructions exist	8
		Illumination (Weight=0.00198)	Sufficient	0
			Insufficient	1
			No illumination	2
	Pavement (Weight=0.07101)	Crossing surface (Weight=0.02029)	Paved	0
			unpaved	20
		Type of road pavement (Weight=0.01014)	Paved	0
			Unpaved	10
		Condition of crossing and road pavement (Weight=0.04058)	Good condition	0
			Poor condition	41
Safety factors (Weight=0.52365)	Type of protection (Weight=0.16588)	-	Full barriers	15
			Half barriers	36
			Light signals / Flashing lights	79
			Passive	166
	Accident history (Weight=0.20409)	Number of accidents (Weight=0.04080)	0	2
			1-2	7
			3-4	18
			>4	41
		Number of fatalities (Weight=0.10226)	0	5
			1-2	17
			3-4	46
			>4	102
		Number of severe injuries (Weight=0.04321)	0	2
			1-2	7
			3-4	20
			>4	43
		Number of slightly injured (Weight=0.01782)	0	1
			1-2	4
			3-4	8
			>4	18
	Road markings (Weight=0.03808)	-	Exist	0
			No road markings	38
	Traffic safety devices (Weight=0.03944)	-	Exist	0
			No traffic safety devices	40

Main criteria (Level 1)	Sub-criteria (Level 2)	Sub-sub-criteria (Level 3)	Alternatives (Level 4)	Priority points
	Hazardous material transportation (Weight=0.07616)	-	No regular hazardous material transportation	0
			Regular hazardous material transportation	76
Social factors (Weight=0.05906)	Emergency services (Weight=0.01454)	-	None exist within a radius of 500m	0
			Exist within a radius of 500m	15
	Schools (Weight=0.02047)	-	None exist within a radius of 500m	0
			Exist within a radius of 500m	21
	Vulnerable population and sensitive facilities (Weight=0.01202)	-	None exist within a radius of 500m	0
			Exist within a radius of 500m	12
	Special social and event venues (Weight=0.01202)	-	None exist within a radius of 500m	0
			Exist within a radius of 500m	12
Environmental and economic factors (Weight=0.04572)	Noise (Weight=0.01829)	No train whistle or pedestrians audible warning signal required at LC (0.00610)	Industrial areas	1
			Commercial and agricultural areas	2
			Residential areas	4
			Near hospitals, schools, health resorts and retirement homes	6
		LC secured by train whistle or pedestrians audible warning signal (0.01219)	Industrial areas	2
			Commercial and agricultural areas	6
			Residential areas	12
			Near hospitals, schools, health resorts and retirement homes	18
	Vehicle emissions (Weight=0.01829)	-	Low emissions	2
			Moderate emissions	7
			High emissions	18
	Operating costs (Weight= 0.00914)	-	Low costs	1
			Moderate costs	4
			High costs	9

The points system was selected to present the output of the model for its simplicity. The user has to simply select the alternative that applies to the crossing under evaluation from the tables of priority scores (Table 46 to 86). The final priority score is simply the summation of all 41 priority scores. Level crossings could be later ranked by this model after calculating the priority score of each crossing. The crossing that has a higher priority score have a higher priority to get consolidated or upgraded. The maximum priority score any level crossing can obtain through this approach is 1000 points.

Additionally, using this model, it is possible to rank crossing based on individual set of criteria such as a ranking based on safety factors only for example.

The priority score tables used to calculate the final priority score of level crossing are presented in the next section.

5.8.2 Priority score tables

In this section the tables of priority scores for all criteria of this model are presented.

Table 46: Area classification priority score

Area classification priority score	
Alternative	Priority points
Rural crossings	3
Urban crossings	12

Table 47: Road type priority score

Road type priority score	
Alternative	Priority points
Federal highways (Bundesstraßen)	4
State roads (Landes-(Staats)-straßen)	2
County roads (Kreisstraßen)	1
City and municipal roads (Stadt und Gemeindestraßen)	1
Others (e.g. field and forest roads)	0

Table 48: Track type priority score

Track type priority score	
Alternative	Priority points
Main track	3
Side track	1

Table 49: Average daily road traffic volume priority score

Average daily road traffic volume priority score	
Alternative	Priority points
Weak: ≤100 vehicles/day	3
Moderate: 101-2500 vehicles/day	19
Strong: >2500 vehicles/day	45

Table 50: Train volume priority score

Train volume priority score	
Alternative	Priority points
≤ 20 Trains/day	3
21-40 Trains/day	11
41-60 Trains/day	20
>60 Trains/day	45

Table 51: Pedestrians and cyclists % priority score

Pedestrians and cyclists % priority score	
Alternative	Priority points
<5%	1
5-20%	4
>20%	10

Table 52: Trucks % priority score

Trucks % priority score	
Alternative	Priority points
<5%	1
5-20%	4
>20%	10

Table 53: Buses and school buses priority score

Buses and school buses priority score	
Alternative	Priority points
Present	10
Not present	0

Table 54: Train types priority score

Train types priority score	
Alternative	Priority points
With passenger traffic	16
Only freight traffic	4

Table 55: Train speed priority score

Train speed priority score	
Alternative	Priority points
≤20 km/h	1
21-40 km/h	1
41-60 km/h	3
61-80 km/h	4
81-100 km/h	7
101-120 km/h	11
121-140 km/h	17
141- 160 km/h	27

Table 56: Maximum road speed priority score

Maximum road speed priority score	
Alternative	Priority points
≤ 10 km/h	1
11-30 km/h	2
31-50 km/h	3
51-70 km/h	6
>70 km/h	14

Table 57: Waiting time (Delay) priority score

Waiting time (Delay) priority score	
Alternative	Priority points
≤30s	1
31-60s	2
61-90s	3
91-120s	5
121-150s	8
151-180s	12
181-210s	18
211-240s	25

Table 58: Angle of intersection priority score

Angle of intersection priority score	
Alternative	Priority points
61°-90°	2
31°-60°	6
0°-30°	14

Table 59: Approach grade priority score

Approach grade priority score	
Alternative	Priority points
<3%	0
3% ≤ AG < 6%	1
6% ≤ AG < 9%	2
9% ≤ AG < 12%	4
AG ≥ 12%	7

Table 60: Track curvature priority score

Track curvature priority score	
Alternative	Priority points
R < 250m	4
250m ≤ R < 500m	3
500m ≤ R < 750m	1
R ≥ 750m	1

Table 61: Road curvature priority score

Road curvature priority score	
Alternative	Priority points
<0.25 gon/m	1
0.25 - 0.5 gon/m	1
0.5 - 0.75 gon/m	2
0.75 - 1 gon/m	4
> 1 gon/m	6

Table 62: Road width priority score

Road width priority score	
Alternative	Priority points
< 4.75m	7
4.75 – 5.5m	4
5.5 – 6.35m	2
≥ 6.35m	1

Table 63: Number of tracks priority score

Number of tracks priority score	
Alternative	Priority points
1	1
2	2
3	6
≥4	13

Table 64: Number of lanes priority score

Number of lanes priority score	
Alternative	Priority points
1	1
2	2
≥3	6

Table 65: Distance to nearby intersections priority score

Distance to nearby intersections priority score	
Alternative	Priority points
In clearance section (≤27m)	9
27 < DNI ≤ 50m	4
50 < DNI ≤ 100m	2
100 < DNI ≤ 150m	1
>150m	0

Table 66: Sight distance priority score

Sight distance priority score	
Alternative	Priority points
>400m	0
200-400m	1
<200m	3

Table 67: Sight obstructions priority score

Sight obstructions priority score	
Alternative	Priority points
No obstructions	0
Obstructions exist	8

Table 68: Illumination priority score

Illumination priority score	
Alternative	Priority points
Sufficient	0
Insufficient	1
No illumination	2

Table 69: Crossing surface priority score

Crossing surface priority score	
Alternative	Priority points
Paved	0
unpaved	20

Table 70: Road pavement priority score

Road pavement priority score	
Alternative	Priority points
Paved	0
Unpaved	10

Table 71: Condition of crossing and road pavement priority score

Condition of crossing and road pavement priority score	
Alternative	Priority points
Good condition	0
Poor condition	41

Table 72: Type of protection priority score

Type of protection priority score	
Alternative	Priority points
Full barriers	15
Half barriers	36
Light signals / Flashing lights	79
Passive	166

Table 73: Number of accidents priority score

Number of accidents priority score	
Alternative	Priority points
0	2
1-2	7
3-4	18
>4	41

Table 74: Number of fatalities priority score

Number of fatalities priority score	
Alternative	Priority points
0	5
1-2	17
3-4	46
>4	102

Table 75: Number of severe injuries priority score

Number of severe injuries priority score	
Alternative	Priority points
0	2
1-2	7
3-4	20
>4	43

Table 76: Number of slightly injured priority score

Number of slightly injured priority score	
Alternative	Priority points
0	1
1-2	4
3-4	8
>4	18

Table 77: Road markings priority score

Road markings priority score	
Alternative	Priority points
Road markings exist	0
No road markings	38

Table 78: Traffic safety devices priority score

Traffic safety devices priority score	
Alternative	Priority points
Traffic safety devices exist	0
No traffic safety devices	40

Table 79: Hazardous material transportation priority score

Hazardous material transportation priority score	
Alternative	Priority points
No regular hazardous material transportation	0
Regular hazardous material transportation	76

Table 80: Emergency services priority score

Emergency services priority score	
Alternative	Priority points
None exist within a radius of 500m	0
Exist within a radius of 500m	15

Table 81: Schools priority score

Schools priority score	
Alternative	Priority points
None exist within a radius of 500m	0
Exist within a radius of 500m	21

Table 82: Vulnerable population and sensitive facilities priority score

Vulnerable population and sensitive facilities priority score	
Alternative	Priority points
None exist within a radius of 500m	0
Exist within a radius of 500m	12

Table 83: Special social and event venues priority score

Special social and event venues priority score	
Alternative	Priority points
None exist within a radius of 500m	0
Exist within a radius of 500m	12

Table 84: Vehicle emissions priority score

Vehicle emissions priority score	
Alternative	Priority points
Low emissions	2
Moderate emissions	7
High emissions	18

Table 85: Operating costs priority score

Operating costs priority score	
Alternative	Priority points
Low costs	1
Moderate costs	4
High costs	9

Table 86: Noise priority score

Noise priority score			
If no train whistle or pedestrians audible warning signal required at the crossing		If the crossing is secured by train whistle or pedestrians audible warning signal	
Type of land	Priority points	Type of land	Priority points
Industrial areas	1	Industrial areas	2
Commercial and agricultural areas	2	Commercial and agricultural areas	6
Residential areas	4	Residential areas	12
Near hospitals, schools, health resorts and retirement homes	6	Near hospitals, schools, health resorts and retirement homes	18

6 Conclusion

The improvement of the safety situation at level crossings remains a challenging task for all authorities involved and achieving a safety situation of zero level crossing accidents is naturally a goal for every country. This goal can never be achieved unless all conflict points are eliminated which consequentially means removing the level crossings.

The consolidation of level crossings is a very costly goal, and it usually accompanies massive infrastructure investments. The scarcity of financial resources is often the reason of the slow rate of level crossing consolidation efforts. The scarcity of resources makes the wise spending on projects a very critical task as decision-makers are obliged to take decisions that could provide the best safety improvement within the available resources. In other words, to make every euro counts.

Therefore, there is a need to develop tools that helps authorities in the decision-making process and provide suggestions on which level crossings impose the highest threat on public safety, environment safety and economy. Such tool could be very valuable in improving the quality of decisions taken by decision-makers and in improving the overall safety situation at level crossings.

The development of such tool is a challenging task since the factors involved in the decision-making process are too many. Many studies from around the world have attempted to figure out the degree of influence for every factor on the LC risk.

In Germany, there is no model currently being implemented for the prioritization of level crossings for consolidation or safety upgrades. Other than the simple criteria to select the appropriate type of protection to be implemented at the crossing, there is no methodology to evaluate crossings. On the other hands, many other countries developed systematic and statistically-driven risk models to evaluate and prioritize level crossings.

In this project the models and LC consolidation methods that are applied by countries all over the world were analyzed and compared to understand the depth of complexity that each country has put into its model and the factors that were identified as relevant and thus applied in the model.

Based on the international models examined and the literature review of criteria, the criteria for the development of a German level crossing prioritization model were selected. It was strived for during the development of this model to be comprehensive and include a wide variety of influencing factors in the calculations. The factors selected for the development of this model were classified into factors related to traffic operations, factors related to the physical design of the crossing, factors related to safety, factors related to special social groups, and economic and environmental factors.

Throughout the process of criteria and alternative selection, the compatibility of factors with the regulations and norms in Germany was taken into account.

The weighting of the criteria was done with the help of a group of level crossing experts from both the academic and professional fields. After selecting the criteria, a web-based survey designed in a pairwise comparisons style was distributed to the experts in which each expert had to compare criteria and alternatives against each other. The results of the survey were later analyzed and used to compute the weights of criteria using the analytic hierarchy process (AHP) methodology.

A priority points system was then developed based on the calculated weights of criteria and alternatives. The points system is very simple to use as a priority score for the level crossing under evaluation can be calculated by taking the summation of priority points for all criteria. The points system produces a priority score out of 1000 points. Level crossings can then be ranked according to the priority score they receive.

This model, thanks to the technique that was used for its development which is AHP methodology, is considered a flexible model and very easy to upgrade. The hierarchy approach that represents the core of the model classifies criteria into four levels. The criteria are combined together like individual blocks in a structure. This gives the opportunity to change or upgrade the criteria easily by taking single blocks and re-evaluate their weights while the weights of the other criteria in other categories will remain stable.

The possible upgrades of this model could include the application of statistical data to obtain the weights, or including a larger sample of experts in the evaluation of criteria to acquire more accurate results and the introduction of benefit-cost methodology to replace the simple operating cost criterion.

This model is not considered as a standalone method of rating level crossings but rather a simple tool that can be used in addition to other tools by engineers and decision-makers in Germany for taking an informed decision and help to make the resource allocation process more efficient.

In this project, the safety situation at level crossings in Germany along with statistics and an overview of the current practices, standards, laws and regulations currently applied in Germany that concerns level crossings. Also, a literature review was performed to analyze the criteria and international models. The models identified as most important while review are described in detail in this project.

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Appendix A

US accident prediction and hazard rating formulas

A list of the main accident prediction and hazard rating formulas currently being applied in each state of the united states of America is presented in this section.

Model	Formula	Comments
Texas Priority Index Formula (also in Florida)	$XPI = V \times T \times (0.1 \times S) \times PF \times (0.01 \times A_5^{1.15}) \times SB_f$	PF= 1.00 for passive; 0.70 for mast-mounted flashing lights; 0.15 for cantilever flashing lights; and 0.10 for gates SB<1= 1 1≤SB<4= 1.2 4≤SB<11= 1.6 SB≥11= 1
Revised Texas Priority Index Formula	$XPI_{rev} = 1000 \times A_p \times (A_5 + 0.1)$ $A_p = \exp[-6.9240 + PF + (0.2587 \times hp) - (0.3722 \times ht) + (0.0706 \times D) + (0.0656 \times C) + (0.0022 \times SD) + (0.0143 \times S_{tmax}) + (0.0126 \times S_{tmin}) + (1.0024 \times Log_{10}(T+0.5)) + (0.4653 \times Log_{10}(AADT)) – (0.2160 \times NIP) + (0.0092 \times SV)$	PF= 0.5061 for flashing lights, - 0.2006 for gates, and 0 for passive Hp= 1 for paved; 2 for unpaved ht= 1 for urban, 2 for rural NIP= 1 if present, 2 if not present
California Hazard Rating Formula	$CaHI = \frac{VxTxPF}{1000} + (A_{10}x3)$	PF= 1.00 for Stop sign or Cross buck; 0.67 for wigwags; 0.33 for flashing lights and 0.13 for gates
CPUC Priority Index Formula	$P = \frac{V\ x\ (T+0.1xT_{LR})\ x\ (A+1)}{PC} + BD + SV + S + CG + Tp$	All values are entered in the formulas factors (points)
Connecticut Hazard Rating Formula	$CoHI = \frac{(T+1)x(A_5+1)xVxPF}{100}$	
Illinois Hazard Index Formula	$IHI = 10^{-6} \times (\ln(VxT))^{2.59088} \times S^{0.09673} \times C^{0.40227} \times D^{0.59262} \times (15.59xA^{5.60977} + PF)$	PF= 86.39 for crossbucks; 68.97 for flashing lights; and 37.57 for gates A= average accidents per year (5 years)
Iowa Accident Prediction Formula	$EF = (\%AADT^{12\ am.-6\ a.m.} \times \%T^{12\ a.m.-6\ a.m.}) + (\%AADT^{6\ am.-12\ p.m.} \times \%T^{6a.m.-12\ p.m.}) + (\%AADT^{12\ pm.-6\ p.m.} \times \%T^{12\ p.m.-6\ p.m.}) + (\%AADT^{6\ pm.-12\ a.m.} \times \%T^{6\ p.m.-12\ a.m.})$ divided by the GREATER of $[(\%AADT^{12\ a.m.-6\ a.m.})^2 + (\%AADT^{6\ a.m.-12\ p.m.})^2 + (\%AADT^{12\ p.m.-6\ p.m.})^2 + (\%AADT^{6\ p.m.-12\ a.m.})^2]$ or $[(\%T^{12\ a.m.-6\ a.m.})^2 + (\%T^{6\ a.m.-12\ p.m.})^2 + (\%T^{12\ p.m.-6\ p.m.})^2 + (\%T^{6\ p.m.-12\ a.m.})^2]$ $E = 1.35EF \times AADT \times T$ For passive level crossings: $PA = 0.0006938[(E+0.2)/0.2]^{0.37} \times [(Td+0.2)/0.2]^{0.1781} \times e^{(0.0077xS)} \times e^{[-0.5966(hp-1)]}$ $PA^{adj} = 0.65\ \frac{PA\left[\frac{1}{0.05+PA}\right]+A_5}{\left[\frac{1}{0.05+PA}\right]+5}$	*based on USDOT %AADT = percentage of AADT in between the mentioned hours %T = percentage of trains in between the mentioned hours hp = 1 for paved, 2 for dirt or gravel C = number of main tracks ht = 1 for urban, 0 for rural

	For level crossings protected with flashing lights: PA = 0.0003351[(E+0.2)/0.2]$^{0.4106}$ x [(d+0.2)/0.2]$^{0.1131}$ x e$^{(0.1917xC)}$ x e$^{[0.1826(D-1)]}$ $PA^{adj} = 0.5001\ \frac{PA\left[\frac{1}{0.05+PA}\right]+A_5}{\left[\frac{1}{0.05+PA}\right]+5}$ For level crossings protected with flashing lights and barriers: PA = 0.0005745[(E+0.2)/0.2]$^{0.2942}$ x [(Td+0.2)/0.2]$^{0.1781}$ x e$^{(0.1512xC)}$ x e$^{[0.142(D-1)]}$ $PA^{adj} = 0.5725\ \frac{PA\left[\frac{1}{0.05+PA}\right]+A_5}{\left[\frac{1}{0.05+PA}\right]+5}$ $PA^{fat} = \frac{PA^{adj}}{1+(440.9xS^{-0.9931})x(T+1)^{-0.0873}x(Ts+1)^{0.0872}xe^{(0.3571xht)}}$ $PA^{cas} = \frac{PA^{adj}}{1+(4.481xS^{-0.343})xe^{0.1153xC}xe^{(0.2961xht)}}$ $PA^{inj} = PA^{cas} – PA^{fat}$ $PA^{prop} = PA^{adj} - PA^{cas}$	
Mississippi Formula	HI = $\frac{\frac{SDR}{8}+A_5}{2}$	
The Ohio Method	HI = $A_f + S_f + G_f + L_f + C_f$ + SDR	
The Wisconsin Method	HI = $\frac{T(\frac{V}{20}+\frac{P}{50})}{5} + SDR + Ae$	
Contra Costa County Method	HI = T x D x $\left[1 - \exp\left(\frac{-Vxtb}{1440xD}\right)\right]$	
The Oregon Method	HI = (Vd x Td x PF + 1.4 x Vn x Tn x PF) x $\frac{Ae}{A_5}$	A_5: Expected number of accidents in 5 years
North Dakota Rating System	HI = $(C_f+L_f)+(PF+ Al_f+G_f+Cc_f)+(VxT_f)$+SDR	
Idaho Formula	HI = V_f x T_f x (S_f + SDR + C_f + Y_f)	
Utah Formula	HI = $\frac{V}{1000}\left(\frac{Tp}{10}+\frac{Tf}{20}+\frac{Ts}{30}\right) + SDR + C_f + Cc_f + R_f + 2xAe + \frac{P}{100000}\left(\frac{Tp}{10}+\frac{Tf}{20}+\frac{Ts}{30}\right) - PF$	
City of Detroit Formula	HI = $\frac{V}{1000}\left(\frac{Tp}{10}+\frac{Tf}{20}+\frac{Ts}{30}\right) + SDR + C_f + Cc_f + R_f(100\% - \%PF) + 2xAe$	
North Carolina Investigative Index Model	II = $\frac{PFxVxTx(\frac{S}{50}+0.8)xC_f}{160} + (70xA_{10})^2 + SDF$	PF: 1.0 for crossbucks; 0.5 for traffic signal; 0.2 for flashing lights and 0.1 for gates
South Dakota Hazard Index Formula	HI = $\frac{T\ x\ V\ x\ PF\ x\ OF}{5}$	
New Mexico Hazard Index Formula	HI = $\frac{T\ x\ V\ x\ PF}{100}\ x\ SD_f\ x\ S\ x\ (0.1xA_{Property\ damaage} + 0.2xA_{injury} + 0.3xA_{fatali})$	
Missouri Exposure Index Formula	TI = $\frac{(VxSV)x[(TfxSft)+(TpxSpt)+(Tsx10)]}{10000}$ EI = TI + $\frac{SD_{req} - SD_{actual}}{SD_{req}}$	

Modified Missouri Exposure Index Formula	TI = $(VxSV)x[(TfxSft) + (TpxSpt) + (Tsx10)]$ HR = $\frac{TIx\left[\left(2x\sqrt[3]{\frac{8000}{sum\ of\ \max SD\ 4ways}}\right)+\sqrt{\frac{90}{L}}+Cm_f\right]}{4}$	
Nevada Hazard Index Formula	HI = T x V x PF x A_f A_f = 1 + (Nr of fatal accidents x 1) + (Nr of injury accidents x 0.1) + (Nr of material damage accidents x 0.05)	PF= 1.00 for passive; 0.66 for flashing lights and 0.1 for gates
Revised Nevada Hazard Index Formula	HI = $\sqrt{VxT}x\left(1.3^{\left(A_5+\frac{NM_3}{3}\right)}\right)xPFxSV_fxS_fxC_fxL_f$	PF= 1.00 for passive or flashing lights; 0.3 for gates only and 0.15 for 4 Quad gate or gates with medians SV= 0.5 (0-15 mph), 1 (20-35 mph), 1.5 (40-65 mph), 2 (≥70 mph) S= 1 (0-59 mph), 1.5 (≥60 mph) C= 1.25 (2), 1.5 (3), 2(4) L= 2 (0°-30°), 1.5 (30°-60°), 1 (60°-90°)
Kansas Hazard Rating Formula	HR = $\frac{\frac{Vx(2xTft+Tst)}{400}x\left[\left(2x\sqrt[3]{\frac{8000}{sum\ of\ \max SD\ 4ways}}\right)+\sqrt{\frac{90}{L}}+Cm_f\right]}{4}$	
Florida Department of Transportation Accident Prediction Model	$t_{ap} = -8.075 + 0.318\ln S + 0.484\ln T + 0.437\ln V + 0.387\ln SV + \left(0.28 - 0.28\frac{MASD}{RSSD}\right) + \left(0.33 - 1.23\frac{MCSD}{RSSD}\right) + (0.15xN_{cb})$ $A_p = \frac{e^{(0.968t_{ap}+1.109)}}{4}$ $t_{aa} = -8.075 + 0.318\ln S + 0.166\ln T + 0.293\ln V + 0.387\ln SV + \left(0.28 - 0.28\frac{MASD}{RSSD}\right) + 0.225x(D-2) - 0.223$* $A_p = \frac{e^{(0.938t_{aa}+1.109)}}{4}$ $A_{adj} = A_p\sqrt{\frac{A_6}{A_p\ x\ A_y}}$ R = SB_f $(1-\sqrt{A_{adj}})$	* only if barriers are present SB_f: 90 for SB<10, 85 for SB≥10 and active protection without barriers, 80 for SB≥10 and passive protection

List of factors abbreviations

V = average daily traffic volume

Vd= average daylight traffic volume

Vn= average traffic volume during dark hours

AADT= Annual Average Daily Traffic

T = average daily train volume

Td = daylight thru trains per day

Tn = Average train volume during dark hours

Tp = number of daily passenger trains

Tf = number of daily freight trains

Tft = number of fast trains

Tst = number of slow trains

Ts = number of switch trains per day

T_{LR} = number of light rail per day

P = number of pedestrians

S = train speed

SV = Speed of road vehicles

Sft = Speed of freight trains

Spt = Speed of passenger trains

S_t = Speed of through trains

S_s = Speed of switching trains

PF = protection factor of traffic control device

OF = Obstruction factor

A_x = number of accidents in x years

A_p = predicted number of accidents per year

A_y = Number of years of accident records

Ae = Accident experience

NM_x = Number of near misses in x years

t_{ap} = ln of predicted number of accidents in four year period at crossings with passive traffic control devices

t_{aa} = ln of predicted number of accidents in four year period at crossings with active traffic control devices

C = Number of tracks

Cm = number of main tracks

D = Number of highway lanes

hp = road surface

ht = Area classification (Urban/Rural)

SD = Sight Distance

SDR = Sight Distance Rating

MASD = actual minimum stopping sight distance along highway

MCSD = clear sight distance

RSSD = required stopping sight distance on wet pavement

X_f = Factor

G = Approach Gradient

L = Intersection angle

tb = Time crossing is blocked

Al = Alignment of track and highway

Cc = Condition of crossing

Y = Severity

R = Road approach

N_{cb} = Number of crossbucks (Andreaskreuze)

SB = Number of school buses

NIP = nearby roadway intersection presence

PC = Project Cost

BD = Blocking Delay

CG = Crossing Geometrics

Appendix B

Overview of criteria in reviewed international models

Tables of significant criteria identified in international accident prediction, hazard prediction, consolidation and prioritization models are demonstrated in this section. These tables are particularly useful for understanding the core components of each criteria and to draw comparisons between criteria used in various models within one country and between models of different countries.

The list of reviewed models include both national models that are currently applied or abandoned old models, in addition to some research models that were developed for research purposes only.

B-1 Significant criteria in US models

Table 87: US reviewed models

	Model name	Developer	Year	States	Model application	Model type	Analysis sample
1	Peabody Dimmick Formula	L.E. Peabody and T.B. Dimmick	1941	Georgia	National model	Accident prediction model	3563
2	NCHRP Hazard Index	Alan M. Voorhees & Associates	1968	-	National model	Accident prediction model	7500
3	New Hampshire Index	-	1971	Louisiana	National model	Accident prediction model	-
4	Coleman-Stewart Model	Janet Coleman and Gerald R. Stewart	1976	-	National model	Accident prediction model	37230
5	USDOT Accident Prediction Formula	USDOT	1982	11 states	National model	Accident prediction model	-
6	FRA New Model	USDOT	2020	-	National model	Accident prediction model	-
7	Jaqua Formula	Oregon DOT	1969	Oregon	National model	Accident prediction model	-
8	Texas Priority Index Formula	-	-	Arizona	National model	Hazard prediction model	-

	Model name	Developer	Year	States	Model application	Model type	Analysis sample
9	Revised Texas Priority Index Formula	Texas DOT, Texas A&M Transportation Institute, the University of Texas	2013	Texas	National model	Hazard prediction model	-
10	Arizona Risk Assessment Methodology***	Kimley-Horn	2022	Arizona	National model	Risk Assessment Methodology	-
11	Arkansas Hazard Rating Formula	Arkansas Highway and Transportation Department (AHTD)	-	Arkansas	National model	Hazard rating index	-
12	Methodology for Evaluating Highway–Railway Grade Separations	Michael H. Schrader and John R. Hoffpauer	2001	Arkansas	National model	Prioritization model	-
13	California Hazard Rating Formula	California Public Utilities Commision (CPUC)	-	California	National model	Hazard prediction model	-
14	CPUC Priority Index Formula	California Public Utilities Commision (CPUC)	1975	California	National model	Priority Index model	-
15	Contra Costa County Method	-	-	California	National model	Hazard prediction model	-
16	Connecticut Hazard Rating Formula	-	-	Connecticut	National model	Hazard prediction model	-
17	City of Detroit Formula	-	-	Michigan	National model	Hazard prediction model	-
18	Florida DOT Accident Prediction Model	The Florida State University	-	Florida	National model	Accident prediction model	-
19	Florida Priority Index Formula	Junayed Pasha, Maxim A. Dulebenets, Olumide F. Abioye, Masoud Kavoosi, Ren Moses, John Sobanjo and Eren E. Ozguven	2020	Florida	National model	Hazard prediction model	589
20	Idaho Formula	-	-	Idaho	National model	Hazard prediction model	-
21	Illinois Hazard Index Formula	-	2000	Illinois	National model	Hazard prediction model	-
22	Iowa Accident Prediction Formula	Iowa DOT	2006	Iowa	National model	Accident prediction model	-
23	Consolidation Rating Formula In Iowa	Zachary Hans, Chris Albrecht, Patrick Johnson, and Inya Nlenanya	2015	Iowa	National model	Consolidation Rating Formula	-
24	Kansas Design Hazard Rating Formula	-	-	Kansas	National model	Hazard prediction model	-
25	The Kansas Grade Crossing Consolidation Model	Russell and Mutabazi	1998	Kansas	National model	Prioritization model	-

	Model name	Developer	Year	States	Model application	Model type	Analysis sample
26	Kern County Grade Separation Prioritization Report	Wilbur Smith Associates	2011	California	National model	Prioritization model	176
27	Michigan Hazard Index Formula*	Michigan DOT	-	Michigan	National model	Accident prediction model	-
28	Improvements to Highway-Rail Grade Crossings and Rail Safety	The Minnesota Department of Transportation	2014	Minnesota	National model	Prioritization model	683
29	Mississippi Formula	Division of Planning - Mississippi	1947	Mississippi	National model	Hazard prediction model	-
30	Missouri Exposure Index Formula	MoDOT	1970´s	Missouri	National model	Hazard prediction model	-
31	Modified Missouri Exposure Index Formula	Dr. Mohammad Qureshi, Dr. Mark R. Virkler, Dr. Kristen L. Sanford Bernhardt, Dr. Gary Spring, Sindhu Avalokita, Naveen Yathapu, Venkata Chilukuri, Tyson King, Katrina Gibbons	2003	Missouri	National model	Hazard prediction model	-
32	Rules And Regulations - Nebraska	Nebraska Department of Transportation	2019	Nebraska	National model	Prioritization model	-
33	Nevada Hazard Index Formula	NDOT	-	Nevada	National model	Hazard prediction model	-
34	Revised Nevada Hazard Index Formula	Christopher Ryan and Andrew Mielke	2017	Nevada	National model	Hazard Index Model	-
35	New Mexico Hazard Index Formula**	the New Mexico State Highway and Transportation Department	-	New Mexico	National model	Accident prediction model	-
36	North Carolina Investigative Index Model	-	-	North Carolina	National model	Hazard prediction model	-
37	Benefit-Cost methodology - North Carolina	Ali Z. Rezvani, Matthew Peach, Andrew Thomas, Ricardo Cruz, Walter Kemmsies	2015	North Carolina	National model	Prioritization model	-
38	North Dakota Rating System	-	-	North Dakota	National model	Hazard prediction model	-
39	The Ohio Method	-	-	Ohio	National model	Hazard prediction model	-
40	Quantitative Multi-Criteria Decision Support Approach	Aleksandr Prodan, Vivek Sakhrani, Marc-Andre´ Roy, Matthew Dietrich, Scott N. Phinney, and Megan McClory	2022	Ohio	National model	Prioritization model	5700

	Model name	Developer	Year	States	Model application	Model type	Analysis sample
41	Selection of at-grade highway-rail crossings for grade separation	Xue Yang, Joshua Q. Li, Wenyao Liu, Kelvin C. P. Wang, Jim Hatt & Jared Schwennesen	2022	Oklahoma	National model	Prioritization model	-
42	The Oregon Method	-	-	Oregon	National model	Hazard prediction model	-
43	Grade Separation Priority Update Study for Alameda Corridor East	InfraConsult LLC	2012	Riverside County, California	National model	Prioritization model	46
44	South Carolina Model	SCDOT	-	South Carolina	National model	Accident prediction model	-
45	South Dakota Hazard Index Formula	SDDOT	-	South Dakota	National model	Hazard prediction model	-
46	Utah Formula	-	-	Utah	National model	Hazard prediction model	-
47	Washington State Priority Matrix	-	-	Washington	National model	Priority Matrix	-
48	The Wisconsin Method	-	-	Wisconsin	National model	Hazard prediction model	-
49	Railroad Crossing Assessment Tool (RCAT)	Mark Berndt, Rahim F. Benekohal, Jacob Mathew, Jeannie Beckett, Jeff McKerrow, Tom Worker-Braddock, Al Cathcart, and Nick Weander	2019	-	National model	Prioritization model	-
50	Web-Based Accident Prediction System (WBAPS)	Federal Railroad Administration (FRA)	-	-	National model	Accident prediction model	-
51	GradeDec.Net	USDOT	2014	-	National model	Prioritization model	-
52	USDOT guidelines for grade separations	USDOT	2019	-	National guidelines	Guidance	-
53	Grade Separations - When Do We Separate?	G. Rex Nichelson and George L. Reed	1999	Texas	National model	Multi-Criteria Analysis	-
54	Negative binomial accident prediction formula	Ross D. Austin, Jodi L. Carson	2000	-	Research	Accident prediction model	80962
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida	Prashant Singh, Junayed Pasha, Amir Khorram-Manesh, Krzysztof Goniewicz, Abdolreza Roshani and Maxim A. Dulebenets	2021	Florida	Research	Accident causes factors	578

	Model name	Developer	Year	States	Model application	Model type	Analysis sample
56	Accident Severity Prediction Formula for Rail-Highway Crossings	E. H. Farr J. S. Hitz	1984	-	Research	Accident prediction model	-
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction Model - A North Dakota Case Study	Ihsan Ullah Khan, EunSu Lee and Muhammad Asif Khan	2018	North Dakota	Research	Accident prediction model	4723
58	Development of railroad at-grade crossing prioritization indices	Jack William Webb	1995	Oklahoma	Research	Prioritization model	4600
59	At grade or not at-grade: The early traffic question in light rail transit route planning	Michael Bates And Leo Lee	1989	California	Research	Multi-Criteria Analysis	5
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois	Illinois Commerce Commission	2002	Illinois	Research	Prioritization model	1732
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model: A Machine Learning Approach	Samira Soleimani, Saleh R. Mousa, Julius Codjoe, Michael Leitner	2019	top 18 safety-challenged states	Research	Consolidation model	18485
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model	Samira Soleimani, Michael Leitner, Julius Codjoe	2021	Louisiana	Research	Consolidation model	235
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives	R. C. Taggart, P. Lauria, G. Groat, C. Rees, and A. Brick-Turin	1987	-	Research	Prioritization factors	-
64	multinomial logit model	Wei (David) Fan, Martin R. Kane, and Elias Haile	2015	-	Research	Factors significance on accidents severity	7414 accidents
65	The Competing Risks model	Amin Keramati, Pan Lu, Xiaoyi Zhou, and Denver Tolliver	2020	-	Research	Accident analysis	3310

* Based on the New Hampshire Hazard Index Formula

** Based on the Modified New Hampshire Hazard Index Formula

*** Based on FRA new model

Table 88: Significant traffic and operational factors in US models

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
1	Peabody Dimmick Formula	X		X																								
2	NCHRP Hazard Index	X		X				X																				
3	New Hampshire Index	X		X																								
4	Coleman-Stewart Model	X		X				X																				
5	USDOT Accident Prediction Formula	X		X		X		X		X	X	X	X															
6	FRA New Model	X		X		X		X																				
7	Jaqua Formula	X		X		X	X	X			X										X							X
8	Texas Priority Index Formula	X		X		X												X										
9	Revised Texas Priority Index Formula	X		X		X	X	X			X																	
10	Arizona Risk Assessment Methodology	X		X		X		X		X																		
11	Arkansas Hazard Rating Formula	X		X																								
12	Methodology for Grade Separations - Arkansas	X		X		X				X			X									X		X	X			X
13	California Hazard Rating Formula	X		X																								

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
14	CPUC Priority Index Formula	X		X		X	X			X	X				X	X		X							X			X
15	Contra Costa County Method	X		X																					X			
16	Connecticut Hazard Rating Formula	X		X																								
17	City of Detroit Formula			X							X																	
18	Florida DOT Accident Prediction Model	X		X		X	X											X										
19	Florida Priority Index Formula	X		X		X																						
20	Idaho Formula	X		X		X					X																	
21	Illinois Hazard Index Formula	X		X		X																						
22	Iowa Accident Prediction Formula	X		X		X		X		X	X	X																
23	Consolidation Rating Formula In Iowa	X						X					X		X													X
24	Kansas Design Hazard Rating Formula	X		X						X	X																	
25	The Kansas Grade Crossing Consolidation Model	X		X		X		X			X																	X

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
26	Kern County Grade Separation Prioritization Report	X	X	X	X	X	X				X			X	X			X							X		X	
27	Michigan Hazard Index Formula	X		X																								
28	Improvements to Highway-Rail Grade Crossings and Rail Safety	X		X			X			X								X										
29	Mississippi Formula																											
30	Missouri Exposure Index Formula	X		X		X	X				X																	
31	Modified Missouri Exposure Index Formula	X		X		X	X			X	X																	
32	Rules And Regulations - Nebraska	X		X			X											X	X									
33	Nevada Hazard Index Formula	X		X																								
34	Revised Nevada Hazard Index Formula	X		X		X	X																					
35	New Mexico Hazard Index Formula	X		X		X																						
36	North Carolina Investigative Index Model	X		X		X				X								X										

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
37	Benefit-Cost methodology - North Carolina	X		X		X		X		X	X	X	X					X										
38	North Dakota Rating System	X		X							X																	
39	The Ohio Method	X		X		X																						
40	Quantitative Multi-Criteria Decision Support Approach	X		X		X		X		X	X	X	X												X			
41	Selection of at-grade highway-rail crossings for grade separation	X		X		X	X	X		X	X	X													X			
42	The Oregon Method	X		X								X																
43	Grade Separation Priority Update Study for Alameda Corridor East			X	X	X									X							X	X		X	X	X	
44	South Carolina Model	X		X		X		X				X	X					X										
45	South Dakota Hazard Index Formula	X		X																								
46	Utah Formula	X		X							X								X									
47	Washington State Priority Matrix	X				X									X		X											
48	The Wisconsin Method	X		X															X									

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
49	Railroad Crossing Assessment Tool (RCAT)	X		X		X	X	X		X	X	X	X		X													
50	Web-Based Accident Prediction System (WBAPS)	X		X		X																						
51	GradeDec.Net	X	X	X	X	X		X		X	X	X			X	X					X	X	X		X		X	
52	USDOT guidelines for grade separations	X		X		X	X	X		X	X	X	X												X			X
53	Grade Separations - When Do We Separate?	X		X		X		X														X						
54	Negative binomial accident prediction formula	X		X*		X				X		X																
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida	X		X		X	X		X	X	X	X	X		X			X		X	X							
56	Accident Severity Prediction Formula for Rail-Highway Crossings			X		X		X																				
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction			X		X																						

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
	Model - A North Dakota Case Study																											
58	Development of railroad at-grade crossing prioritization indices			X		X					X	X	X		X			X										
59	At grade or not at-grade: The early traffic question in light rail transit route planning	X												X										X	X		X	
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois	X		X		X				X	X											X	X		X			
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model	X		X		X	X	X				X			X			X										
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model			X		X	X	X			X				X			X										

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	School buses	Number of pedestrians and/or cyclists	Number of rail passengers per day	Number of cars in a train	Train length	Barriers down time (Waiting time)	Signal activation time	Delay	Predicted future Delay	Queuing	Out of distance travel / Accessibility
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives												X					X	X						X		X	
64	multinomial logit model	X				X	X																					
65	The Competing Risks model	X		X		X					X	X			X													

Table 89: Significant physical factors in US models

	Model name	Number of tracks	Number of lanes	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Nearby traffic signals	Grade separations per km along the railroad subdivision	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Vehicle storage Area	Illumination
1	Peabody Dimmick Formula																		
2	NCHRP Hazard Index		X	X	X														
3	New Hampshire Index																		
4	Coleman-Stewart Model	X																	

	Model name	Number of tracks	Number of lanes	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Nearby traffic signals	Grade separations per km along the railroad subdivision	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Vehicle storage Area	Illumination
5	USDOT Accident Prediction Formula	X	X												X				
6	FRA New Model													X					
7	Jaqua Formula	X	X	X	X	X		X					X						
8	Texas Priority Index Formula																		
9	Revised Texas Priority Index Formula	X	X					X				X			X				
10	Arizona Risk Assessment Methodology	X	X		X	X						X		X					
11	Arkansas Hazard Rating Formula	X																	
12	Methodology for Evaluating Highway–Railway Grade Separations	X	X								X				X				
13	California Hazard Rating Formula																		
14	CPUC Priority Index Formula	X		X			X	X		X		X							
15	Contra Costa County Method		X																
16	Connecticut Hazard Rating Formula																		
17	City of Detroit Formula	X			X							X							
18	Florida DOT Accident Prediction Model		X									X							
19	Florida Priority Index Formula																		
20	Idaho Formula	X										X							
21	Illinois Hazard Index Formula	X	X																
22	Iowa Accident Prediction Formula	X	X												X				
23	Consolidation Rating Formula In Iowa																		
24	Kansas Design Hazard Rating Formula	X		X								X							
25	The Kansas Grade Crossing Consolidation Model	X		X	X	X						X	X			X			
26	Kern County Grade Separation Prioritization Report																		
27	Michigan Hazard Index Formula																		
28	Improvements to Highway-Rail Grade Crossings and Rail Safety	X										X		X					
29	Mississippi Formula											X							
30	Missouri Exposure Index Formula											X	X						

	Model name	Number of tracks	Number of lanes	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Nearby traffic signals	Grade separations per km along the railroad subdivision	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Vehicle storage Area	Illumination
31	Modified Missouri Exposure Index Formula	X		X								X	X						
32	Rules And Regulations - Nebraska			X								X							
33	Nevada Hazard Index Formula														X				
34	Revised Nevada Hazard Index Formula	X		X															
35	New Mexico Hazard Index Formula												X						
36	North Carolina Investigative Index Model	X										X	X						
37	Benefit-Cost methodology - North Carolina	X	X									X	X		X				
38	North Dakota Rating System	X	X	X	X							X							
39	The Ohio Method	X		X	X							X							
40	Quantitative Multi-Criteria Decision Support Approach	X	X												X				
41	Selection of at-grade highway-rail crossings for grade separation	X	X												X				
42	The Oregon Method				X														
43	Grade Separation Priority Update Study for Alameda Corridor East		X																
44	South Carolina Model	X	X									X			X				
45	South Dakota Hazard Index Formula												X						
46	Utah Formula	X			X							X							
47	Washington State Priority Matrix	X		X	X					X		X					X	X	
48	The Wisconsin Method											X							
49	Railroad Crossing Assessment Tool (RCAT)	X	X	X				X						X	X				
50	Web-Based Accident Prediction System (WBAPS)	X	X												X				
51	GradeDec.Net	X	X					X							X				
52	USDOT guidelines for grade separations	X	X												X				
53	Grade Separations - When Do We Separate?																		
54	Negative binomial accident prediction formula	X	X											X	X				
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida	X	X					X					X	X	X				X

	Model name	Number of tracks	Number of lanes	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Nearby traffic signals	Grade separations per km along the railroad subdivision	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Vehicle storage Area	Illumination
56	Accident Severity Prediction Formula for Rail-Highway Crossings	X																	
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction Model - A North Dakota Case Study	X	X																
58	Development of railroad at-grade crossing prioritization indices	X	X	X	X							X			X				
59	At grade or not at-grade: The early traffic question in light rail transit route planning																		
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois																		
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model: A Machine Learning Approach							X						X					
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model			X				X											
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives																		
64	multinomial logit model													X					
65	The Competing Risks model		X												X				

Table 90: Significant safety factors in US models

	Model name	Type of protection	Number of accidents	Near misses	Crossing Pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	Type of train detection system	Presence of highway monitoring devices (photo, video)	Crossbucks
1	Peabody Dimmick Formula	X								

	Model name	Type of protection	Number of accidents	Near misses	Crossing Pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	Type of train detection system	Presence of highway monitoring devices (photo, video)	Crossbucks
2	NCHRP Hazard Index	X								
3	New Hampshire Index	X								
4	Coleman-Stewart Model	X								
5	USDOT Accident Prediction Formula	X	X							
6	FRA New Model	X	X							
7	Jaqua Formula	X								
8	Texas Priority Index Formula	X	X							
9	Revised Texas Priority Index Formula	X	X							
10	Arizona Risk Assessment Methodology	X	X							
11	Arkansas Hazard Rating Formula		X							
12	Methodology for Evaluating Highway–Railway Grade Separations	X	X							
13	California Hazard Rating Formula	X	X							
14	CPUC Priority Index Formula		X			X	X			
15	Contra Costa County Method									
16	Connecticut Hazard Rating Formula	X	X							
17	City of Detroit Formula	X	X							
18	Florida DOT Accident Prediction Model	X	X							X
19	Florida Priority Index Formula	X	X							
20	Idaho Formula									
21	Illinois Hazard Index Formula	X	X							
22	Iowa Accident Prediction Formula	X	X							
23	Consolidation Rating Formula In Iowa		X							
24	Kansas Design Hazard Rating Formula									
25	The Kansas Grade Crossing Consolidation Model									
26	Kern County Grade Separation Prioritization Report		X							
27	Michigan Hazard Index Formula	X								
28	Improvements to Highway-Rail Grade Crossings and Rail Safety	X	X	X						
29	Mississippi Formula		X							
30	Missouri Exposure Index Formula									
31	Modified Missouri Exposure Index Formula									
32	Rules And Regulations - Nebraska		X							

	Model name	Type of protection	Number of accidents	Near misses	Crossing Pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	Type of train detection system	Presence of highway monitoring devices (photo, video)	Crossbucks
33	Nevada Hazard Index Formula	X	X							
34	Revised Nevada Hazard Index Formula	X	X	X						
35	New Mexico Hazard Index Formula	X	X							
36	North Carolina Investigative Index Model	X	X							
37	Benefit-Cost methodology - North Carolina	X	X				X			
38	North Dakota Rating System	X								
39	The Ohio Method	X	X							
40	Quantitative Multi-Criteria Decision Support Approach	X	X							
41	Selection of at-grade highway-rail crossings for grade separation	X	X							
42	The Oregon Method	X	X							
43	Grade Separation Priority Update Study for Alameda Corridor East		X							
44	South Carolina Model	X	X				X			
45	South Dakota Hazard Index Formula	X								
46	Utah Formula	X	X							
47	Washington State Priority Matrix		X			X	X			
48	The Wisconsin Method		X							
49	Railroad Crossing Assessment Tool (RCAT)	X	X				X			
50	Web-Based Accident Prediction System (WBAPS)	X	X							
51	GradeDec.Net	X	X			X			X	
52	USDOT guidelines for grade separations	X	X							
53	Grade Separations - When Do We Separate?		X							
54	Negative binomial accident prediction formula	X			X					
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida	X			X				X	
56	Accident Severity Prediction Formula for Rail-Highway Crossings									
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction Model - A North Dakota Case Study	X			X					
58	Development of railroad at-grade crossing prioritization indices	X	X				X			
59	At grade or not at-grade: The early traffic question in light rail transit route planning									
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois									

	Model name	Type of protection	Number of accidents	Near misses	Crossing Pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	Type of train detection system	Presence of highway monitoring devices (photo, video)	Crossbucks
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model: A Machine Learning Approach	X								X
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model		X		X					X
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives		X				X			
64	multinomial logit model									
65	The Competing Risks model							X		

Table 91: Significant social factors in US models

	Model name	Population density	Proximity to emergency services[1]	Proximity to schools	Nearby Businesses[2]	Sites of social significance[3]	vulnerable population and sensitive facilities[4]	Community cohesion / severance	Visual appearance
1	Peabody Dimmick Formula								
2	NCHRP Hazard Index								
3	New Hampshire Index								
4	Coleman-Stewart Model								
5	USDOT Accident Prediction Formula								
6	FRA New Model								
7	Jaqua Formula								
8	Texas Priority Index Formula								
9	Revised Texas Priority Index Formula								
10	Arizona Risk Assessment Methodology								
11	Arkansas Hazard Rating Formula								
12	Methodology for Evaluating Highway–Railway Grade Separations	X						X	
13	California Hazard Rating Formula								
14	CPUC Priority Index Formula								
15	Contra Costa County Method								
16	Connecticut Hazard Rating Formula								

	Model name	Population density	Proximity to emergency services[1]	Proximity to schools	Nearby Businesses[2]	Sites of social significance[3]	vulnerable population and sensitive facilities[4]	Community cohesion / severance	Visual appearance
17	City of Detroit Formula								
18	Florida DOT Accident Prediction Model								
19	Florida Priority Index Formula								
20	Idaho Formula								
21	Illinois Hazard Index Formula								
22	Iowa Accident Prediction Formula								
23	Consolidation Rating Formula In Iowa		X	X					
24	Kansas Design Hazard Rating Formula								
25	The Kansas Grade Crossing Consolidation Model								
26	Kern County Grade Separation Prioritization Report		X						
27	Michigan Hazard Index Formula								
28	Improvements to Highway-Rail Grade Crossings and Rail Safety	X	X	X			X		
29	Mississippi Formula								
30	Missouri Exposure Index Formula								
31	Modified Missouri Exposure Index Formula								
32	Rules And Regulations - Nebraska		X	X				X	
33	Nevada Hazard Index Formula								
34	Revised Nevada Hazard Index Formula								
35	New Mexico Hazard Index Formula								
36	North Carolina Investigative Index Model								
37	Benefit-Cost methodology - North Carolina								
38	North Dakota Rating System								
39	The Ohio Method								
40	Quantitative Multi-Criteria Decision Support Approach		X					X	
41	Selection of at-grade highway-rail crossings for grade separation								
42	The Oregon Method								
43	Grade Separation Priority Update Study for Alameda Corridor East	X							
44	South Carolina Model								
45	South Dakota Hazard Index Formula								
46	Utah Formula								
47	Washington State Priority Matrix								

	Model name	Population density	Proximity to emergency services[1]	Proximity to schools	Nearby Businesses[2]	Sites of social significance[3]	vulnerable population and sensitive facilities[4]	Community cohesion / severance	Visual appearance
48	The Wisconsin Method								
49	Railroad Crossing Assessment Tool (RCAT)	X	X	X		X	X	X	
50	Web-Based Accident Prediction System (WBAPS)								
51	GradeDec.Net								
52	USDOT guidelines for grade separations								
53	Grade Separations - When Do We Separate?								
54	Negative binomial accident prediction formula								
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida								
56	Accident Severity Prediction Formula for Rail-Highway Crossings								
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction Model - A North Dakota Case Study	X							
58	Development of railroad at-grade crossing prioritization indices								
59	At grade or not at-grade: The early traffic question in light rail transit route planning								
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois								
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model: A Machine Learning Approach								
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model		X						
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives								X
64	multinomial logit model								
65	The Competing Risks model								

[1] Medical, Fire and Police facilities in the vicinity of the LC

[2] Markets and Commercial Centers

[3] includes Tribal lands, Federal or state-owned lands, Military installations, Historical properties, Parks and recreation areas

[4] includes Senior and disabled residences, prisons, city halls, Low-income populations, Minority populations and Limited Language proficiency populations

Table 92: Significant environmental, economic, and other factors in US models

	Model name	Whistle prohibition	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Local natural environment[2]	Type of Land use[3]	Crossing upgrade records
1	Peabody Dimmick Formula												
2	NCHRP Hazard Index												
3	New Hampshire Index												
4	Coleman-Stewart Model												
5	USDOT Accident Prediction Formula												
6	FRA New Model												
7	Jaqua Formula												
8	Texas Priority Index Formula												
9	Revised Texas Priority Index Formula												
10	Arizona Risk Assessment Methodology												
11	Arkansas Hazard Rating Formula												
12	Methodology for Evaluating Highway–Railway Grade Separations		X										
13	California Hazard Rating Formula												
14	CPUC Priority Index Formula				X								
15	Contra Costa County Method												
16	Connecticut Hazard Rating Formula												
17	City of Detroit Formula												
18	Florida DOT Accident Prediction Model												
19	Florida Priority Index Formula												X
20	Idaho Formula												
21	Illinois Hazard Index Formula												
22	Iowa Accident Prediction Formula												
23	Consolidation Rating Formula In Iowa												
24	Kansas Design Hazard Rating Formula												
25	The Kansas Grade Crossing Consolidation Model												
26	Kern County Grade Separation Prioritization Report		X		X								
27	Michigan Hazard Index Formula												

	Model name	Whistle prohibition	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Local natural environment[2]	Type of Land use[3]	Crossing upgrade records
28	Improvements to Highway-Rail Grade Crossings and Rail Safety												
29	Mississippi Formula												
30	Missouri Exposure Index Formula												
31	Modified Missouri Exposure Index Formula												
32	Rules And Regulations - Nebraska				X					X			
33	Nevada Hazard Index Formula												
34	Revised Nevada Hazard Index Formula												
35	New Mexico Hazard Index Formula												
36	North Carolina Investigative Index Model												
37	Benefit-Cost methodology - North Carolina				X	X	X	X	X				
38	North Dakota Rating System												
39	The Ohio Method												
40	Quantitative Multi-Criteria Decision Support Approach												
41	Selection of at-grade highway-rail crossings for grade separation			X	X	X	X	X	X				
42	The Oregon Method												
43	Grade Separation Priority Update Study for Alameda Corridor East		X	X						X			
44	South Carolina Model				X								
45	South Dakota Hazard Index Formula												
46	Utah Formula												
47	Washington State Priority Matrix												
48	The Wisconsin Method												
49	Railroad Crossing Assessment Tool (RCAT)			X	X						X	X	
50	Web-Based Accident Prediction System (WBAPS)												X
51	GradeDec.Net			X	X	X	X	X	X				
52	USDOT guidelines for grade separations				X								
53	Grade Separations - When Do We Separate?				X	X	X		X	X			
54	Negative binomial accident prediction formula												
55	A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida	X										X	

	Model name	Whistle prohibition	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Local natural environment[2]	Type of Land use[3]	Crossing upgrade records
56	Accident Severity Prediction Formula for Rail-Highway Crossings												
57	Developing a Highway Rail Grade Crossing Accident Probability Prediction Model - A North Dakota Case Study												
58	Development of railroad at-grade crossing prioritization indices												
59	At grade or not at-grade: The early traffic question in light rail transit route planning												
60	Motorist Delay at Public Highway – Rail Grade Crossings In Northeastern Illinois						X						
61	A Comprehensive Railroad-Highway Grade Crossing Consolidation Model: A Machine Learning Approach												
62	Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model											X	
63	Evaluating Grade-Separated Rail And Highway Crossing Alternatives		X	X	X				X			X	
64	multinomial logit model											X	
65	The Competing Risks model												

[1] includes the cost of vehicles fuel, vehicles maintenance and LC maintenance

[2] includes Coastal management areas, Critical habitat for threatened and endangered species, Wetlands, Wild and scenic rivers and Superfund sites in the vicinity of the LC

[3] whether the LC is located in industrial, commercial, institutional, residential, agricultural or recreation land

B-2 Significant criteria in Canadian models

Table 93: Canadian reviewed models

	Model name	Developer	Year	Model application	Model type	Analysis sample
1	GradeX	Transport Canada	2006	National model	Risk assessment model	-
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation	Peel Regional Council	2014	National model	Prioritization model	12
3	LRT Crossing Assessment Framework	City of Edmonton	2017	National model	Prioritization model	-
4	Grade Separation Assessment Guidelines	Transport Canada	2019	National guidelines	Grade separation assessment model	-
5	Calculation Of Hazard Indices for Highway-Railway Crossings in Canada	D. A. Zalinger, B. A. Rogers And H. P. Johri	1977	Research	Hazard index model	2450
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots	Frank F. Saccomanno, Liping Fu, and Luis F. Miranda-Moreno	2004	Research	Accident prediction model	29500
7	A model for evaluating countermeasures at highway–railway grade crossings	Frank F. Saccomanno and Xiaoming Lai	2005	Research	Accident prediction model	10449
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings	Peter Young-Jin Park	2007	Research	Accident prediction model	-
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study of Canada	Shahram Heydari and Liping Fu	2015	Research	Factors significance	14380

Table 94: Significant traffic and operational factors in Canadian models

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	vehicles speed	Area Classification (Urban/Rural)	Track type (Mainline or non-mainline)	Train types	Road type	Road level of service	Trucks percentage	School buses	Number of pedestrians and/or cyclists	Number of cars in a train	Train length	Delay	Predicted future Delay	Queuing
1	GradeX	X		X		X	X	X												
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation	X	X	X	X	X							X			X	X		X	
3	LRT Crossing Assessment Framework																	X		
4	Grade Separation Assessment Guidelines	X		X		X	X			X	X	X		X	X			X		X
5	Calculation Of Hazard Indices for Highway-Railway Crossings In Canada	X		X		X	X	X	X											
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots	X		X		X	X				X									
7	A model for evaluating countermeasures at highway–railway grade crossings	X		X		X	X		X		X									
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings	X		X		X	X		X		X									
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study of Canada	X		X		X	X													

Table 95: Significant physical factors in Canadian models

	Model name	number of tracks	number of lanes	Road width	Crossing width	Angle of intersection	Approach grade	Road curvature	Track alignment	nearby intersections	Sight distance	Crossing Surface	Road pavement
1	GradeX	X	X										
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation												
3	LRT Crossing Assessment Framework												
4	Grade Separation Assessment Guidelines	X	X							X			X
5	Calculation of Hazard Indices for Highway-Railway Crossings in Canada			X							X		X
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots	X			X	X							X
7	A model for evaluating countermeasures at highway–railway grade crossings	X		X		X							X
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings	X			X	X						X	
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study Of Canada		X										

Table 96: Significant safety factors in Canadian models

	Model name	Type of protection	Number of accidents	Rail/Road users carrying hazardous material
1	GradeX	X	X	
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation			

	Model name	Type of protection	Number of accidents	Rail/Road users carrying hazardous material
3	LRT Crossing Assessment Framework			
4	Grade Separation Assessment Guidelines		X	X
5	Calculation Of Hazard Indices for Highway-Railway Crossings In Canada	X	X	
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots	X	X	
7	A model for evaluating countermeasures at highway–railway grade crossings	X	X	
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings	X		
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study Of Canada	X		

Table 97: Significant social factors in Canadian models

	Model name	Proximity to emergency services[1]	Sites of social significance[4]	Community cohesion / severance	Visual appearance
1	GradeX				
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation				
3	LRT Crossing Assessment Framework		X	X	X
4	Grade Separation Assessment Guidelines	X		X	
5	Calculation Of Hazard Indices for Highway-Railway Crossings In Canada				
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots				
7	A model for evaluating countermeasures at highway–railway grade crossings				
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings				
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study of Canada				

Table 98: Significant environmental, economic, and other factors in Canadian models

	Model name	Whistle prohibition	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Surrounding Land Development opportunities
1	GradeX					X	
2	Improvements to at grade rail crossings: Prioritizing crossings for grade separation						X
3	LRT Crossing Assessment Framework		X		X		X
4	Grade Separation Assessment Guidelines		X	X	X		
5	Calculation Of Hazard Indices for Highway-Railway Crossings In Canada	X					
6	Risk-Based Model for Identifying Highway–Rail Grade Crossing Blackspots						
7	A model for evaluating countermeasures at highway–railway grade crossings	X					
8	Estimating Effectiveness of Countermeasures Based on Multiple Sources - Application to Highway-Railway Grade Crossings	X					
9	Developing Safety Performance Functions for Railway Grade Crossings: A Case Study of Canada	X					

B-3 Significant criteria in models of Australia and New Zealand

Table 99: Reviewed models of Australia and New Zealand

	Model name	Developer	Year	Country	Model application	Model type	Analysis sample
1	Australian Level Crossing Assessment Model (ALCAM)	National ALCAM Committee	2003	Australia	National model	Hazard Index Model	-
2	Level Crossing Safety Impact Assessment (LCSIA)	KiwiRail	2016	New Zealand	National model	Hazard Index Model	-
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach	Jonathan Taylor and Russell Crawford	2009	Australia	National model	Prioritization model	177
4	Product Assessment model	-	1980´s	New Zealand	National model	Risk Assessment Methodology	-
5	Accident Prediction Model	-	2002	New Zealand	National model	Accident prediction model	-
6	Consolidation of Public Level Crossings	Rail Industry Safety & Standards Board (RISSB)	2018	Australia	National guidelines	Consolidation guide	-
7	Prioritising future level crossing removals: Site prioritisation framework	Level Crossing Removal Project	2013	Australia	Framework	Prioritization model	-
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)*	University of South Australia	2004	Australia	Research	Risk Assessment Methodology	-

*Based on ALCAM

Table 100: Significant traffic and operational factors in Australian and NZ models

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Train types	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	Number of pedestrians and/or cyclists	Number of cars in a train	Train length	Barriers down time (Waiting time)	Delay	Queuing	Out of distance travel / Accessibility
1	Australian Level Crossing Assessment Model (ALCAM)	X		X		X	X	X	X		X	X	X		X	X	X			X	
2	Level Crossing Safety Impact Assessment (LCSIA)	X		X		X	X	X	X		X	X	X		X	X	X			X	

	Model name	AADT	Road vehicles traffic growth	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Train types	Road type	Road level of service	Trucks percentage	Buses percentage	Public transport	Number of pedestrians and/or cyclists	Number of cars in a train	Train length	Barriers down time (Waiting time)	Delay	Queuing	Out of distance travel / Accessibility
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach	X	X		X					X				X				X	X		X
4	Product Assessment model	X		X																	
5	Accident Prediction Model	X		X																	
6	Consolidation of Public Level Crossings	X		X		X	X	X	X	X	X	X	X		X	X	X			X	X
7	Prioritising future level crossing removals: Site prioritisation framework	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)	X		X		X	X	X	X		X	X	X		X	X	X			X	

Table 101: Significant physical factors in Australian and NZ models

	Model name	number of tracks	number of lanes	Crossing width	Angle of intersection	Approach grade	Road curvature	Track alignment	nearby intersections	Nearby traffic signals	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Vehicle storage Area	Illumination
1	Australian Level Crossing Assessment Model (ALCAM)	X	X	X	X	X		X	X	X	X	X		X		X	X
2	Level Crossing Safety Impact Assessment (LCSIA)	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach				X	X											
4	Product Assessment model	X										X					

5	Accident Prediction Model																
6	Consolidation of Public Level Crossings	X	X	X	X	X		X	X	X	X	X	X	X		X	X
7	Prioritising future level crossing removals: Site prioritisation framework	X	X	X	X	X		X	X	X	X	X		X		X	X
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)	X	X	X	X	X		X	X	X	X	X		X		X	X

Table 102: Significant safety factors in Australian and NZ models

	Model name	Type of protection	Number of accidents	Near misses	Crossing pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	Coordination with adjacent traffic signal	Presence of highway monitoring devices (photo, video)	Proximity to siding/shunting yard	Proximity to the nearest station/stop
1	Australian Level Crossing Assessment Model (ALCAM)	X	X		X	X	X	X	X	X	X
2	Level Crossing Safety Impact Assessment (LCSIA)	X	X	X	X	X	X	X	X	X	X
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach		X	X							
4	Product Assessment model	X	X								
5	Accident Prediction Model	X									
6	Consolidation of Public Level Crossings	X	X	X	X	X	X	X	X	X	X
7	Prioritising future level crossing removals: Site prioritisation framework	X	X	X	X	X	X	X	X	X	X
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)	X	X		X	X	X	X	X	X	X

Table 103: Significant social factors in Australian and NZ models

	Model name	Proximity to emergency services[1]	Proximity to schools	Nearby Businesses[2]	Proximity to special social and event venues[3]	Sites of social significance[4]	vulnerable population and sensitive facilities[5]	Community cohesion / severance	Visual appearance
1	Australian Level Crossing Assessment Model (ALCAM)	X	X		X		X		
2	Level Crossing Safety Impact Assessment (LCSIA)	X	X		X		X		
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach					X		X	X
4	Product Assessment model								
5	Accident Prediction Model								
6	Consolidation of Public Level Crossings	X	X	X	X		X	X	
7	Prioritising future level crossing removals: Site prioritisation framework	X	X	X	X		X		
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)	X	X		X		X		

Table 104: Significant environmental, economic, and other factors in Australian and NZ models

	Model name	Noise	Vehicle emissions / Air quality	Energy consumption	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Local natural environment[2]	Type of Land use[3]	Seasonal / infrequent weather or train patterns[4]	Experts/Engineers assessment
1	Australian Level Crossing Assessment Model (ALCAM)	X											X	
2	Level Crossing Safety Impact Assessment (LCSIA)	X											X	X
3	Prioritising Road-Rail Level Crossings for Grade Separation Using a Multi-Criteria Approach	X	X	X	X	X	X		X	X	X			
4	Product Assessment model													
5	Accident Prediction Model													

6	Consolidation of Public Level Crossings	X			X	X	X	X	X			X	X	
7	Prioritising future level crossing removals: Site prioritisation framework	X								X			X	
8	The Risk Assessment of Accidents and Incidents at Level Crossings (RAAILc)	X											X	

B-4 Significant Criteria in European models

Table 105: European reviewed models

	Model name	Developer	Year	Country	Model application	Model type	Analysis sample
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	SELCAT consortium	2008	EU	Research	Risk Assessment Model	-
2	Automatic Level Crossing Model	Arthur D Little	1996	UK	National model (Abandoned)	Hazard Index Model	650
3	All Level Crossing Risk Model (ALCRM)	Rail Safety and Standards Board (RSSB)	2006	UK	National model	Hazard Index Model	-
4	Level Crossing Risk Management Toolkit (LXRMTK)	Rail Safety and Standards Board (RSSB)	2006	UK	National model	Accident prediction model	-
5	The Event Window Model	Halcrow Group Ltd	2006	UK	National model	Hazard Index Model	170
6	Level Crossing Prioritisation Tool	Arthur D Little	mid 1990´s	Ireland	National model	Prioritization model	1800
7	Network Wide Risk Model	Sotera Risk Solutions	2003	Ireland	National model	Prioritization model	-
8	Risk Assessment & Investment Appraisal	Mott MacDonald	1999	Northern Ireland	National model	Hazard Index Model	170
9	Crossing categorising criteria	Spanish regulations	-	Spain	National regulations	Level crossings classification methodology	-
10	FMEA method	UPC Technical University of Catalonia	-	Spain	Research	Risk Assessment Methodology	-
11	Legislative Framework of LC in Bulgaria	Bulgarian regulations	-	Bulgaria	National regulations	Level crossings protection regulations	-

	Model name	Developer	Year	Country	Model application	Model type	Analysis sample
12	Factors to determine crossing protection	Level Crossing Delegation Working Group	1986	Sweden	National model	Level crossings protection regulations	-
13	Legislative Framework of LC in Hungary	KÖVIM-regulation	1987	Hungary	National model	Level crossings protection regulations	-
14	Safety ranking of railway crossings in Hungary	Attila Borsos, Miklos Gabor and Csaba Koren	2016	Hungary	Research	Accident prediction model	1700
15	Development of a risk model for railroad crossings for ÖBB Infrastruktur AG	Christian Stefan, Rainer Stütz and Klaus Machata	2012	Austria	National model	Hazard prediction model	-
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system	Goran Ćirović and Dragan Pamučar	2013	Serbia	Research	Prioritization model	88
17	FUCOM-MAIRCA model	Dragan Pamučar, Vesko Lukovac, Darko Božanić and Nenad Komazec	2018	Serbia	Research	Prioritization model	10
18	Models For Ranking Railway Crossings for Safety Improvement	Sandra Kasalica, Marko Obradović, Aleksandar Blagojević, Dušan Jeremić and Milivoje Vuković	2020	Serbia	Research	Accident frequency and severity models	745
19	Model of Heterogeneous Queuing System	Pamela Ercegovac, Gordan Stojić, Miloš Kopić, Željko Stević, Feta Sinani and Ilija Tanackov	2021	Serbia	Research	Hazard prediction model	2
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways	Gintautas Bureika, Eduardas Gaidamauskas, Jonas Kupinas, Marijonas Bogdevičius and Stasys Steišūnas	2016	Lithuania	Research	Risk Assessment Model	15
21	Modelling the ranking of lithuanian railways level crossing by safety level	Gintautas Bureika, Marek Komaiško and Virgilijus Jastremskas	2017	Lithuania	Research	Hazard prediction model	337
22	Developing accident prediction model for railway level crossings	Ci Liang, Mohamed Ghazel, Olivier Cazier, El Miloudi El Koursi	2018	France	Research	Accident prediction model	8332
23	Advanced model-based risk reasoning on automatic railway level crossings	Ci Liang, Mohamed Ghazel, Olivier Cazier, Laurent Bouillaut	2020	France	Research	Risk analysis model	-
24	Enhancing the insight into Czech railway level crossings' safety performance	J. Ambros, J. Perůtka, P. Skládaný & P. Tučka	2020	Czech Republic	Research	safety factors analysis	206

Table 106: Significant traffic and operational factors in European models

	Model name	AADT	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Trucks percentage	Low Ground Clearance Vehicles	Buses percentage	Number of pedestrians and/or cyclists	Number of rail passengers per day	Train length	Barriers down time (Waiting time)	Activation time	Delay	Out of distance travel / Accessibility
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	X	X		X	X	X	X		X		X	X		X		X		X		X	X
2	Automatic Level Crossing Model	X	X		X	X				X			X		X	X		X		X		
3	All Level Crossing Risk Model (ALCRM)	X	X		X	X				X			X	X	X	X		X	X	X	X	
4	Level Crossing Risk Management Toolkit (LXRMTK)	X	X		X	X	X			X	X		X			X			X	X		X
5	The Event Window Model	X	X		X					X						X						
6	Level Crossing Prioritisation Tool	X	X		X	X										X						
7	Network Wide Risk Model	X	X		X					X												
8	Risk Assessment & Investment Appraisal	X	X		X											X						
9	Crossing categorising criteria	X	X		X																	
10	FMEA method	X	X		X	X										X						
11	Legislative Framework of LC in Bulgaria	X	X												X							
12	Factors to determine crossing protection	X	X		X			X	X			X				X						
13	Legislative Framework of LC in Hungary	X			X							X			X							
14	Safety ranking of railway crossings in Hungary	X	X		X	X	X															

	Model name	AADT	Average daily train volume	Train traffic growth	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Type of crossing (Public/private)	Track type (Mainline or non-mainline)	Train types	Time (day trains VS night trains)	Road type	Trucks percentage	Low Ground Clearance Vehicles	Buses percentage	Number of pedestrians and/or cyclists	Number of rail passengers per day	Train length	Barriers down time (Waiting time)	Activation time	Delay	Out of distance travel / Accessibility
15	Development of a risk model for railroad crossings for ÖBB Infrastruktur AG	X	X		X	X	X															
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system	X	X		X																	
17	FUCOM-MAIRCA model	X		X	X																	
18	Models For Ranking Railway Crossings for Safety Improvement	X	X		X		X		X			X										
19	Model of Heterogeneous Queuing System	X	X		X	X												X				
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways	X	X		X				X													
21	Modelling the ranking of Lithuanian railways level crossing by safety level	X	X		X				X													
22	Developing accident prediction model for railway level crossings	X	X		X																	
23	Advanced model-based risk reasoning on automatic railway level crossings	X	X		X																	
24	Enhancing the insight into Czech railway level crossings' safety performance	X	X			X																

Table 107: Significant physical factors in European models

	Model name	Number of tracks	Number of lanes	Road width	Crossing width	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Illumination
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	X					X	X		X		X	X	X	X	X		
2	Automatic Level Crossing Model	X			X		X	X					X	X				
3	All Level Crossing Risk Model (ALCRM)	X			X		X	X				X	X	X				
4	Level Crossing Risk Management Toolkit (LXRMTK)	X		X	X	X	X	X	X	X	X	X	X	X			X	X
5	The Event Window Model	X			X							X						
6	Level Crossing Prioritisation Tool	X		X			X					X	X	X		X		
7	Network Wide Risk Model	X																
8	Risk Assessment & Investment Appraisal	X										X						
9	Crossing categorising criteria											X						
10	FMEA method	X	X				X	X	X	X		X						
11	Legislative Framework of LC in Bulgaria																	
12	Factors to determine crossing protection	X		X								X						
13	Legislative Framework of LC in Hungary																X	
14	Safety ranking of railway crossings in Hungary	X		X		X			X			X	X					
15	Development of a risk model for railroad crossings for ÖBB Infrastruktur AG	X		X		X		X	X	X								X
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system	X			X	X						X						
17	FUCOM-MAIRCA model	X				X						X						
18	Models For Ranking Railway Crossings for Safety Improvement	X			X	X						X		X				
19	Model of Heterogeneous Queuing System	X		X														
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways				X							X						

	Model name	Number of tracks	Number of lanes	Road width	Crossing width	Angle of intersection	Approach grade	Road curvature	Track alignment	Nearby intersections	Proximity to the closest LC	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Pavement condition	Cycle/Pedestrians designated road	Illumination
21	Modelling the ranking of lithuanian railways level crossing by safety level				X							X						
22	Developing accident prediction model for railway level crossings				X		X	X										
23	Advanced model-based risk reasoning on automatic railway level crossings			X			X	X										
24	Enhancing the insight into Czech railway level crossings' safety performance									X		X	X					

Table 108: Significant safety factors in European models

	Model name	Type of protection	Number of accidents	Crossing pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	LC obstacle detection system	Presence of highway monitoring devices (photo, video)	Proximity to siding/shunting yard	Proximity to the nearest station/stop
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	X	X			X	X			
2	Automatic Level Crossing Model	X	X							X
3	All Level Crossing Risk Model (ALCRM)	X	X						X	X
4	Level Crossing Risk Management Toolkit (LXRMTK)	X		X	X			X	X	
5	The Event Window Model	X			X					
6	Level Crossing Prioritisation Tool	X				X				

	Model name	Type of protection	Number of accidents	Crossing pavement markings	Existence of traffic safety devices	Rail/Road users carrying hazardous material	LC obstacle detection system	Presence of highway monitoring devices (photo, video)	Proximity to siding/shunting yard	Proximity to the nearest station/stop
7	Network Wide Risk Model	X								
8	Risk Assessment & Investment Appraisal	X								
9	Crossing categorising criteria	X							X	
10	FMEA method	X							X	X
11	Legislative Framework of LC in Bulgaria									
12	Factors to determine crossing protection									
13	Legislative Framework of LC in Hungary									
14	Safety ranking of railway crossings in Hungary	X	X							
15	Development of a risk model for railroad crossings for ÖBB Infrastruktur AG	X	X							
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system		X							
17	FUCOM-MAIRCA model		X							
18	Models For Ranking Railway Crossings for Safety Improvement	X								
19	Model of Heterogeneous Queuing System									
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways									
21	Modelling the ranking of lithuanian railways level crossing by safety level									
22	Developing accident prediction model for railway level crossings		X							
23	Advanced model-based risk reasoning on automatic railway level crossings									
24	Enhancing the insight into Czech railway level crossings' safety performance									

Table 109: Significant social factors in European models

	Model name	Population density	Proximity to emergency services[1]	Proximity to schools	Proximity to special social and event venues[3]	vulnerable population and sensitive facilities[5]
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	X				
2	Automatic Level Crossing Model					X
3	All Level Crossing Risk Model (ALCRM)				X	X
4	Level Crossing Risk Management Toolkit (LXRMTK)		X		X	X
5	The Event Window Model					
6	Level Crossing Prioritisation Tool			X		X
7	Network Wide Risk Model					
8	Risk Assessment & Investment Appraisal					
9	Crossing categorising criteria					
10	FMEA method					X
11	Legislative Framework of LC in Bulgaria					
12	Factors to determine crossing protection					
13	Legislative Framework of LC in Hungary					
14	Safety ranking of railway crossings in Hungary					
15	Development of a risk model for railroad crossings for ÖBB Infrastruktur AG					
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system					
17	FUCOM-MAIRCA model					
18	Models For Ranking Railway Crossings for Safety Improvement					
19	Model of Heterogeneous Queuing System					
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways					
21	Modelling the ranking of lithuanian railways level crossing by safety level					
22	Developing accident prediction model for railway level crossings					
23	Advanced model-based risk reasoning on automatic railway level crossings					
24	Enhancing the insight into Czech railway level crossings’ safety performance					

Table 110: Significant environmental, economic, and other factors in European models

	Model name	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Type of Land use[3]	Seasonal / infrequent weather or train patterns[4]
1	Safer European Level Crossing Appraisal and Technology (SELCAT)	X	X	X	X	X	X	X			X
2	Automatic Level Crossing Model										
3	All Level Crossing Risk Model (ALCRM)	X		X		X			X		
4	Level Crossing Risk Management Toolkit (LXRMTK)	X							X	X	X
5	The Event Window Model										
6	Level Crossing Prioritisation Tool										X
7	Network Wide Risk Model			X							
8	Risk Assessment & Investment Appraisal										
9	Crossing categorising criteria										
10	FMEA method										
11	Legislative Framework of LC in Bulgaria										
12	Factors to determine crossing protection										
13	Legislative Framework of LC in Hungary									X	
14	Safety ranking of railway crossings in Hungary										
15	Development of a risk model for railroad crossings for ÖBB Infrastructure AG									X	
16	Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system										
17	FUCOM-MAIRCA model										
18	Models For Ranking Railway Crossings for Safety Improvement										
19	Model of Heterogeneous Queuing System										
20	Modelling The Assessment of Traffic Risk at Level Crossings of Lithuanian Railways										
21	Modelling the ranking of Lithuanian railways level crossing by safety level										
22	Developing accident prediction model for railway level crossings										
23	Advanced model-based risk reasoning on automatic railway level crossings										

	Model name	Noise	Vehicle emissions / Air quality	Financial Feasibility or Project Cost	Safety benefits (costs of accidents)	Delay savings (Travel time, Network benefits)	Environmental benefits	Operating Cost Savings[1]	Surrounding Land Development opportunities	Type of Land use[3]	Seasonal / infrequent weather or train patterns[4]
24	Enhancing the insight into Czech railway level crossings' safety performance										

B-5 Significant Criteria in international models

Table 111: Reviewed models in other countries

	Model name	Developer	Year	Country	Model application	Model type	Analysis sample
1	The safety level Index	V. B. G. Campos, R.C. do Carmo and A.M. Freitas	2007	Brazil	Research	Prioritization model	-
2	Train Vehicle Unit (TVU)	Indian Railways	-	India	National model	Prioritization model	-
3	Level crossing assessment and prioritization criteria in Iran	The Iranian Islamic Republic Railways	-	Iran	National model	Prioritization model	-
4	Closed Road Traffic Indicator (CRT)	Japan Rail	-	Japan	National model (Abandoned)	Prioritization model	-
5	Level Crossing Danger Index	Japan Rail West	-	Japan	National model	Hazard Index Model	-
6	Rail and Road Intensity Matrix	The Russian Federation Railways	-	Russia	National model (not obligatory)	Prioritization matrix	-
7	The gamma model	Jutaek Oh, Simon P. Washington and Doohee Nam	2005	South Korea	Research	Accident prediction model	162
8	Logit Model	Shou-Ren Hu, Chin-Shang Li and Chi-Kang Lee	2010	Taiwan	Research	Factors significance on accidents severity	592
9	Level crossing upgrading priorities criteria in Vietnam	The Vietnamese Ministry of Transport	-	Vietnam	National model	Prioritization criteria	-

	Model name	Developer	Year	Country	Model application	Model type	Analysis sample
10	The Safety Assessment System	Hongde Wang and Tiejun Cui	2011	China	Research	Risk assessment model	-

Table 112: Significant traffic and operational factors in International models

	Model name	AADT	Average daily train volume	Train Speed	Vehicles speed	Area Classification (Urban/Rural)	Track type (Mainline or non-mainline)	Time (day trains VS night trains)	Road type	Trucks percentage	Public transport	Number of pedestrians and/or cyclists	Number of rail passengers per day	Barriers down time (Waiting time)	Activation time
1	The safety level Index	X	X	X	X	X*		X	X*	X		X			
2	Train Vehicle Unit (TVU)	X	X	X											
3	Level crossing assessment and prioritization criteria in Iran	X	X			X									
4	Closed Road Traffic Indicator (CRT)	X	X											X	
5	Level Crossing Danger Index	X	X										X		
6	Rail and Road Intensity Matrix	X	X				X								
7	The gamma model	X	X												X
8	Logit Model		X							X					
9	Level crossing upgrading priorities criteria in Vietnam	X	X			X			X		X				
10	The Safety Assessment System	X							X						

* Factor is considered only if accidents data are not available

Table 113: Significant physical factors in International models

	Model name	Number of tracks	Number of lanes	Road width	Crossing width	Angle of intersection	Approach grade	Nearby intersections	Nearby traffic signals	Sight distance	Sight obstructions	Crossing Surface	Road pavement	Illumination
1	The safety level Index	X	X				X			X		X		X
2	Train Vehicle Unit (TVU)									X				

3	Level crossing assessment and prioritization criteria in Iran			X										
4	Closed Road Traffic Indicator (CRT)													
5	Level Crossing Danger Index	X		X	X									
6	Rail and Road Intensity Matrix													
7	The gamma model													
8	Logit Model													
9	Level crossing upgrading priorities criteria in Vietnam									X				
10	The Safety Assessment System	X			X	X	X				X			X

Table 114: Significant safety factors in International models

	Model name	Type of protection	Number of accidents	Crossing pavement markings	Existence of traffic safety devices	LC obstacle detection system	Presence of highway monitoring devices (photo, video)	Proximity to train detector
1	The safety level Index		X					
2	Train Vehicle Unit (TVU)							
3	Level crossing assessment and prioritization criteria in Iran		X					
4	Closed Road Traffic Indicator (CRT)							
5	Level Crossing Danger Index		X					
6	Rail and Road Intensity Matrix							
7	The gamma model				X			X
8	Logit Model			X		X		
9	Level crossing upgrading priorities criteria in Vietnam							
10	The Safety Assessment System	X			X	X	X	

Table 115: Significant social factors in International models

	Model name	Proximity to schools	Nearby Businesses[2]

1	The safety level Index		
2	Train Vehicle Unit (TVU)		
3	Level crossing assessment and prioritization criteria in Iran		
4	Closed Road Traffic Indicator (CRT)		
5	Level Crossing Danger Index		
6	Rail and Road Intensity Matrix		
7	The gamma model		X
8	Logit Model		
9	Level crossing upgrading priorities criteria in Vietnam		
10	The Safety Assessment System		

Table 116: Significant environmental, economic, and other factors in International models

	Model name	Financial Feasibility or Project Cost	Delay savings (Travel time, Network benefits)	Operating Cost Savings	Type of Land use[3]
1	The safety level Index				
2	Train Vehicle Unit (TVU)				
3	Level crossing assessment and prioritization criteria in Iran	X	X	X	
4	Closed Road Traffic Indicator (CRT)				
5	Level Crossing Danger Index				
6	Rail and Road Intensity Matrix				
7	The gamma model				
8	Logit Model				
9	Level crossing upgrading priorities criteria in Vietnam				
10	The Safety Assessment System	X			

Appendix C

Survey manual

The following is the survey manual that was distributed along with the survey link for all experts participating in the evaluation of criteria. The purpose of the manual was to describe some of the criteria in the model to avoid any confusions, provide aiding statistics for experts to assist them throughout the evaluation process and explain the evaluation technique and scale for AHP to ensure a correct implementation of the methodology. The survey and survey manual were created in German language to maintain a high level of accuracy for answers and avoid any unclarities or confusions resulting from translations.

Sehr geehrter Teilnehmer, sehr geehrte Teilnehmerin,

die Verbesserung der Sicherheit an Bahnübergängen ist eine kritische Aufgabe für alle beteiligten Behörden, da Bahnübergänge als einer der Hauptrisikopunkte im Verkehrsnetz gelten. Zwischen 2011 und 2020 kam es an deutschen Bahnübergängen zu 1602 Unfällen, bei denen 344 Menschen ums Leben kamen. Der effizienteste Weg, diese Unfälle zu vermeiden, ist die Begrenzung der Anzahl der Kreuzungspunkte zwischen Straßen- und Schienenverkehr. Die Beseitigung von Bahnübergängen ist jedoch ein sehr kostspieliger Prozess, weshalb jedes Jahr nur eine begrenzte Anzahl von Bahnübergängen beseitigt wird. Die Zahl der bestehenden Bahnübergänge in Deutschland sank von 19.173 im Jahr 2011 auf 16.098 im Jahr 2020, wobei durchschnittlich 308 Bahnübergänge pro Jahr beseitigt wurden. Aufgrund der hohen Kosten von Projekten zur Beseitigung von Bahnübergängen und zur Verbesserung der Sicherheit ist es notwendig, ein Tool zu besitzen, das die Entscheidungsträger dabei unterstützt, die begrenzten Ressourcen bestmöglich einzusetzen.

Dieser Fragebogen ist Teil eines Masterarbeitsprojekts, das eine Methodik zur Bewertung, Evaluierung und Priorisierung von Bahnübergängen in Deutschland auf der Grundlage von Multikriterien entwickeln soll, um Behörden und Entscheidungsträger bei der effizienten Zuweisung von Ressourcen zu unterstützen.

Bei der Auswahl der zu fördernden Projekte hängen Entscheidungen der Planer und Ingenieure in der Regel von vielen Faktoren ab, welche sich auf die aktuelle Verkehrssituation, die Sicherheitssituation, physikalische sowie auf soziale, ökologische und wirtschaftliche Faktoren beziehen können. Das Hauptziel dieses Fragebogens ist es, die Bedeutung eines jeden Kriteriums aus der Perspektive der Experten und Entscheidungsträger zu bestimmen, um ein multikriterielles Bewertungsverfahren zu schaffen, dass die Bahnübergänge basierend auf ihrer Priorität für die Beseitigung oder Sicherheitsverbesserung bewertet und einstuft. Ein solches Verfahren kann nicht nur bei der effizienten Zuweisung von Ressourcen nützlich sein, sondern auch bei der Identifizierung der Bahnübergänge mit dem höchsten Risiko und der Vermeidung möglicher Unfälle durch die Anwendung kurzfristiger Sofortmaßnahmen.

Das Modell wird auf der Grundlage des Analytic Hierarchy Process (AHP) entwickelt. AHP gilt als eine sehr effiziente Methode, die bei der Priorisierung sehr komplexer Entscheidungen, an denen mehrere Entscheidungsträger beteiligt sind, hilft. Die AHP-Methode basiert auf paarweisen Vergleichen.

In diesem Fragebogen möchten wir Ihre Meinung als Experten auf dem Gebiet der Bahnübergänge einholen, wobei Sie gebeten werden, die einzelnen Faktoren miteinander zu vergleichen, und zwar im Hinblick auf den Einfluss eines Faktors bezüglich der Erhöhung des Unfallrisikos und/oder des negativen Beitrags zur Umwelt, zur Wirtschaft und zur Lebensqualität der betroffenen Bevölkerung.

Wie in Tabelle 1 dargestellt, werden die Hauptkriterien des Modells in der ersten Hierarchieebene angegeben. Die zweite und dritte Ebene stellen die Unterkriterien dar, anhand derer die Bahnübergänge bewertet werden sollen, und schließlich stellt die vierte Ebene die verschiedenen Alternativen (Optionen) vor, die sich auf die untersuchten Kriterien beziehen. In den Abschnitten B und C finden Sie eine Übersicht der im Modell berücksichtigten Kriterien und eine kurze Erläuterung ausgewählter Faktoren sowie Statistiken und Grafiken, die den Bewertungsprozess unterstützen könnten. Die Bewertungstechnik wird in Abschnitt D erläutert.

Die Informationen, die Sie zur Verfügung stellen, werden für diese Forschung von großem Wert sein, und daher bitten wir Sie um Ihre Mitwirkung.

Wir hoffen sehr, dass Sie uns mit Ihrer Expertise und Wissen helfen können.

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Einverständniserklärung

Sehr geehrter Teilnehmer, sehr geehrte Teilnehmerin,

Sie werden gebeten, an einer Forschungsstudie zur Priorisierung von Faktoren zur Beseitigung und Bewertung von Bahnübergängen in Deutschland teilzunehmen. Masterstudent Omar Abu Saad führt diese Forschung unter der Leitung von Prof. Elena Queck und Dr. Eric Schöne durch.

Bitte lesen Sie die Informationen in den Abschnitten A und B sorgfältig durch. Bei Unklarheiten oder Fragen zum Fragebogen wenden Sie sich bitte per E-Mail an den Forscher, Herrn Omar Abu Saad, um Erläuterungen und Antworten zu erhalten: Omar.Abu.Saad.k40@fh-zwickau.de.

Durch das Ausfüllen des beigefügten Fragebogens erklären Sie sich mit der Teilnahme an dieser Studie einverstanden.

Abschnitt A – Informationen für Teilnehmer

Teilnehmer
Verkehrsprofessoren, Bahnübergangsexperten, Sicherheitsexperten und Verkehrsingenieure werden als Hauptteilnehmer dieser Studie identifiziert. Zu den Experten gehören diejenigen, die über umfassende Kenntnisse in den Bereichen Bahnübergangssicherheit, Bahnübergangsbeseitigung und Bahnübergangsplanung verfügen. Es wird erwartet, dass das Expertengremium Universitätsakademiker, professionelle Ingenieure, Planer usw. umfasst.

Ablehnungsrecht der Teilnehmer
Ihre Teilnahme ist freiwillig und Sie können sich von der Umfrage zurückziehen, nachdem Sie der Teilnahme zugestimmt haben. Aus Gründen der Konsistenz und Vollständigkeit des Modells lassen Sie bitte keine paarweisen Vergleiche unbeantwortet. Es steht Ihnen frei, die Beantwortung aller anderen im Fragebogen gestellten Fragen zu verweigern.

Zeitauswand der Umfrage
Das Ausfüllen der Umfrage dauert ungefähr 45 Minuten.

Hinweise zum Kriterien Vergleich

- Bitte verwenden Sie dieses Umfragehandbuch als Nachschlagewerk und zum besseren Verständnis des Analytic Hierarchy Process (AHP), der die Grundlage für die Bewertung bildet.
- Bitte berücksichtigen Sie die Gesamtheit der Kriterien in den unteren Ebenen, während Sie zwischen den Kriterien in den oberen Ebenen bewerten. Die Hierarchie der Kriterien finden Sie in Abschnitt B.
- Bitte bemühen Sie sich um Konsistenz bei den Antworten und Bedeutungen. Wenn zum Beispiel Kriterium A wichtiger als Kriterium B und Kriterium B wichtiger als Kriterium C bestimmt werden, dann würde eine Entscheidung, dass Kriterium C wichtiger als Kriterium A, als inkonsistent angesehen.

Vertraulichkeit
Die Angaben der Teilnehmer werden nicht weitergegeben. Die angeforderten persönlichen Daten des Teilnehmers dienen nur zur Information des Forschers und der Betreuer und werden nicht an Dritte weitergegeben. Der Teilnehmer hat das Recht, keine persönlichen Daten anzugeben. Die Antworten der Experten werden nur für Forschungszwecke und für das Verfassen der Abschlussarbeit verwendet.

Verwendung von Informationen
Die erhaltenen Informationen und Erkenntnisse werden zur Erfüllung der Anforderungen für den Abschluss der Masterarbeit verwendet. Darüber hinaus können sie in Seminaren, Konferenzen und Forschungspublikationen eingesetzt werden.

Verfügbarkeit der Ergebnisse
Eine Zusammenfassung der Ergebnisse wird voraussichtlich bis September 2022 vorliegen. Teilnehmer, die ein Exemplar wünschen, wenden sich bitte an Herr Omar Abu Saad per E-Mail: Omar.Abu.Saad.k40@fh-zwickau.de

Abschnitt B – Kriterien Übersicht

Tabelle 117: Hierarchie der Modellkriterien

<table>
<tr><th>Hauptkriterien (Stufe 1)</th><th>Unterkriterien (Stufe 2)</th><th>Unter-Teil-Kriterien (Stufe 3)</th><th>Alternativen (Stufe 4)</th></tr>
<tr><td rowspan="39">Verkehrliche und betriebliche Faktoren</td><td rowspan="9">funktionelle Klassifizierung</td><td rowspan="2">Lage des BÜ</td><td>ländliche Gebieten</td></tr>
<tr><td>städtische Gebieten</td></tr>
<tr><td rowspan="5">Straßenklasse</td><td>Bundesstraßen</td></tr>
<tr><td>Landes- (Staats-) straßen</td></tr>
<tr><td>Kreisstraßen</td></tr>
<tr><td>Stadt- und Gemeindestraßen</td></tr>
<tr><td>sonstige Straßen</td></tr>
<tr><td rowspan="2">Lage auf Haupt- oder Nebenbahnen</td><td>Hauptbahn</td></tr>
<tr><td>Nebenbahn</td></tr>
<tr><td rowspan="7">Verkehrsstärke</td><td rowspan="3">Straßenverkehrsstärke</td><td>Schwacher Verkehr: ≤100 Kfz/Tag</td></tr>
<tr><td>Mäßiger Verkehr: 101-2500 Kfz/Tag</td></tr>
<tr><td>Starker Verkehr: >2500 Kfz/Tag</td></tr>
<tr><td rowspan="4">Schienenverkehrsstärke</td><td>≤20 Züge/Tag</td></tr>
<tr><td>21-40 Züge/Tag</td></tr>
<tr><td>41-60 Züge/Tag</td></tr>
<tr><td>>60 Züge/Tag</td></tr>
<tr><td rowspan="8">Straßenverkehrsteilnehmer</td><td rowspan="3">Rad- und Fußgängerverkehr</td><td><5%</td></tr>
<tr><td>5-20%</td></tr>
<tr><td>>20%</td></tr>
<tr><td rowspan="3">LKW-Anteil</td><td><5%</td></tr>
<tr><td>5-20%</td></tr>
<tr><td>>20%</td></tr>
<tr><td rowspan="2">Busse und Schulbusse</td><td>Ja</td></tr>
<tr><td>Nein</td></tr>
<tr><td rowspan="13">Geschwindigkeit</td><td rowspan="8">Streckengeschwindigkeit</td><td>≤20 km/h</td></tr>
<tr><td>21-40 km/h</td></tr>
<tr><td>41-60 km/h</td></tr>
<tr><td>61-80 km/h</td></tr>
<tr><td>81-100 km/h</td></tr>
<tr><td>101-120 km/h</td></tr>
<tr><td>121-140 km/h</td></tr>
<tr><td>141-160 km/h</td></tr>
<tr><td rowspan="5">Höchstgeschwindigkeit auf der Straße</td><td>≤10 km/h</td></tr>
<tr><td>11-30 km/h</td></tr>
<tr><td>31-50 km/h</td></tr>
<tr><td>51-70 km/h</td></tr>
<tr><td>>70 km/h</td></tr>
</table>

	Schienenfahrzeuge	Zuggattungen	Strecke mit Personenverkehr
			Strecke ohne Personenverkehr
		Schienenfahrzeuglänge	≤100m
			101-200m
			>200m
	Annäherungszeit	-	≤30s
			31-60s
			61-90s
			91-120s
			121-150s
			151-180s
			181-210s
			211-240s
Physikalische Faktoren	geometrische Faktoren	Kreuzungswinkel	0°- 30°
			31° - 60°
			61° - 90°
		Straßenlängsneigung	SLN < 3%
			3% ≤ SLN < 6%
			6% ≤ SLN < 9%
			9% ≤ SLN < 12%
			SLN ≥ 12%
		Gleisbogen-Radius	< 250m
			250 ≤ GBR < 500m
			500 ≤ GBR < 750m
			≥750m
		Straßenkurvigkeit	<0,25 gon/m
			0,25-0,5 gon/m
			0,5-0,75 gon/m
			0,75-1 gon/m
			>1 gon/m
		Fahrbahnbreite	<4,75m
			4,75-5,50m
			5,50-6,35m
			≥6,35m
		Anzahl der Gleise	1
			2
			3
			≥4
		Anzahl der Fahrstreifen	1
			2
			≥3
		Entfernung zum nächsten Knotenpunkt	in Räumstrecke (≤27m)
			27 < EKP ≤ 50m
			50 < EKP ≤ 100m
			100 < EKP ≤ 150m
			> 150m
	Sichtverhältnisse	Sichtweite der Straßenverkehrsteilnehmer	<200m
			200-400m
			>400m

		Sichtbehinderung	vorhanden
			nicht vorhanden
		Beleuchtung	nicht vorhanden
			unzureichend
			ausreichend
	BÜ- und Straßenoberfläche	BÜ-Belag	Gummi
			Beton
			Asphalt
			Mineralgemisch
		Straßenbefestigung	unbefestigt
			befestigt
		Zustand der BÜ und Straßenbeläge	guter Zustand
			schlechter Zustand
Sicherheitsfaktoren	Sicherungsart	-	nicht technische Sicherung
			Blinklichter oder Lichtzeichen
			Halbschranken
			Vollabschluss
	Unfallzahlen	Unfallanzahl	0
			1-2
			3-4
			>4
		Anzahl Todesfälle	0
			1-2
			3-4
			>4
		Anzahl Schwerverletzte	0
			1-2
			3-4
			>4
		Anzahl Leichtverletzte	0
			1-2
			3-4
			>4
	Fahrbahnmarkierung	-	vorhanden
			nicht vorhanden
	Schutzeinrichtungen	-	vorhanden
			nicht vorhanden
	Gefahrguttransporte	-	regelmäßige Gefahrguttranspo-rte
			Kein regelmäßige Gefahrguttranspo-rte
Gesellschaftlicher Faktoren	Notfalldienste in der Nähe des BÜ	-	vorhanden
			nicht vorhanden
	Schulen in der Nähe des BÜ	-	vorhanden
			nicht vorhanden
		-	

	gefährdete Bevölkerungsgruppen und sensible Einrichtungen		vorhanden
			nicht vorhanden
	besondere Gesellschafts- und Veranstaltungsorte	-	vorhanden
			nicht vorhanden
Umwelt- und Wirtschaftsfaktoren	Verkehrslärm	mit Pfeifsignal/Fußgängerakustik gesichert	Krankenhäuser, Schulen, Kur- und Altenheime
			reine und allgemeine Wohngebiete
			Kern-, Dorf- und Mischgebiete
			Gewerbegebiete
		ohne Pfeifsignal/Fußgängerakustik gesichert	Krankenhäuser, Schulen, Kur- und Altenheime
			reine und allgemeine Wohngebiete
			Kern-, Dorf- und Mischgebiete
			Gewerbegebiete
	Schadstoffausstoß	-	niedrige Emissionen
			mäßige Emissionen
			hohe Emissionen
	Betriebskosten	-	niedrige Kosten
			mäßiger Kosten
			hohe Kosten

Abschnitt C – Erläuterung und unterstützende Fakten zu ausgewählten Kriterien

Lage des BÜ

Die Lage eines Bahnübergangs innerhalb oder außerhalb einer Stadt ist ein wichtiger Faktor, der auch einen hohen Einfluss auf andere Faktoren hat. Die Verkehrsstärke, die Dichte von Schulen, Krankenhäusern und der Bevölkerung in der Nähe unterscheiden sich erheblich zwischen städtischen und ländlichen Gebieten. Andererseits kann die Beseitigung eines Bahnübergangs in einem ländlichen Gebiet die Reisezeit für Verkehrsteilnehmer erheblich verlängern, da weniger oder keine alternativen Routen vorhanden sind. Einige Länder verwenden unterschiedliche Modelle für städtische und ländliche Gebiete.

Straßenklasse

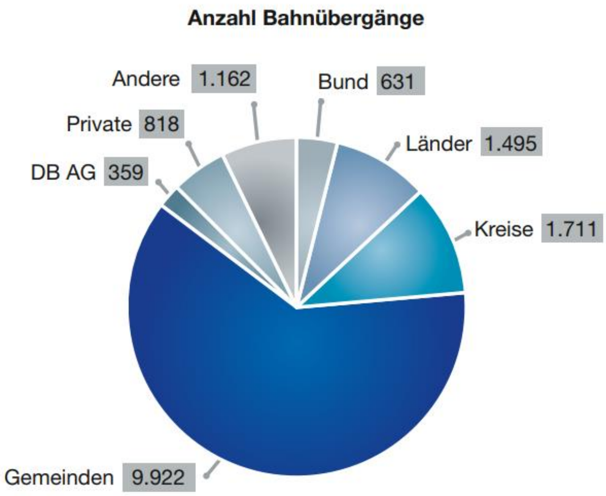

Figure 56: Anzahl Bahnübergänge nach Straßenklasse in 2020 (Quelle: DB Netz AG, 2021)

Tabelle 118: Unfallanzahl und Personenschäden nach Straßenklasse in 2020 (Quelle: DB Netz AG, 2021)

Baulastträger	Bund	Länder	Kreise	Gemeinden	DB AG	Private	Andere	Summe
Unfallanzahl	11	11	7	78	1	0	6	114
… mit Entgleisung	1	0	0	3	0	0	0	4

Baulastträger	Bund	Länder	Kreise	Gemeinden	DB AG	Private	Andere	Summe
Anzahl Getötete	3	1	2	18	0	0	1	25
Anzahl Schwerverletzte	3	2	0	22	0	0	0	27
Anzahl Leichtverletzte	12	11	4	81	2	0	4	114
Kennzahl für Personenschäden	3,4	1,3	2,0	21,0	0,0	0,0	1,0	28,8

Straßenverkehrsteilnehmer

Tabelle 119: Unfallanzahl und Personenschäden nach Straßenverkehrsteilnehmer in 2020 (Quelle: DB Netz AG, 2021)

Straßenverkehrsteilnehmer	PKW/Kombi	LKW/Lastzug/ Sattelzug	Omnibus/Obus/ Straßenbahn	Traktor/landw. Fahrzeug/Zug-maschine	motorisiertes Zweirad	Fahrrad (auch mit Hilfsmotor)	Fußgänger	übrige Straßenver-kehrsteilnehmer*	Summe
Unfallanzahl	59	11	2	8	3	22	11	0	116 *
...mit Entgleisung	0	4	0	0	0	0	0	0	4
Anzahl Getötete	11	0	0	0	1	6	7	0	25
Anzahl Schwerverletzte	14	1	0	4	3	4	1	0	27
Anzahl Leichtverletzte	58	21	1	6	2	19	7	0	114

Streckengeschwindigkeit

Tabelle 120: Unfallanzahl und Personenschäden nach Streckengeschwindigkeit in 2020 (Quelle: DB Netz AG, 2021)

Zulässige Geschwindigkeit [km/h]	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100	101 - 120	121 - 140	141 - 160
Unfallanzahl	3	6	36	19	18	18	5	9
… mit Entgleisung	0	1	1	0	1	1	0	0

Zulässige Geschwindigkeit [km/h]	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100	101 - 120	121 - 140	141 - 160	Summe
Anzahl Getötete	0	0	5	6	3	6	1	4	25
Anzahl Schwerverletzte	0	0	6	5	10	4	1	1	27
Anzahl Leichtverletzte	4	5	29	18	35	16	4	3	114
Kennzahl für Personenschäden	0,0	0,1	5,9	6,7	4,4	6,6	1,1	4,1	28,8

Zuggattungen

Die Konsequenzen eines Unfalls an einem Bahnübergang, an dem ein Personenzug beteiligt ist, sind nicht dieselben wie bei einem Güterzug. Da auf den meisten deutschen Bestandsstrecken sowohl Güter- als auch Personenzüge verkehren können, unterscheidet dieses Modell zwischen Strecken mit gemeinsamem Betrieb und Strecken ohne Personenverkehr.

Schienenfahrzeuglänge

Die Zuglänge trägt zur Wartezeit am Bahnübergang bei, da längere Züge mehr Zeit benötigen, um den Bereich des Bahnübergangs zu räumen, und somit die Wartezeit der Straßenfahrzeuge verlängert. Außerdem erhöht sich das Kollisionsrisiko entsprechend, wenn die Zeit der Bahnübergangsbelegung zunimmt.

Annäherungszeit

Die Wartezeit an einem Bahnübergang wirkt sich auf den Frustrationsgrad der Fahrer aus und kann die Zahl der Verstöße an einem Bahnübergang erhöhen. Je mehr Zeit die Fahrzeuge an einer Kreuzung im Leerlauf verbringen, desto mehr Kraftstoff wird verschwendet und desto mehr Emissionen werden ausgestoßen. Dieses Modell verwendet den Wert der Annäherungszeit des BÜ als Indikator für die Wartezeit der Fahrer.

Anzahl der Gleise und Fahrstreifen

Mehr Gleise und Fahrspuren bedeuten mehr Kollisionspunkte am BÜ, was ebenfalls ein höheres Risiko und eine höhere Exposition bedeutet. Ein Bahnübergang mit 2 Fahrspuren bietet die Möglichkeit, dass 2 Autos gleichzeitig im BÜ Kreuzungsstück existieren, womit sich das Risiko verdoppelt. Je höher die Anzahl der Gleise, die innerhalb des Bahnübergangs verlaufen, desto höher ist die Zeit, die Verkehrsteilnehmer benötigen, um die Gefahrenraum zu räumen.

Entfernung zum nächsten Knotenpunkt

Die Entfernung zum nächsten Knotenpunkt trägt zum Risiko von Warteschlangen am Bahnübergang bei. Je näher die Kreuzung am Bahnübergang liegt, desto kürzer kann die Länge einer Warteschlange sein und damit das Risiko einer unvollständigen Räumung des BÜ entstehen.

Sichtverhältnisse

Sichtweiten und Sichtbehinderungen können die Qualität des Urteilsvermögens des Fahrers und damit die Reaktion und Reaktionszeiten stark beeinflussen. Objekte, die in diesem Modell als Sichtbehinderungen betrachtet werden, umfassen Bäume und Pflanzen, Werbetafeln, Bebauung, Schienenausrüstungen und Verkehrsschutzeinrichtungen, usw. Als Sichtbehinderungen gelten auch vorübergehende Sichtbehinderungen wie z. B. tiefstehende Sonne.

BÜ und Straßenoberfläche

Die Art des BÜ-Belags ist bei der Untersuchung von Bahnübergängen von Bedeutung, da sie zu der Zeit beiträgt, die das Fahrzeug benötigt, um die Kreuzung zu räumen. Auch steigt die Gefahr, dass ein Fahrzeug auf den Schienen stecken bleibt, wenn ein BÜ nicht befestigt ist.

Nicht nur die Art des BÜ und Straßenbelags, sondern auch der Zustand kann ein großer Risikofaktor sein. Schlechte Beläge behindern die Bewegung der Verkehrsteilnehmer und verlangsamen sie, was zu einer längeren benötigten Räumzeit führt. Darüber hinaus können schwerwiegende Mängel des BÜ-Belags dazu führen, dass die Fahrzeugführer in der Mitte der BÜ anhalten oder ihre Geschwindigkeit erheblich reduzieren, was zu Auffahrunfällen führen kann. Beispiele für Mängel, die zu einer schlechten Zustandsklassifizierung führen, sind Spurrinnen, Ausbrüche, Netz- und Einzelrisse, und Flickstellen.

Sicherungsart

Tabelle 121: Unfallanzahl und Personenschäden nach Sicherungsart in 2020 (Quelle: DB Netz AG, 2021)

	Sicherungsart	Unfallanzahl	… mit Entgleisung
technische Sicherung	Blinklichter	7	0
	Lichtzeichen	3	0
	Blinklichter oder Lichtzeichen mit Halbschranken	54	2
	Blinklichter oder Lichtzeichen mit Schranken	4	0
	wärterbediente Schranken	2	0
	Anrufschranken	2	0
nicht techn. Sicherung	Übersicht	6	1
	Übersicht und Pfeifen	29	1
	Übersicht, Pfeifen und Langsamfahren	7	0
	Postensicherung	0	0
	Abschlüsse mit Sprechanlage	0	0
	Abschlüsse ohne Sprechanlage	0	0
	Summe	114	4

	Sicherungsart	Todesfälle	Schwerverletzte	Leichtverletzte	Kennzahl für Personenschäden
technische Sicherung	Blinklichter	1	3	5	1,4
	Lichtzeichen	0	1	3	0,1
	Blinklichter oder Lichtzeichen mit Halbschranken	13	14	64	15,0
	Blinklichter oder Lichtzeichen mit Schranken	2	1	2	2,1
	wärterbediente Schranken	1	0	1	1,0
	Anrufschranken	0	0	0	0,0
nicht techn. Sicherung	Übersicht		1	7	0,2
	Übersicht und Pfeifen	8	7	27	9,0
	Übersicht, Pfeifen und Langsamfahren	0	0	5	0,1
	Postensicherung	0	0	0	0,0
	Abschlüsse mit Sprechanlage	0	0	0	0,0
	Abschlüsse ohne Sprechanlage	0	0	0	0,0
	Summe	25	27	114	28,8

Unfallzahlen

Dieses Modell berücksichtigt die Unfallhistorie für die Bahnübergänge in den letzten 5 Jahren. Wenn jedoch die Sicherungsart an Bahnübergängen in den letzten 5 Jahren geändert wurde, werden nur die Jahre nach der Änderung berücksichtigt.

Schutzeinrichtungen

Das Modell berücksichtigt das Vorhandensein einer oder mehrerer der folgenden Schutzeinrichtungen: Geländer, Umlaufsperren, Gitterbehang, Fußgängerakustik, Zäune, Schutzplanken und erhöhte Mittelstreifen. Auch das Vorhandensein einer Bodenschwelle innerhalb des Räumstrecke wird als Teil dieses Kriteriums betrachtet.

Gefahrguttransporte

Dieses Modell räumt Bahnübergängen, die sich in der Nähe oder an der Strecke von regelmäßige Gefahrgut-LKW oder Güterzügen mit Gefahrgut befinden, eine besondere Priorität ein. Ein Beispiel wäre, dass sich der BÜ in der Nähe eines Tanklagers oder einer Fabrik befindet, wo regelmäßig mehrere Gefahrgut-Lkw den Bahnübergang befahren.

Notfalldienste in der Nähe des BÜ

Zu den Notfalldiensten gehören Krankenhäuser, Feuerwehren und Polizeidienststellen im Umkreis von 500m um den Bahnübergang. Dieser Faktor berücksichtigt mögliche Verzögerungen, die der bestehende Bahnübergang auf die Reaktionszeit der Rettungsfahrzeuge und der auferlegten Zeit, die Einzelpersonen benötigen, um die medizinischen Dienste zu erreichen. Außerdem besteht an Bahnübergängen in der Nähe von Rettungsdiensten ein höheres Kollisionsrisiko, da ein höherer Prozentsatz von Verkehrsteilnehmern bereit ist, Sicherheitsvorschriften zu missachten oder unter Stress zu fahren, um ihr Ziel so schnell wie möglich zu erreichen.

Schulen in der Nähe des BÜ

Dieser Faktor umfasst Schulen und Kindergärten in einem Umkreis von 500m um den Bahnübergang. Es kompensiert den höheren Anteil an gefährdeten Bahnübergangsnutzern im jungen Alter. Weiterhin werden Bahnübergänge in der Nähe von Schulen zu bestimmten Tageszeiten häufig öfter durch öffentliche Busse voller Schüler und Schulbusse befahren, was die Konsequenzen möglicher Kollisionen erhöht.

Gefährdete Bevölkerungsgruppen und sensible Einrichtungen

Zu diese Kriterien gehören Alten- und Behindertenheimen und Gefängnisse in einem Umkreis von 500 m um den Bahnübergang.

Besondere Gesellschafts- und Veranstaltungsorte

Zu den besonderen Gesellschafts- und Veranstaltungsorten gehören Kneipen, Clubs, Stadien und Schwimmbäder im Umkreis von 500 m um den Bahnübergang. Darüber hinaus werden alle besonderen Orte, die zu bestimmten Zeiten des Jahres (d. h. an bestimmten Tagen im Jahr deutlich stärkere Verkehrsstärke als üblich) beliebt sind, wie Badeseen oder Skigebiete, ebenfalls in diesen Faktor einbezogen.

Bahnübergänge in der Nähe von Kneipen und Clubs haben ein höheres Risiko als andere Bahnübergänge, da sie einer höheren Exposition gegenüber Benutzern mit geringerer Umgebungswahrnehmung ausgesetzt sind und diese eher schlechte Urteile fällen. Bahnübergänge in der Nähe von Stadien und Sportstätten erhalten zu besonderen Zeiten in der Woche deutlich höhere Verkehrsstärken und daher steigt das Risiko innerhalb dieser Zeiten deutlich an. Beispielsweise könnte die vorhandene Sicherungsart für den regulären Verkehr ausreichen, aber nicht für die hohe Verkehrsstärke während der Veranstaltungszeiten.

Verkehrslärm

Bahnübergänge sind oft eine Lärmquelle und beeinträchtigen die Lebensqualität der Anwohner. Außerdem kann es für Bürger, die in der Nähe eines Bahnübergangs wohnen, ein wirtschaftlicher Nachteil sein, da eine Immobilie, die einem höheren Verkehrslärm ausgesetzt ist, normalerweise einen geringeren Marktwert hat. Dieses Modell unterscheidet zwischen Bahnübergängen, die mit Pfeifsignalen gesichert sind und bei denen Züge nicht verpflichtet sind, ihre Ankunft durch Pfeifen anzukündigen. Bei technisch gesicherten Bahnübergängen berücksichtigt das Modell das Vorhandensein eines Fußgängerakustik. Die Lärmempfindlichkeit wird dann anhand des Baugebiets bewertet. Tabelle 6 zeigt die Lärmemissionsgrenzwerte nach §2 der 16. BImSchV.

Tabelle 122: Immissionsgrenzwerte der Lärmvorsorge bei der Planung von Neu- und Ausbau von Schienenwegen (Quelle: BMDV, 2022)

Immissionsgrenzwerte der Lärmvorsorge in dB(A)

	Tag 6 bis 22 Uhr	Nacht 22 bis 6 Uhr
Krankenhäuser, Schulen	57	47
Reine und allgemeine Wohngebiete	59	49
Kern-, Dorf- und Mischgebiete	64	54
Gewerbegebiete	69	59

Schadstoffausstoß und Betriebskosten

Die Menge der von Straßenfahrzeugen ausgestoßenen Emissionen und der Kraftstoffverschwendung im Leerlauf bei Halt am Bahnübergang steigen mit dem durchschnittlichen täglichen Verkehr, dem Anteil der Lkw und der Sicherungsart, da sich die Wartezeiten bei einer Änderung der Sicherungsart erheblich ändern. Daher schlägt das Modell drei verschiedene Ansätze vor, die von den Experten verglichen werden sollen.

1- Niedrige Emissionen/Betriebskosten: Schwacher Straßenverkehr, niedriger LKW- Anteil und nicht technisch gesicherte BÜ.
2- Mäßiger Emissionen/Betriebskosten: Mäßiger Straßenverkehr, mäßiger LKW- Anteil und mit Lichtsignalen/Blinklichter gesicherter BÜ.
3- Hohe Emissionen/Betriebskosten: Starker Straßenverkehr, großer LKW- Anteil und mit Schranken gesicherter BÜ.

Abschnitt D – Erläuterung der Vergleichsskala

Bitte verwenden Sie die folgende paarweise Vergleichsskala, um die Bedeutung eines Faktors/einer Alternative gegenüber dem anderen auszudrücken. Die Bedeutung hängt davon ab, wie sehr der genannte Faktor A im Vergleich zu Faktor B zum Risiko/zur Priorität der Beseitigung beiträgt.

Gerade AHP-Werte (Zwischenwerte) könnten ausgewählt werden, wenn der Experte in einem Dilemma zwischen zwei Werten steht.

Tabelle 123: AHP-Skala (Quelle: Mühlbacher und Kaczynski, 2013)

AHP-Werte	Definition	Interpretation
1	Gleiche Bedeutung (Indifferenz)	Beide miteinander verglichenen Kriterien i und j haben die gleiche Bedeutung (immer in Bezug auf das Element der nächsthöheren Stufe).
3	Etwas größere Bedeutung	Erfahrung und Einschätzung sprechen für eine etwas größere Bedeutung des einen Kriteriums im Vergleich zum anderen Kriterium.
5	Erheblich größere Bedeutung	Erfahrung und Einschätzung sprechen für eine erheblich größere Bedeutung des einen Kriteriums im Vergleich zum anderen Kriterium.
7	Sehr viel größere Bedeutung	Die sehr viel größere Bedeutung des Kriteriums i im Vergleich zum anderen Kriterium j hat sich in der Vergangenheit klar gezeigt.
9	Absolut dominierend	Der größtmögliche Bedeutungsunterschied, der zwischen zwei Kriterien i und j möglich ist.
2,4,6,8	Zwischenwerte	Feinabstufung

Beispiel

Sie können die relative Wichtigkeit von zwei Kriterien, wie unten in diesem Beispiel gezeigt, beurteilen:

Wenn Sie der Meinung sind, dass das Kriterium "Lage des BÜ" erheblich wichtiger ist als das Kriterium "Straßenklasse", dann wählen Sie bitte 5 auf der linken Seite.

Wenn Sie der Meinung sind, dass das Kriterium "Lage auf Haupt- oder Nebenbahnen" extrem wichtiger ist als das Kriterium "Straßenklasse", wählen Sie bitte 9 auf der rechten Seite.

Tabelle 124: Beispiel für AHP-Vergleich

Lage des BÜ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Straßenklasse
Straßenklasse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lage auf Haupt- oder Nebenbahnen

Quellen

[102] DB Netz AG, 2021. Bahnübergänge im Spiegel der Statistik-Bahnübergangsstatistik 2020, Berlin.

[135] Bundesministerium für Digitales und Verkehr, 2022. Lärmschutz im Schienenverkehr, Berlin.

(Mühlbacher und Kaczynski, 2013) Mühlbacher, A.C. and Kaczynski, A., 2013. Der Analytic Hierarchy Process (AHP): Eine Methode zur Entscheidungsunterstützung im Gesundheitswesen. *PharmacoEconomics German Research Articles, 11*(2), pp.119-132.

Appendix D

Pairwise comparison results

Table 125: Pairwise comparison results of the main criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Traffic and operational factors							■											Physical factors
Traffic and operational factors													■					Safety factors
Traffic and operational factors							■											Social factors
Traffic and operational factors					■													Environmental and economic factors
Physical factors											■							Safety factors
Physical factors							■											Social factors
Physical factors					■													Environmental and economic factors
Safety factors				■														Social factors
Safety factors		■																Environmental and economic factors
Social factors									■									Environmental and economic factors

Table 126: Pairwise comparison results of traffic and operational factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Functional classification												■						Traffic Exposure
Functional classification										■								Road users factor
Functional classification										■								Speed factor
Functional classification									■									Train characteristics
Functional classification									■									Waiting time (Delay)
Traffic Exposure						■												Road users factor
Traffic Exposure							■											Speed factor
Traffic Exposure						■												Train characteristics
Traffic Exposure							■											Waiting time (Delay)
Road users factor									■									Speed factor
Road users factor								■										Train characteristics
Road users factor									■									Waiting time (Delay)

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Speed factor						■												Train characteristics
Speed factor								■										Waiting time (Delay)
Train characteristics										■								Waiting time (Delay)

Table 127: Pairwise comparison results of physical factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Geometrical factors									■									Visibility
Geometrical factors					■													Pavement
Visibility				■														Pavement

Table 128: Pairwise comparison results of safety factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Type of protection									■									Accident history
Type of protection						■												Road markings
Type of protection						■												Traffic safety devices
Type of protection								■										Hazardous material transportation
Accident history				■														Road markings
Accident history					■													Traffic safety devices
Accident history							■											Hazardous material transportation
Road markings									■									Traffic safety devices
Road markings										■								Hazardous material transportation
Traffic safety devices										■								Hazardous material transportation

Table 129: Pairwise comparison results of social factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Emergency services									■									Schools
Emergency services									■									Vulnerable population and sensitive facilities
Emergency services									■									Special social and event venues
Schools								■										Vulnerable population and sensitive facilities
Schools								■										Special social and event venues
Vulnerable population and sensitive facilities									■									Special social and event venues

Table 130: Pairwise comparison results of environmental and economic factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Noise									■									Vehicle emissions
Noise								■										Operating costs
Vehicle emissions								■										Operating costs

Table 131: Pairwise comparison results of functional classification criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Area classification							■											Road type
Area classification						■												Track type
Road type									■									Track type

Table 132: Pairwise comparison results of traffic exposure criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Average daily road traffic volume									■									Train volume

Table 133: Pairwise comparison results of road users factor

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Pedestrians and cyclists %									■									Trucks %
Pedestrians and cyclists %									■									Buses and school buses
Trucks %									■									Buses and school buses

Table 134: Pairwise comparison results of speed factor

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Train speed								■										Maximum road speed

Table 135: Pairwise comparison results of train characteristics criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Train types								■										Train length

Table 136: Pairwise comparison results of geometrical factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Angle of intersection							■											Approach grade
Angle of intersection						■												Track curvature
Angle of intersection							■											Road curvature
Angle of intersection								■										Road width
Angle of intersection									■									Number of tracks
Angle of intersection								■										Number of lanes
Angle of intersection									■									Distance to nearby intersection
Approach grade									■									Track curvature
Approach grade									■									Road curvature
Approach grade									■									Road width
Approach grade										■								Number of tracks
Approach grade								■										Number of lanes
Approach grade									■									Distance to nearby intersection
Track curvature									■									Road curvature

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Track curvature										■								Road width
Track curvature											■							Number of tracks
Track curvature										■								Number of lanes
Track curvature										■								Distance to nearby intersection
Road curvature										■								Road width
Road curvature										■								Number of tracks
Road curvature									■									Number of lanes
Road curvature									■									Distance to nearby intersection
Road width										■								Number of tracks
Road width									■									Number of lanes
Road width									■									Distance to nearby intersection
Number of tracks								■										Number of lanes
Number of tracks								■										Distance to nearby intersection
Number of lanes										■								Distance to nearby intersection

Table 137: Pairwise comparison results of visibility factors

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Sight distance											■							Sight obstructions
Sight distance								■										Illumination
Sight obstructions							■											Illumination

Table 138: Pairwise comparison results of pavement criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Type of crossing surface								■										Type of road pavement
Type of crossing surface										■								Condition of crossing and road pavement
Type of road pavement												■						Condition of crossing and road pavement

Table 139: Pairwise comparison results of accident history criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Number of accidents										■								Number of fatalities
Number of accidents									■									Number of severe injuries
Number of accidents								■										Number of slightly injured
Number of fatalities						■												Number of severe injuries
Number of fatalities						■												Number of slightly injured
Number of severe injuries						■												Number of slightly injured

Table 140: Pairwise comparison results of noise criteria

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
LC secured by train whistle or pedestrians audible warning signal								■										No train whistle or pedestrians audible warning signal required at LC

Table 141: Pairwise comparison results of area classification alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Rural											■							Urban

Table 142: Pairwise comparison results of road type alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Federal highways							■											State roads
Federal highways						■												County roads
Federal highways								■										City and municipal roads
Federal highways						■												Other roads
State roads							■											County roads
State roads								■										City and municipal roads
State roads						■												Other roads
County roads								■										City and municipal roads
County roads								■										Other roads
City and municipal roads						■												Other roads

Table 143: Pairwise comparison results of track type alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Main track							■											Side track

Table 144: Pairwise comparison results of average daily road traffic volume alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Weak: ≤100 vehicles/day														■				Moderate: 101-2500 vehicles/day
Weak: ≤100 vehicles/day														■				Strong: >2500 vehicles/day
Moderate: 101-2500 vehicles/day										■								Strong: >2500 vehicles/day

Table 145: Pairwise comparison results of train volume

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
≤ 20 Trains/day											■							21-40 Trains/day
≤ 20 Trains/day											■							41-60 Trains/day
≤ 20 Trains/day													■					>60 Trains/day
21-40 Trains/day										■								41-60 Trains/day
21-40 Trains/day											■							>60 Trains/day
41-60 Trains/day												■						>60 Trains/day

Table 146: Pairwise comparison results of pedestrians and cyclists % alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Pedestrians and cyclists %: <5%											■							Pedestrians and cyclists %: 5-20%
Pedestrians and cyclists %: <5%												■						Pedestrians and cyclists %: >20%
Pedestrians and cyclists %: 5-20%											■							Pedestrians and cyclists %: >20%

Table 147: Pairwise comparison results of trucks % alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Trucks %: <5%											■							Trucks %: 5-20%
Trucks %: <5%												■						Trucks %: >20%
Trucks %: 5-20%											■							Trucks %: >20%

Table 148: Pairwise comparison results of train speed alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
≤20 km/h										■								21-40 km/h
≤20 km/h											■							41-60 km/h
≤20 km/h												■						61-80 km/h
≤20 km/h													■					81-100 km/h
≤20 km/h														■				101-120 km/h
≤20 km/h														■				121-140 km/h

≤20 km/h														■				141- 160 km/h
21-40 km/h										■								41-60 km/h
21-40 km/h											■							61-80 km/h
21-40 km/h												■						81-100 km/h
21-40 km/h													■					101-120 km/h
21-40 km/h														■				121-140 km/h
21-40 km/h															■			141- 160 km/h
41-60 km/h										■								61-80 km/h
41-60 km/h												■						81-100 km/h
41-60 km/h													■					101-120 km/h
41-60 km/h														■				121-140 km/h
41-60 km/h														■				141- 160 km/h
61-80 km/h											■							81-100 km/h
61-80 km/h												■						101-120 km/h
61-80 km/h													■					121-140 km/h
61-80 km/h														■				141- 160 km/h
81-100 km/h											■							101-120 km/h
81-100 km/h												■						121-140 km/h
81-100 km/h													■					141- 160 km/h
101-120 km/h											■							121-140 km/h
101-120 km/h												■						141- 160 km/h
121-140 km/h												■						141- 160 km/h

Table 149: Pairwise comparison results of maximum road speed alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
≤ 10 km/h										■								11-30 km/h
≤ 10 km/h											■							31-50 km/h
≤ 10 km/h													■					51-70 km/h
≤ 10 km/h															■			>70 km/h
11-30 km/h											■							31-50 km/h
11-30 km/h												■						51-70 km/h
11-30 km/h														■				>70 km/h
31-50 km/h											■							51-70 km/h
31-50 km/h													■					>70 km/h
51-70 km/h													■					>70 km/h

Table 150: Pairwise comparison results of train types alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
With passenger traffic							■											Only freight traffic

Table 151: Pairwise comparison results of train length alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
≤ 100m									■									101-200m
≤ 100m									■									>200m
101-200m									■									>200m

Table 152: Pairwise comparison results of waiting time (Delay) alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
≤30s										■								31-60s
≤30s										■								61-90s
≤30s											■							91-120s
≤30s												■						121-150s
≤30s												■						151-180s
≤30s												■						181-210s
≤30s													■					211-240s
31-60s										■								61-90s
31-60s										■								91-120s
31-60s											■							121-150s
31-60s												■						151-180s
31-60s												■						181-210s
31-60s												■						211-240s
61-90s										■								91-120s
61-90s											■							121-150s
61-90s											■							151-180s
61-90s												■						181-210s
61-90s												■						211-240s
91-120s										■								121-150s

91-120s											■							151-180s
91-120s											■							181-210s
91-120s												■						211-240s
121-150s										■								151-180s
121-150s											■							181-210s
121-150s											■							211-240s
151-180s										■								181-210s
151-180s											■							211-240s
181-210s											■							211-240s

Table 153: Pairwise comparison results of angle of intersection alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
0°-30°							■											31°-60°
0°-30°						■												61°-90°
31°-60°							■											61°-90°

Table 154: Pairwise comparison results of approach grade alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
AG<3%										■								3% ≤ AG < 6%
AG<3%											■							6% ≤ AG < 9%
AG<3%												■						9% ≤ AG < 12%
AG<3%													■					AG ≥ 12%
3% ≤ AG < 6%										■								6% ≤ AG < 9%
3% ≤ AG < 6%											■							9% ≤ AG < 12%
3% ≤ AG < 6%												■						AG ≥ 12%
6% ≤ AG < 9%										■								9% ≤ AG < 12%
6% ≤ AG < 9%											■							AG ≥ 12%
9% ≤ AG < 12%											■							AG ≥ 12%

Table 155: Pairwise comparison results of track curvature alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
R < 250m								■										250m ≤ R < 500m
R < 250m								■										500m ≤ R < 750m
R < 250m								■										R ≥ 750m
250m ≤ R < 500m								■										500m ≤ R < 750m
250m ≤ R < 500m								■										R ≥ 750m
500m ≤ R < 750m								■										R ≥ 750m

Table 156: Pairwise comparison results of road curvature alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
<0.25 gon/m										■								0.25 - 0.5 gon/m
<0.25 gon/m										■								0.5 - 0.75 gon/m
<0.25 gon/m										■								0.75 - 1 gon/m
<0.25 gon/m											■							> 1 gon/m
0.25 - 0.5 gon/m										■								0.5 - 0.75 gon/m
0.25 - 0.5 gon/m										■								0.75 - 1 gon/m
0.25 - 0.5 gon/m										■								> 1 gon/m
0.5 - 0.75 gon/m										■								0.75 - 1 gon/m
0.5 - 0.75 gon/m										■								> 1 gon/m
0.75 - 1 gon/m										■								> 1 gon/m

Table 157: Pairwise comparison results of road width alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
< 4.75m								■										4.75 – 5.5m
< 4.75m								■										5.5 – 6.35m
< 4.75m							■											≥ 6.35m
4.75 – 5.5m								■										5.5 – 6.35m
4.75 – 5.5m							■											≥ 6.35m
5.5 – 6.35m								■										≥ 6.35m

Table 158: Pairwise comparison results of number of tracks alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Number of tracks: 1												■						Number of tracks: 2
Number of tracks: 1													■					Number of tracks: 3
Number of tracks: 1														■				Number of tracks: ≥4
Number of tracks: 2											■							Number of tracks: 3
Number of tracks: 2													■					Number of tracks: ≥4
Number of tracks: 3											■							Number of tracks: ≥4

Table 159: Pairwise comparison results of number of lanes alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Number of lanes: 1											■							Number of lanes: 2
Number of lanes: 1												■						Number of lanes: ≥3
Number of lanes: 2											■							Number of lanes: ≥3

Table 160: Pairwise comparison results of distance to nearby intersection alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
In clearance section (≤27m)						■												27 < DNI ≤ 50m
In clearance section (≤27m)						■												50 < DNI ≤ 100m
In clearance section (≤27m)					■													100 < DNI ≤ 150m
In clearance section (≤27m)					■													>150m
27 < DNI ≤ 50m							■											50 < DNI ≤ 100m
27 < DNI ≤ 50m						■												100 < DNI ≤ 150m
27 < DNI ≤ 50m						■												>150m
50 < DNI ≤ 100m							■											100 < DNI ≤ 150m
50 < DNI ≤ 100m							■											>150m
100 < DNI ≤ 150m								■										>150m

Table 161: Pairwise comparison results of sight distance alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
<200m							■											200-400m
<200m							■											>400m
200-400m								■										>400m

Table 162: Pairwise comparison results of illumination alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
No illumination								■										Illumination: Insufficient
No illumination							■											Illumination: Sufficient
Illumination: Insufficient							■											Illumination: Sufficient

Table 163: Pairwise comparison results of type of crossing surface alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Rubber									■									Concrete
Rubber									■									Asphalt
Rubber										■								unpaved
Concrete									■									Asphalt
Concrete										■								unpaved
Asphalt										■								unpaved

Table 164: Pairwise comparison results of type of protection alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Passive							■											Light signals / Flashing lights
Passive						■												Half barriers
Passive						■												Full barriers
Light signals / Flashing lights							■											Half barriers
Light signals / Flashing lights							■											Full barriers
Half barriers								■										Full barriers

Table 165: Pairwise comparison results of number of accidents alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
0											■							1-2
0													■					3-4
0														■				>4
1-2												■						3-4
1-2													■					>4
3-4											■							>4

Table 166: Pairwise comparison results of number of fatalities alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
0												■						1-2
0														■				3-4
0															■			>4
1-2												■						3-4
1-2													■					>4
3-4											■							>4

Table 167: Pairwise comparison results of number of severe injuries alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
0											■							1-2
0													■					3-4
0														■				>4
1-2												■						3-4
1-2													■					>4
3-4											■							>4

Table 168: Pairwise comparison results of number of slightly injured alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
0											■							1-2
0												■						3-4
0													■					>4
1-2											■							3-4
1-2												■						>4
3-4											■							>4

Table 169: Pairwise comparison results of noise alternatives for crossings with no train whistle or pedestrians audible warning signal

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Near hospitals, schools, health resorts and retirement homes									■									Residential areas
Near hospitals, schools, health resorts and retirement homes								■										Commercial and agricultural areas
Near hospitals, schools, health resorts and retirement homes							■											Industrial areas
Residential areas								■										Commercial and agricultural areas
Residential areas								■										Industrial areas
Commercial and agricultural areas								■										Industrial areas

Table 170: Pairwise comparison results of noise alternatives for crossings secured by train whistle or pedestrians audible warning signal

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Near hospitals, schools, health resorts and retirement homes									■									Residential areas
Near hospitals, schools, health resorts and retirement homes								■										Commercial and agricultural areas
Near hospitals, schools, health resorts and retirement homes							■											Industrial areas
Residential areas								■										Commercial and agricultural areas
Residential areas								■										Industrial areas
Commercial and agricultural areas								■										Industrial areas

Table 171: Pairwise comparison results of vehicle emissions alternatives

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Low emissions											■							Moderate emissions
Low emissions												■						High emissions
Moderate emissions											■							High emissions

Table 172: Pairwise comparison results of operating costs

Criterion 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criterion 2
Low costs											■							Moderate costs
Low costs												■						High costs
Moderate costs											■							High costs

Appendix E

Decision matrices and calculations of criteria weights

Table 173: Comparison matrix and weights of main criteria

	Traffic and operational factors	Physical factors	Safety factors	Social factors	Environmental and economic factors	Local weight	Global weight
Traffic and operational factors	1	3	1/5	3	5	-	0.22116
Physical factors	1/3	1	1/3	3	5	-	0.15041
Safety factors	5	3	1	6	8	-	0.52365
Social factors	1/3	1/3	1/6	1	1	-	0.05906
Environmental and economic factors	1/5	1/5	1/8	1	1	-	0.04572
CR = 7.78% < 10% ✓					Total	-	1

Table 174: Comparison matrix and weights of traffic and operational factors

	Functional classification	Traffic Exposure	Road users factor	Train characteristics	Speed factor	Waiting time (Delay)	Local weight	Global weight
Functional classification	1	1/4	1/2	1	1/2	1	0.08687	0.01921
Traffic Exposure	4	1	4	4	3	3	0.40397	0.08934
Road users factor	2	1/4	1	2	1	1	0.13867	0.03067
Train characteristics	1	1/4	1/2	1	1/4	1/2	0.07000	0.01548
Speed factor	2	1/3	1	4	1	2	0.18554	0.04103
Waiting time (Delay)	1	1/3	1	2	1/2	1	0.11496	0.02542
CR = 2.53 < 10% ✓						Total	1	0.22116

Table 175: Comparison matrix and weights of physical factors

	Geometrical factors	Visibility	Pavement	Local weight	Global weight
Geometrical factors	1	1	5	0.44427	0.06682
Visibility	1	1	6	0.47211	0.01258
Pavement	1/5	1/6	1	0.08362	0.07101
CR = 0.36% < 10% ✓			Total	1	0.15041

Table 176: Comparison matrix and weights of safety factors

	Type of protection	Accident history	Road markings	Traffic safety devices	Hazardous material transportation	Local weight	Global weight
Type of protection	1	1	4	4	2	0.31677	0.16588
Accident history	1	1	6	5	3	0.38975	0.20409
Road markings	1/4	1/6	1	1	1/2	0.07272	0.03808
Traffic safety devices	1/4	1/5	1	1	1/2	0.07531	0.03944
Hazardous material transportation	1/2	1/3	2	2	1	0.14544	0.07616
CR = 0.4% < 10% ✓					Total	1	0.52365

Table 177: Comparison matrix and weights of social factors

	Emergency services	Schools	Vulnerable population and sensitive facilities	Special social and event venues	Local weight	Global weight
Emergency services	1	1	1	1	0.24627	0.01454
Schools	1	1	2	2	0.34654	0.02047
Vulnerable population and sensitive facilities	1	1/2	1	1	0.20360	0.01202
Special social and event venues	1	1/2	1	1	0.20360	0.01202
CR = 2.27% < 10% ✓				Total	1	0.05906

Table 178: Comparison matrix and weights of environmental and economic factors

	Noise	Vehicle emissions	Operating costs	Local weight	Global weight
Noise	1	1	2	0.40000	0.01829
Vehicle emissions	1	1	2	0.40000	0.01829
Operating costs	1/2	1/2	1	0.20000	0.00914
CR = 0.00% < 10% ✓			Total	1	0.04572

Table 179: Comparison matrix and weights of functional classification criteria

	Area classification	Road type	Track type	Local weight	Global weight
Area classification	1	3	4	0.63371	0.01217
Road type	1/3	1	1	0.19192	0.00369
Track type	1/4	1	1	0.17437	0.00335
CR = 0.89% < 10% ✓			Total	1	0.01921

Table 180: Comparison matrix and weights of traffic exposure criteria

	Average daily road traffic volume	Train volume	Local weight	Global weight
Average daily road traffic volume	1	1	0.5000	0.04467
Train volume	1	1	0.5000	0.04467
CR = 0.00% < 10% ✓		Total	1	0.08934

Table 181: Comparison matrix and weights of road users factors

	Pedestrians and cyclists %	Trucks %	Buses and school buses	Local weight	Global weight
Pedestrians and cyclists %	1	1	1	0.33333	0.01022
Trucks %	1	1	1	0.33333	0.01022
Buses and school buses	1	1	1	0.33333	0.01022
CR = 0.00% < 10% ✓			Total	1	0.03067

Table 182: Comparison matrix and weights of speed criteria

	Train speed	Maximum road speed	Local weight	Global weight
Train speed	1	2	0.66667	0.02735
Maximum road speed	1/2	1	0.33333	0.01368
CR = 0.00% < 10% ✓		Total	1	0.04103

Table 183: Comparison matrix and weights of geometrical factors

	Angle of intersection	Approach grade	Track curvature	Road curvature	Road width	Number of tracks	Number of lanes	Distance to nearby intersection	Local weight	Global weight
Angle of intersection	1	3	4	3	2	1	2	1	0.21513	0.01437
Approach grade	1/3	1	1	1	1	1/2	2	1	0.10260	0.00686
Track curvature	1/4	1	1	1	1/2	1/3	1/2	1/2	0.06536	0.00437
Road curvature	1/3	1	1	1	1/2	1/2	1	1	0.08477	0.00566
Road width	1/2	1	2	2	1	1/2	1	1	0.11424	0.00763
Number of tracks	1	2	3	2	2	1	2	2	0.20000	0.01336
Number of lanes	1/2	1/2	2	1	1	1/2	1	1/2	0.08999	0.00601
Distance to nearby intersection	1	1	2	1	1	1/2	2	1	0.12791	0.00855
CR = 2.56% < 10% ✓								Total	1	0.06682

Table 184: Comparison matrix and weights of visibility criteria

	Sight distance	Sight obstructions	Illumination	Local weight	Global weight
Sight distance	1	1/3	2	0.24931	0.00314
Sight obstructions	3	1	3	0.59363	0.00747
Illumination	1/2	1/3	1	0.15706	0.00198
CR = 5.16% < 10% ✓			Total	1	0.01258

Table 185: Comparison matrix and weights of pavement criteria

	Type of crossing surface	Type of road pavement	Condition of crossing and road pavement	Local weight	Global weight
Type of crossing surface	1	2	1/2	0.28571	0.02029
Type of road pavement	1/2	1	1/4	0.14286	0.01014
Condition of crossing and road pavement	2	4	1	0.57143	0.04058
CR = 0.00% < 10% ✓			Total	1	0.07101

Table 186: Comparison matrix and weights of type of accident history criteria

	Number of accidents	Number of fatalities	Number of severe injuries	Number of slightly injured	Local weight	Global weight
Number of accidents	1	1/2	1	2	0.19993	0.04080
Number of fatalities	2	1	4	4	0.50103	0.10226
Number of severe injuries	1	1/4	1	4	0.21173	0.04321
Number of slightly injured	1/2	1/4	1/4	1	0.08732	0.01782
CR = 6.95% < 10% ✓				Total	1	0.20409

Table 187: Comparison matrix and weights of Noise alternatives

	No train whistle or pedestrians audible warning signal required at LC	LC secured by train whistle or pedestrians audible warning signal	Local weight	Global weight
No train whistle or pedestrians audible warning signal required at LC	1	1/2	0.33333	0.00610
LC secured by train whistle or pedestrians audible warning signal	2	1	0.66667	0.01219
CR = 0.00% < 10% ✓		Total	1	0.01829

Table 188: Comparison matrix and weights of area classification alternatives

	Rural	Urban	Local weight	Global weight	Final weight
Rural	1	1/3	0.25000	0.00304	0.00304
Urban	3	1	0.75000	0.00913	0.01217
CR = 0.00% < 10% ✓		Total	1	0.01217	-

Table 189: Comparison matrix and weights of road type alternatives

	Federal highways	State roads	County roads	City and municipal roads	Other roads	Local weight	Global weight	Final weight
Federal highways	1	3	4	2	4	0.41220	0.00152	0.00369
State roads	1/3	1	3	2	4	0.24536	0.00091	0.00218
County roads	1/4	1/3	1	2	2	0.13584	0.00050	0.00073
City and municipal roads	1/2	1/2	1/2	1	4	0.14556	0.00054	0.00127
Other roads	1/4	1/4	1/2	1/4	1	0.06103	0.00023	0.00023
CR = 8.98% < 10% ✓					Total	1	0.00369	-

Table 190: Comparison matrix and weights of track type alternatives

	Main track	Side track	Local weight	Global weight	Final weight
Main track	1	3	0.75000	0.00251	0.00335
Side track	1/3	1	0.25000	0.00084	0.00084
CR = 0.00% < 10% ✓		Total	1	0.00335	-

Table 191: Comparison matrix and weights of average daily road traffic volume alternatives

	Weak: ≤100 vehicles/day	Moderate: 101-2500 vehicles/day	Strong: >2500 vehicles/day	Local weight	Global weight	Final weight
Weak: ≤100 vehicles/day	1	1/6	1/6	0.07507	0.00335	0.00335
Moderate: 101-2500 vehicles/day	6	1	1/2	0.35748	0.01597	0.01932
Strong: >2500 vehicles/day	6	2	1	0.56746	0.02535	0.04467
CR = 5.16% < 10% ✓			Total	1	0.04467	-

Table 192: Comparison matrix and weights of train volume alternatives

	≤ 20 Trains/day	21-40 Trains/day	41-60 Trains/day	>60 Trains/day	Local weight	Global weight	Final weight
≤ 20 Trains/day	1	1/3	1/3	1/5	0.07453	0.00333	0.00333
21-40 Trains/day	3	1	1/2	1/3	0.16255	0.00726	0.01059
41-60 Trains/day	3	2	1	1/4	0.21671	0.00968	0.02027
>60 Trains/day	5	3	4	1	0.54621	0.02440	0.04467
CR = 6.07% < 10% ✓				Total	1	0.04467	-

Table 193: Comparison matrix and weights of Pedestrians and cyclists % alternatives

	Pedestrians and cyclists %: <5%	Pedestrians and cyclists %: 5-20%	Pedestrians and cyclists %: >20%	Local weight	Global weight	Final weight
Pedestrians and cyclists %: <5%	1	1/3	1/4	0.11722	0.00120	0.00120
Pedestrians and cyclists %: 5-20%	3	1	1/3	0.26837	0.00274	0.00394
Pedestrians and cyclists %: >20%	4	3	1	0.61441	0.00628	0.01022
CR = 7.07% < 10% ✓			Total	1	0.01022	-

Table 194: Comparison matrix and weights of trucks % alternatives

	Trucks %: <5%	Trucks %: 5-20%	Trucks %: >20%	Local weight	Global weight	Final weight
Trucks %: <5%	1	1/3	1/4	0.11722	0.00120	0.00120
Trucks %: 5-20%	3	1	1/3	0.26837	0.00274	0.00394
Trucks %: >20%	4	3	1	0.61441	0.00628	0.01022
CR = 7.07% < 10% ✓			Total	1	0.01022	-

Table 195: Comparison matrix and weights of train speed alternatives

	≤20 km/h	21-40 km/h	41-60 km/h	61-80 km/h	81-100 km/h	101-120 km/h	121-140 km/h	141- 160 km/h	Local weight	Global weight	Final weight
≤20 km/h	1	1/2	1/3	1/4	1/5	1/6	1/6	1/7	0.02293	0.00063	0.00063
21-40 km/h	2	1	1/2	1/3	1/4	1/5	1/6	1/7	0.02965	0.00081	0.00144
41-60 km/h	3	2	1	1/2	1/4	1/5	1/6	1/6	0.04002	0.00109	0.00253
61-80 km/h	4	3	2	1	1/3	1/4	1/5	1/6	0.05641	0.00154	0.00407
81-100 km/h	5	4	4	3	1	1/3	1/4	1/5	0.09582	0.00262	0.00669
101-120 km/h	6	5	5	4	3	1	1/3	1/4	0.15037	0.00411	0.01080
121-140 km/h	6	6	6	5	4	3	1	1/4	0.22719	0.00621	0.01701
141- 160 km/h	7	7	6	6	5	4	4	1	0.37761	0.01033	0.02735
CR = 7.91% < 10% ✓								Total	1	0.02735	-

Table 196: Comparison matrix and weights of maximum road speed alternatives

	≤ 10 km/h	11-30 km/h	31-50 km/h	51-70 km/h	>70 km/h	Local weight	Global weight	Final weight
≤ 10 km/h	1	1/2	1/3	1/5	1/7	0.04503	0.00062	0.00062
11-30 km/h	2	1	1/3	1/4	1/6	0.06406	0.00088	0.00150
31-50 km/h	3	3	1	1/3	1/5	0.11836	0.00162	0.00312
51-70 km/h	5	4	3	1	1/5	0.21937	0.00300	0.00612
>70 km/h	7	6	5	5	1	0.55318	0.00757	0.01369
CR = 7.08% < 10% ✓					Total	1	0.01368	-

Table 197: Comparison matrix and weights of train types alternatives

	With passenger traffic	Only freight traffic	Local weight	Global weight	Final weight
With passenger traffic	1	3	0.75000	0.01161	0.01548
Only freight traffic	1/3	1	0.25000	0.00387	0.00387
CR = 0.00% < 10% ✓		Total	1	0.01548	-

Table 198: Comparison matrix and weights of waiting time (delay) alternatives

	≤30s	31-60s	61-90s	91-120s	121-150s	151-180s	181-210s	211-240s	Local weight	Global weight	Final weight
≤30s	1	1/2	1/2	1/3	1/4	1/4	1/4	1/5	0.03468	0.00088	0.00088
31-60s	2	1	1/2	1/2	1/3	1/4	1/4	1/4	0.04599	0.00117	0.00205
61-90s	2	2	1	1/2	1/3	1/3	1/4	1/4	0.05633	0.00143	0.00348
91-120s	3	2	2	1	1/2	1/3	1/3	1/4	0.07592	0.00193	0.00541
121-150s	4	3	3	2	1	1/2	1/3	1/3	0.11409	0.00290	0.00831
151-180s	4	4	3	3	2	1	1/2	1/3	0.15538	0.00395	0.01226
181-210s	4	4	4	3	3	2	1	1/3	0.20626	0.00524	0.01750
211-240s	5	4	4	4	3	3	3	1	0.31136	0.00791	0.02542
CR = 4.39% < 10% ✓								Total	1	0.02542	-

Table 199: Comparison matrix and weights of angle of intersection alternatives

	61°-90°	31°-60°	0°-30°	Local weight	Global weight	Final weight
61°-90°	1	1/3	1/4	0.11722	0.00168	0.00168
31°-60°	3	1	1/3	0.26837	0.00386	0.00554
0°-30°	4	3	1	0.61441	0.00883	0.01437
CR = 7.07% < 10% ✓			Total	1	0.01437	-

Table 200: Comparison matrix and weights of approach grade alternatives

	AG<3%	3% ≤ AG < 6%	6% ≤ AG < 9%	9% ≤ AG < 12%	AG ≥ 12%	Local weight	Global weight	Final weight
AG<3%	1	1/2	1/3	1/4	1/5	0.06032	0.00041	0.00041
3% ≤ AG < 6%	2	1	1/2	1/3	1/4	0.09464	0.00065	0.00106
6% ≤ AG < 9%	3	2	1	1/2	1/3	0.15508	0.00106	0.00212
9% ≤ AG < 12%	4	3	2	1	1/3	0.23884	0.00164	0.00376
AG ≥ 12%	5	4	3	3	1	0.45113	0.00309	0.00686
CR = 2.84% < 10% ✓					Total	1	0.00686	-

Table 201: Comparison matrix and weights of track curvature alternatives

	R < 250m	250m ≤ R < 500m	500m ≤ R < 750m	R ≥ 750m	Local weight	Global weight	Final weight
R < 250m	1	2	2	2	0.39052	0.00171	0.00437
250m ≤ R < 500m	1/2	1	2	2	0.27614	0.00121	0.00266
500m ≤ R < 750m	1/2	1/2	1	2	0.19526	0.00085	0.00145
R ≥ 750m	1/2	1/2	1/2	1	0.13807	0.00060	0.00060
CR = 4.54% < 10% ✓				Total	1	0.00437	-

Table 202: Comparison matrix and weights of road curvature alternatives

	<0.25 gon/m	0.25 - 0.5 gon/m	0.5 - 0.75 gon/m	0.75 - 1 gon/m	> 1 gon/m	Local weight	Global weight	Final weight
<0.25 gon/m		1/2	1/2	1/2	1/3	0.09538	0.00054	0.00054
0.25 - 0.5 gon/m	2		1/2	1/2	1/2	0.13841	0.00078	0.00132
0.5 - 0.75 gon/m	2	2		1/2	1/2	0.18309	0.00104	0.00236
0.75 - 1 gon/m	2	2	2		1/2	0.24220	0.00137	0.00373
> 1 gon/m	3	2	2	2		0.34092	0.00193	0.00566
CR = 3.27% < 10% ✓					Total	1	0.00566	-

Table 203: Comparison matrix and weights of road width alternatives

	< 4.75m	4.75 – 5.5m	5.5 – 6.35m	≥ 6.35m	Local weight	Global weight	Final weight
< 4.75m	1	2	2	3	0.41549	0.00317	0.00763
4.75 – 5.5m	1/2	1	2	3	0.29259	0.00223	0.00446
5.5 – 6.35m	1/2	1/2	1	2	0.18495	0.00141	0.00223
≥ 6.35m	1/3	1/3	1/2	1	0.10697	0.00082	0.00082
CR = 2.66% < 10% ✓				Total	1	0.00763	-

Table 204: Comparison matrix and weights of number of tracks alternatives

	Number of tracks: 1	Number of tracks: 2	Number of tracks: 3	Number of tracks: ≥4	Local weight	Global weight	Final weight
Number of tracks: 1	1	1/4	1/5	1/6	0.05506	0.00074	0.00074
Number of tracks: 2	4	1	1/3	1/5	0.13006	0.00174	0.00248
Number of tracks: 3	5	3	1	1/3	0.26394	0.00353	0.00601
Number of tracks: ≥4	6	5	3	1	0.55095	0.00736	0.01336
CR = 8.13% < 10% ✓				Total	1	0.01336	-

Table 205: Comparison matrix and weights of number of lanes alternatives

	Number of lanes: 1	Number of lanes: 2	Number of lanes: ≥3	Local weight	Global weight	Final weight
Number of lanes: 1	1	1/3	1/4	0.11722	0.00070	0.00070
Number of lanes: 2	3	1	1/3	0.26837	0.00161	0.00231
Number of lanes: ≥3	4	3	1	0.61441	0.00369	0.00601
CR = 7.07% < 10% ✓			Total	1	0.00601	-

Table 206: Comparison matrix and weights of distance to nearby intersection alternatives

	In clearance section (≤27m)	27 < DNI ≤ 50m	50 < DNI ≤ 100m	100 < DNI ≤ 150m	>150m	Local weight	Global weight	Final weight
In clearance section (≤27m)	1	4	4	5	5	0.49516	0.00423	0.00855
27 < DNI ≤ 50m	1/4	1	3	4	4	0.24077	0.00206	0.00431
50 < DNI ≤ 100m	1/4	1/3	1	3	3	0.13578	0.00116	0.00225
100 < DNI ≤ 150m	1/5	1/4	1/3	1	2	0.07275	0.00062	0.00109
>150m	1/5	1/4	1/3	1/2	1	0.05553	0.00047	0.00047
CR = 7.53% < 10% ✓					Total	1	0.00855	-

Table 207: Comparison matrix and weights of sight distance alternatives

	<200m	200-400m	>400m	Local weight	Global weight	Final weight
<200m	1	3	3	0.59363	0.00186	0.00314
200-400m	1/3	1	2	0.24931	0.00078	0.00127
>400m	1/3	1/2	1	0.15706	0.00049	0.00049
CR = 5.17% < 10% ✓			Total	1	0.00314	-

Table 208: Comparison matrix and weights of illumination alternatives

	No illumination	Illumination: Insufficient	Illumination: Sufficient	Local weight	Global weight	Final weight
No illumination	1	2	3	0.52784	0.00105	0.00198
Illumination: Insufficient	1/2	1	3	0.33252	0.00066	0.00094
Illumination: Sufficient	1/3	1/3	1	0.13965	0.00028	0.00028
CR = 5.17% < 10% ✓			Total	1	0.00198	-

Table 209: Comparison matrix and weights of crossing surface alternatives

	Rubber	Concrete	Asphalt	unpaved	Local weight	Global weight	Final weight
Rubber	1	1	1	1/2	0.20000	0.00406	Cancelled
Concrete	1	1	1	1/2	0.20000	0.00406	Cancelled
Asphalt	1	1	1	1/2	0.20000	0.00406	Cancelled
unpaved	2	2	2	1	0.40000	0.00812	0.02029
CR = 0.00% < 10% ✓				Total	1	0.02029	-

Table 210: Comparison matrix and weights of type of protection alternatives

	Passive	Light signals / Flashing lights	Half barriers	Full barriers	Local weight	Global weight	Final weight
Passive	1	3	4	4	0.52336	0.08681	0.16588
Light signals / Flashing lights	1/3	1	3	3	0.26113	0.04332	0.07907
Half barriers	1/4	1/3	1	2	0.12615	0.02093	0.03575
Full barriers	1/4	1/3	1/2	1	0.08936	0.01482	0.01482
CR = 5.39% < 10% ✓				Total	1	0.16588	-

Table 211: Comparison matrix and weights of number of accidents alternatives

	0	1-2	3-4	>4	Local weight	Global weight	Final weight
0	1	1/3	1/5	1/6	0.05772	0.00235	0.00235
1-2	3	1	1/4	1/5	0.11041	0.00450	0.00685
3-4	5	4	1	1/3	0.28482	0.01162	0.01847
>4	6	5	3	1	0.54705	0.02232	0.04080
CR = 7.65% < 10% ✓				Total	1	0.04080	-

Table 212: Comparison matrix and weights of number of fatalities alternatives

	0	1-2	3-4	>4	Local weight	Global weight	Final weight
0	1	1/4	1/6	1/7	0.04795	0.00490	0.00490
1-2	4	1	1/4	1/5	0.11538	0.01180	0.01670
3-4	6	4	1	1/3	0.28794	0.02944	0.04614
>4	7	5	3	1	0.54873	0.05611	0.10226
CR = 8.89% < 10% ✓				Total	1	0.10226	-

Table 213: Comparison matrix and weights of number of severe injuries alternatives

	0	1-2	3-4	>4	Local weight	Global weight	Final weight
0	1	1/3	1/5	1/6	0.05772	0.00249	0.00249
1-2	3	1	1/4	1/5	0.11041	0.00477	0.00726
3-4	5	4	1	1/3	0.28482	0.01231	0.01957
>4	6	5	3	1	0.54705	0.02364	0.04321
CR = 7.65% < 10% ✓				Total	1	0.04321	-

Table 214: Comparison matrix and weights of number of slightly injured alternatives

	0	1-2	3-4	>4	Local weight	Global weight	Final weight
0	1	1/3	1/4	1/5	0.06842	0.00122	0.00122
1-2	3	1	1/3	1/4	0.13423	0.00239	0.00361
3-4	4	3	1	1/3	0.26811	0.00478	0.00839
>4	5	4	3	1	0.52924	0.00943	0.01782
CR = 6.77% < 10% ✓				Total	1	0.01782	-

Table 215: Comparison matrix and weights of alternatives for crossings secured by train whistle or pedestrians audible warning signal

	Near hospitals, schools, health resorts and retirement homes	Residential areas	Commercial and agricultural areas	Industrial areas	Local weight	Global weight	Final weight
Near hospitals, schools, health resorts and retirement homes	1	1	2	3	0.35644	0.00652	0.01829
Residential areas	1	1	2	2	0.32573	0.00596	0.01177
Commercial and agricultural areas	1/2	1/2	1	2	0.19358	0.00354	0.00581
Industrial areas	1/3	1/2	1/2	1	0.12426	0.00227	0.00227
CR = 1.72% < 10% ✓				Total	1	0.01829	-

Table 216: Comparison matrix and weights of alternatives for crossings with no train whistle or pedestrians audible warning signal

	Near hospitals, schools, health resorts and retirement homes	Residential areas	Commercial and agricultural areas	Industrial areas	Local weight	Global weight	Final weight
Near hospitals, schools, health resorts and retirement homes	1	1	2	3	0.35644	0.00217	0.00610
Residential areas	1	1	2	2	0.32573	0.00199	0.00393
Commercial and agricultural areas	1/2	1/2	1	2	0.19358	0.00118	0.00194
Industrial areas	1/3	1/2	1/2	1	0.12426	0.00076	0.00076
CR = 1.72% < 10% ✓				Total	1	0.00610	-

Table 217: Comparison matrix and weights of vehicle emissions alternatives

	Low emissions	Moderate emissions	High emissions	Local weight	Global weight	Final weight
Low emissions	1	1/3	1/4	0.11722	0.00214	0.00214
Moderate emissions	3	1	1/3	0.26837	0.00491	0.00705
High emissions	4	3	1	0.61441	0.01124	0.01829
CR = 7.07% < 10% ✓			Total	1	0.01829	-

Table 218: Comparison matrix and weights of operating costs alternatives

	Low costs	Moderate costs	High costs	Local weight	Global weight	Final weight
Low costs	1	1/3	1/4	0.11722	0.00107	0.00107
Moderate costs	3	1	1/3	0.26837	0.00245	0.00352
High costs	4	3	1	0.61441	0.00562	0.00914
CR = 7.07% < 10% ✓			Total	1	0.00914	-