



The Safety Level of Railway Infrastructure and Its Correlation with the Cost of Preventive and Mitigation Measures

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ABSTRACT

This paper develops a methodology which allows the correlation between the cost which is required for the application of preventive and mitigation measures dealing with accidents which occur within a railway system and the improvement of the level of safety as a result from their implementation. The safety level is expressed either quantitatively, by the decrease of “fatality risk” indicator or other indicators as defined by the European Railway Agency (ERA), or qualitatively by the change of “risk level”, as defined by CENELEC. Research focuses on accidents and, more specifically, on accidents caused by the railway infrastructure. The proposed methodology may be applied in all incident categories and for various causes subject to appropriate modifications. This research paper is a first attempt to provide answers in an important research field for railway companies, as many issues should be further explored. More specifically, further research shall include a) with respect to the approach based on the change in the “risk level”: definition of the values of each frequency and severity category, for each incident and cause category b) with respect to the approach based on the indicators: selection of an appropriate indicator for each incident category (definition of indicator, measurement units).

Keywords: Railway safety, Railway accidents, Safety level, Level railway crossings, Safety

1. Introduction

In this paper, a methodology is developed which allows the correlation between the cost which is required for the application of preventive and mitigation measures dealing with accidents which occur within a railway system and the improvement of the level of safety as a result from their implementation [1].

The cost of the investment is calculated in Euros (€). Safety level improvement is expressed either quantitatively, by the decrease of “fatality risk” indicator or other indicators as defined by the European Railway Agency (ERA) [2], or qualitatively by the change of “risk level”, as defined by CENELEC [3].

Incidents (accidents, events and failures, [4], [5]) which take place in a railway system characterise its

level of safety. The more frequent and more severe the incidents are, the lower the level of safety provided by the network is.

Research focuses on accidents and, more specifically, on accidents caused by the railway infrastructure. The proposed methodology may be applied in all incident categories and for various causes subject to appropriate modifications.

One of the main issues that railway companies have traditionally dealt with is the amount of money they need to invest initially or during the system’s operation in order to ensure a specific level of safety. Safety improvement is costly, however what is not often known is its correlation with the required cost. The quantification of this correlation is difficult because it is defined by a number of factors, whose characteristics are yet to be specified.

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This research work is a first attempt to approach this correlation and to provide the theoretical background that will support further research and will address the aforementioned issue.

2. Definitions

Railway System: Inland mass transport mode which is defined by three components: railway infrastructure, rolling stock, operation.

Incident: It is a unified definition of an accident, an event or a failure.

Accident: All non-desired or non-expected sudden occurrences or a specific chain of similar incidents that bring (or brought) unwanted consequences to the railway system (railway infrastructure, rolling stock, and operation), its users, general public and the environment.

Accidents are classified as follows [6]:

- Collisions of trains
- Derailments of trains
- Level- crossings accidents
- Accidents to persons caused by rolling stock in motion
- Fires in rolling stock
- Other accidents

Event: Every incident not characterized as an accident that concerns the operation/ circulation of the trains and also affects their safety. An event may be the cause of an accident.

Failure: Failure represents a specific category of an event. It can be defined as any technical malfunction of the railway infrastructure and of the rolling stock that affects the safety of the circulation and the operation of the whole system. Accordingly, a failure may be the cause of an accident [4], [5].

Causes of incidents: Causes are defined as actions, omissions, events or conditions, or a combination thereof, which led to an accident or incident.

Railway incident causes are divided in 3 levels according to the “source” which provoked them. As a first level incident cause can be considered one of the following [4]:

- One of the three components of the railway system (railway infrastructure, rolling stock,

operation) and / or, most commonly, a combination thereof

- A series of incidents caused by sources extrinsic to the railway system

In case of e.g. a vehicle derailment due to wheel failure (breakage) rolling stock can be seen as a first level cause, failure in the wheelset system can be seen as a second level cause while wheel cracking can be seen as a third level cause.

Railway Infrastructure: The term includes the railway track (superstructure, substructure), the civil engineering structures and the track and operation facilities that ensure the circulation of trains.

Average daily traffic movement: The number of trains moving on the track in both directions per 24hours multiplied by the number of passing road vehicles of all types in both directions of the crossing during the same 24hour period.

Railway Safety: (definition according to CENELEC [3]): The term includes all the components and elements of the railway system, which ensure that during operation the risk level is not described as “non permissible” (descriptive assessment of the level of risk, which is determined as the product of the frequency of an incident, combined with its severity).

According to E.U. the above combination determines four (4) safety/risk levels as follows (Table 1):

- **Non permissible:** accidents of this category must be eliminated. It represents the most significant category and necessitates urgent safety measures by the services responsible, regardless of the financial and operational cost.
- **Non desirable:** accidents of this category can be accepted only in case of inability to contain their consequences and always upon the relevant approval of the authority in-charge.
- **Permissible:** it corresponds to a generally acceptable safety level, without excluding further improvements, if it is feasible.
- **Unimportant:** the incidents of this category are acceptable, provided that there is approval of the competent authority.

In order to classify the various accidents according to the severity of their consequences, CENELEC European standards adopt specific definitions

(catastrophic, severe etc) which are analyzed in paragraph 5.1.2.

However, as far as accident frequency is concerned, there are as yet no European standards clearly defining the borderlines between the various classifications (Possible, Occasional, etc), and this causes difficulties in applying Table 1.

Railway safety – Definition according to ERA indicators [2]:

A railway system's safety is evaluated according to the incidents that occurred during a specific time period (e.g, one year) and affected the track, the rolling stock, the passengers / goods and the environment.

In order to apply the EU directive 2004/49 for safety and its revision 2009/149/EC [6], ERA proposed a series of indicators [2] concerning rail incidents, their impact in relation to human life, economic impact, technical impact, etc. More emphasis is placed on human life, as any incident is directly related to its consequences upon it. Consequences may include fatality, serious injury and light injury.

These consequences are combined with the number of accidents and the economic impact form the values of corresponding indicators. This combination is necessary for further decisions on prevention measures that need to be adopted.

The following indicators are part of the so-called Common Safety Indicators (CSIs) that ERA proposed:

Indicators related to accidents (per year)

- Total Number of Serious Accidents (number)
- Relative Number of Serious Accidents (number/train - kilometers)
- Distribution of accidents per accident category

- Fatality risk indicator: death toll as a result of train accidents per million train - kilometers

Taking into consideration all fatalities from rail accidents (excluding suicides), the EU "fatality risk indicator" in 2009-2011 had a value of 0.31 fatalities per million train - kilometers [2].

- Total Number of persons seriously injured and killed per accident category (number)
- Relative Number of persons seriously injured and killed per accident category (number / train - kilometers)
- Distribution of accidents according to different users / stakeholders of the rail system

Indicators for the financial impact assessment of accidents

- Total cost (in €)
- Unit Costs (€/train - kilometers) for the number of fatalities and serious injuries, the cost of environmental impact, the cost of damage to rolling stock or infrastructure and the cost of delays resulting from accidents respectively

Measures addressing railway incidents

The measures addressing railway incidents are as follows [5]:

- Measures taken by the railway company in order to reduce the probability of incidents' occurrence.

Measures addressing railway incidents

The measures addressing railway incidents are as follows [5]:

Table 1: Risk Levels based on accidents' frequency and severity

Risk Levels	Accident severity			
	Catastrophic	Severe	Low severity	Negligible
Frequent	Non permissible	Non permissible	Non permissible	Non desirable
Possible	Non permissible	Non permissible	Non desirable	Permissible
Occasional	Non permissible	Non desirable	Non desirable	Permissible
Unusual	Non desirable	Non desirable	Permissible	Unimportant
Rare	Permissible	Permissible	Unimportant	Unimportant
Unlikely	Unimportant	Unimportant	Unimportant	Unimportant

- Measures taken by the railway company in order to reduce the probability of incidents' occurrence
- Measures which should preexist so that actions following the incident (e.g. in case of train immobilized on the track) be rational and adverse impacts be reduced

The former are classified as preventive measures while the latter are classified as administrative or repressive measures.

Depending on the track components on which they are taken, the aforementioned preventive and mitigation measures are classified as follows:

- Measures / interventions on civil engineering structures (on bridges, in tunnels, etc.)
- Measures / interventions at the area of stations /stops
- Measures / interventions on the open track
- Measures / interventions at level crossings

Any work which may upgrade railway infrastructure by improving its geometric, operational and structural characteristics can be considered as railway infrastructure intervention. Interventions may include changes in the track alignment characteristics, removal of track defects, renovations to the track's superstructure and substructure, reconstruction or maintenance of old civil engineering structures, removal of level crossings or replacement of level crossings by overpasses, etc.

3. Correlation between intervention costs and improvement of safety level- General methodological approach

As already mentioned in section 1 for the correlation between the interventions' cost and the anticipated safety improvement two approaches were followed (Figure 1). In the first approach (Indicators method) the aim is that the measures addressing incidents should assist towards the reduction of the selected accident's quantification indicator, while in the second approach (RAMS method [1], [3]) the aim is to assist towards the qualitative improvement of the initial risk level.

As seen in the chart illustrated in Figure 2, regardless from the methodology that will be followed, the correlation between interventions' cost and

anticipated safety improvement presupposes the following:

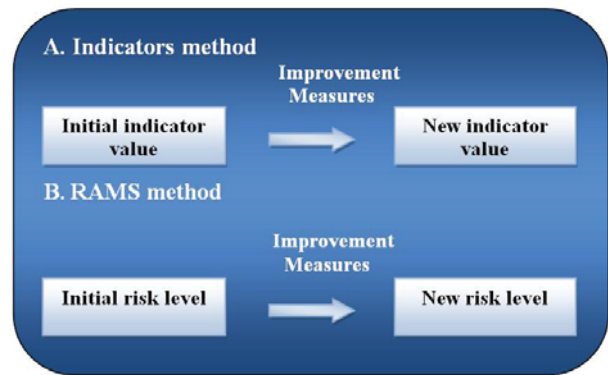


Figure 1: Approaches for the correlation between interventions' cost and anticipated safety level improvement

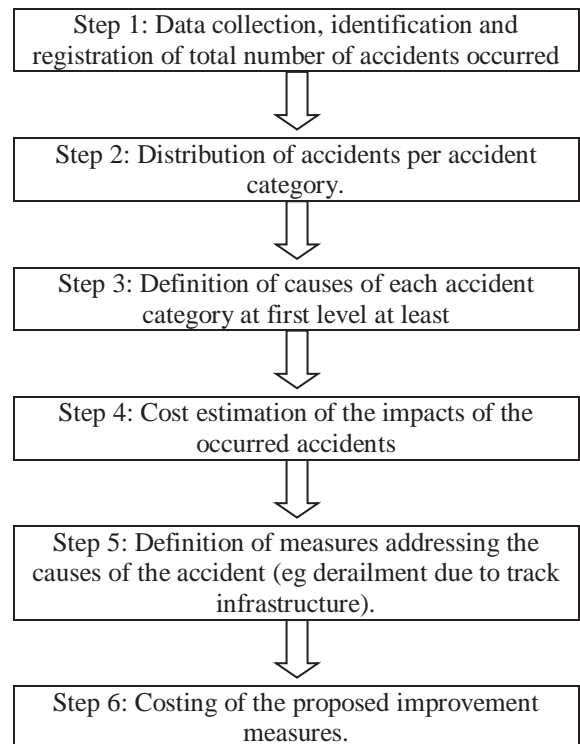


Figure 2: Proposed methodology for the correlation between interventions' cost and anticipated safety improvement – first common steps for the two (2) approaches

- Definition of the study area and, particularly, the "level" of the railway system for which accidents are assessed (e.g. whole network, railway corridor, track section, specific element of the track, rolling stock etc).
- The approach per accident category and, for each accident category, per accident cause at first level at least.

- The costing of the accidents' consequences.
- The definition of the type and magnitude of the measures to be taken. The combination of study area, accident category and accident cause will determine the relevant range of choices.
- The costing of the above measures.

Consequences of accidents include fatalities, injuries, materiel damage which covers both rolling stock and infrastructure damages, environmental damage and delays of service. The listed categories are the main costs. However, there could also be additional costs, e.g. damages of property for third party and damages to transported goods. These consequences have a monetary cost. In more detail:

The "*Fatality risk cost*": It is the value of prevention of loss of a human life assigned by the society. It is calculated based on the "price of loss prevention" and is composed of:

- The value of safety itself: Willingness to Pay (WTP) prices based on preference studies conducted at the member state where those are applied
- Direct and indirect economic cost: prices for the cost applied at the member state which are composed of:
 - ✓ Hospital and rehabilitation costs
 - ✓ Court costs, costs of police investigations, cost of private investigations, cost of emergency services and administrative insurance costs
 - ✓ Production losses: societal value of goods and services that would have been produced by a person, if the accident had not occurred.

The "*cost of severe rolling stock, track, other installations' and environmental damage*": It is the cost needed in order to restore the damaged area to its pre-accident state. It basically involves damage equivalent to €150,000 [6] or more, and is composed of:

- The cost of damage imposed on rolling stock or infrastructure: Both can be estimated by railway companies / infrastructure managers based on their experience.
- The cost of damage imposed on the environment which is composed of the following :

- ✓ Pollution caused by liquids, solids or gases
- ✓ Property damage in the area (e.g. trees swept away by moving rolling stock)
- ✓ Fires within or outside the railway premises (e.g. tree fires caused by moving rolling stock).

The costs are incurred by the railway companies / infrastructure managers in order to restore the damaged area to its state prior to the train accident. It is estimated based on experience.

The "*Cost of prolonged traffic disruption*" represents the monetary value of delays experienced by users of rail transport (passengers and customers of rail freight transport) as a result of an accident.

The "*Fatality cost*" refers to the EU average of the so-called VPF and amounting to €1,500,000. It measures the economic cost of fatalities and is primarily borne by society and the individuals concerned. The biggest component of this value represents the WTP that an individual is prepared to pay in order to reduce the fatality risk.

In order to reduce the aforementioned costs of accident impacts, various safety measures need to be adopted. The immediate application of these measures requires investment. The cost of the interventions is formed based on the type of intervention which is selected for implementation.

For example, in case of a passive Level Crossing (LC) with a high average daily traffic movement and high number of accidents, especially fatal ones, three (3) actions can be taken in order to improve safety, namely [4]:

- Improvement of the construction and operating characteristics (eg, improved vision, installation of automatic protection systems, etc.)
- Removal

This action includes the closure of a LC and the diversion of road traffic flow through the adjacent road network to the next level crossing. This action may have a negative impact on road users as it is likely to increase the journey time.

- Replacement by an overpass

This action involves the conversion of a LC to an overpass, resulting to elimination of rail accidents.

Table 2 shows indicative costs of various alternative interventions at a Passive Level Railway Crossing.

For an investment to qualify as socially profitable, the total cost of the required interventions should be lower than the benefits associated with lower accidents also taking into account impacts on road users (e.g. from higher journey times).

In order to evaluate the economic efficiency of the investment and for a given time period the cost benefit analysis method can be applied.

Table 2: costs of various alternative mitigation interventions at a passive Level Crossing [7]

Type of intervention	Installation cost (in €)	Annual maintenance cost (in €)
Installation of semi-automatic barriers at the LC	370,000	2,300-5,700
Installation of automatic barriers at the LC	570,000	2,300-5,700
Removal of the LC	50,000-70,000 (+ construction of road connection in parallel and near the track)	-
Conversion to overpass	3,200 per m ²	3,500

4. Correlation between intervention costs of interventions and safety level improvements- Indicators method

4.1 Theoretical approach

This methodology uses an indicator which, depending on the incident, can be one of the indicators proposed by ERA, such as “fatality risk indicator” or an indicator that involves the number of accidents for a specific accident category per vehicle - kilometre (e.g. number of derailments per train - kilometre, number of collisions per train - kilometre).

The correlation between the cost of interventions and safety improvement lay with the calculation of the amount of money that should be invested in order to reduce the current value of the indicator by a specific percentage or to set a new target value (i.e. the average rate applicable for EU countries for this incident category).

The first six (6) steps which are common to both approaches are followed by the steps outlined here under:

Step 7: Assessment of the impact that the intervention’s implementation has on the parameters that form the numerical expression and, as a result, the value of the indicator.

Step 8: New situation - Calculation of new indicator’s value.

Step 9: Correlation between the change in the indicator’s value and the cost of interventions.

The assessment of the impact that the intervention’s implementation has on the change of the indicator’s value is the most difficult task. It can potentially be addressed by one of three (3) ways, namely:

- By appropriate prediction models (eg the conversion of a passive LC to a guarded one with the installation of sound and visual signals and automatic barriers can reduce the number of incidents by 50 % [4])
- By recording the number of incidents that have taken place or will take place at a particular component of the railway system for at least five years after the implementation of preventive and mitigation measures and comparing them with the previous situation.
- Based on statistics from other networks with similar functionality.

4.2 Case studies

Two (2) case studies are being examined. The first one (A1) involves the case of a particular passive level crossing in a railway network which is identified as particularly problematic due to the large number of accidents that occur there. The second one (A2) involves the case of all passive level crossings of a railway network. In both cases the intervention measure chosen is the installation of automatic barriers and it is considered that the target is to reduce accidents by 50% [8].

A1: Particular passive level crossing

Incident type: Accident

Accident category: Accident at passive level crossing

Special accident category: Collision of a train with a road vehicle

Cause of accident: Railway infrastructure - Poor visibility

Used indicator: Number of fatal accidents (each with at least one fatality) hence number of fatalities in the long term of 25 years = 10 fatalities = 0.40 fatalities per year

Measure: Installation of Automatic barriers

Intervention Cost: 570,000 € (Installation of Automatic barriers) + 5,000 € (Annual maintenance cost)

Impact of measure implementation: Reduction of fatal accidents and, therefore, of the number of fatalities by 50 % [8]

New indicator' value: 5 fatalities over 25 years - 0.20 fatalities per year

Cost of fatalities: 836,000 € x number of fatalities +760,000 € per year (fixed premiums) [9].

Economic Life period of barriers = 25 years

Results of cost - benefit analysis: cost-benefit factor = 4.761069 >> 1 (25 year assessment period, 5.5 % discount rate)

A2 : Passive level crossings at railway network level

Incident type: Accident

Accident category: Accident at passive level crossing

Special accident category: Collision of a train with a road vehicle

Cause of accident: Railway infrastructure - Poor visibility

Total number of fatalities per year: 10

Number of passive level crossings = 500

Total length of track: 2,500 km

Used indicator: “fatality risk indicator” per year: Number of fatalities as a result from accidents at passive LCs per LC/track km = 0.000008 fatalities per year

Measure: Installation of 500 Automatic barriers

Intervention Cost: 570,000 € (Installation of Automatic barriers) + 5,000 € (Annual maintenance cost)

Impact of measure implementation: Reduction of fatal accidents by 50 % (i.e. 5 per year) [8]

New indicator' value: 0.000004

Cost of fatalities: 836,000 € x number of fatalities +760,000 € per year (fixed premiums) [9]

Economic Life period of barriers = 25 years

Results of cost - benefit analysis: cost-benefit factor = 0, 1846377 (25 year assessment period, 5.5 % discount rate)

5. Correlation between the cost of interventions and safety level improvement – RAMS method

5.1 Theoretical Approach

In the RAMS Method the correlation between the cost of interventions and safety improvement lays with the assessment of the money that must be invested in order to change the current level of risk of a railway

system to a lower one or to a desired level. This change can only be made by changing the frequency of accident occurrence, by altering the severity of accidents or, finally, by a simultaneous change of both.

The first six (6) steps which are common to both approaches are followed by the steps outlined here under:

Step 7: Classification of the accidents' frequency per accident category and causing source. For this process, a specific methodology is proposed in paragraph 5.1.1

Step 8: Classification of the accident's severity per accident category. For this process a specific methodology is proposed in paragraph 5.1.2

Step 9: Definition of risk level for each accident in combination with the frequency and severity, as defined in steps 7 and 8

Step 10: Assessment of the intervention's impact on the accident's frequency and severity. Classification of the new accident's frequency and severity
Step 11: New situation – Calculation of the new level of risk

Step 12: Correlation between the results of the cost - benefit analysis and the new level of risk

The RAMS method appears more problematic than the Indicators method. In particular, the problems are related to:

- The quantification of six (6) categories proposed in Table 1 regarding the frequency of incident occurrence. The key questions raised are:
 - ✓ What is the value of each frequency category, what are its measurement units and which time period does it refer to?
 - ✓ Is the value of the frequency that characterizes each frequency category the same for all accident categories?
 - ✓ Is there a distinction depending on the cause of the accident?
 - ✓ Is there a distinction depending on the category of railway system (metro, tram, high speed trains, suburban trains, etc.)?
 - The quantification of four (4) categories proposed in Table 1 regarding the severity of incidents. The key questions raised are:
 - ✓ How is each category of severity defined?
 - ✓ Do the various accident categories belong uniquely to a particular category of severity?

- The assessment of the impact that the application of specific measures have on the value of their frequency of occurrence. This assessment can be done for the three (3) measures, already outlined for the Indicators methodological approach and are the following [7]:
 - ✓ The improvement of the construction and operating characteristics (eg, improved vision, installation of automatic protection systems, etc.)
 - ✓ Removal of LC
 - ✓ Replacement of LC by an overpass

The assessment of the impact that the application of specific measures has on the value of severity of the incidents' impacts.

5.1.1 Classification of a specific accident's frequency

The quantification of frequency is a topic that remains under research. This paper attempts an approach towards it. More specifically, a methodology is proposed in order to set quantitative limits of frequency categories as listed in Table 1 for each accident category. The main indicator used in order to set the values for frequency categories is the average number of accidents per accident category which have occurred at a large number of representative networks (eg the EU countries). It is expressed in different measurement units depending on the accident category and has a specific year as a reference. The average is considered to be the value for the "Occasional" frequency category while as the values for the other categories are based on the average, by increasing or decreasing it. An indication of the recommended percentages is provided in Table 3.

Table 3: Indicative percentages that form the values for the various frequency categories

Frequency Category	Indicative percentage so as to set the values
Frequent	40% increase of the average.
Possible	20% increase of the average.
Occasional	Average number of accidents per accident category
Unusual	20% decrease of the average
Rare	30% decrease of the average
Unlikely	40% decrease of the average

Based on the above, the steps of the proposed methodology for a specific accident and for a given year are as follows:

1. Assignment of the accident to the appropriate category
2. Collection of the necessary data so as to allow for the calculation of the average number of accidents.
3. Calculation of the average for the accident's category, by using the measurement unit that corresponds to the particular accident category.
4. Setting the average as value for the "Occasional" frequency category
5. Calculation and setting of the values of other frequency categories using Table 3 for the specific accident category.
6. Determination of the accident's frequency category on the basis of the position of its average value in Table 3.

In many cases, the proposed methodology should be further specialized in order to address a particular cause of occurrence for each incident (eg derailment (incident), infrastructure (cause)).

Two (2) examples of the application of the above method for the accident categories "collisions" and "accidents at level crossings" are described in the following.

The data used for this purpose refer to railway accidents which occurred at EU level, using 2011 as reference year.

Collisions

The indicator used is the "average number of collisions per million train - kilometres". In order for this indicator to be formed, the following accident data are required:

- Number of collisions
- Number of million train- kilometres

Figure 3 illustrates the number of train collisions that occurred in Europe in 2011 [2].

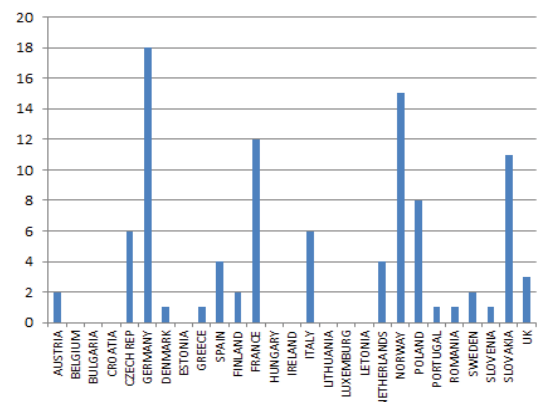


Figure 3: Number of train collisions, EU-27, 2011

Figure 4 illustrates the number of million train-kilometres for each EU country in 2011 [2].

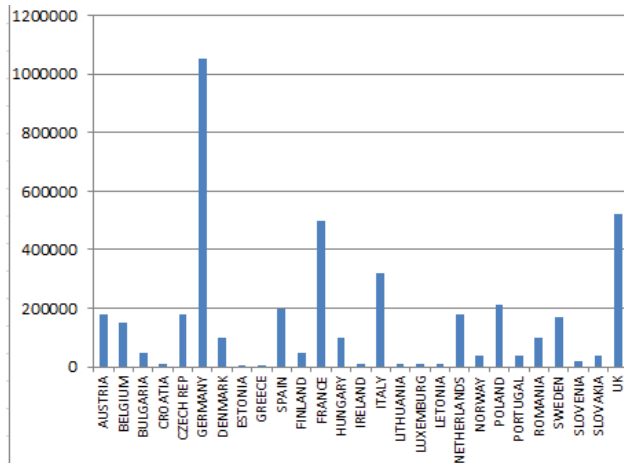


Figure 4: Number of train - kilometres, 2011

Figure 5 illustrates the number of train collisions per million train - kilometres for each EU country and the respective average in 2011 [2].

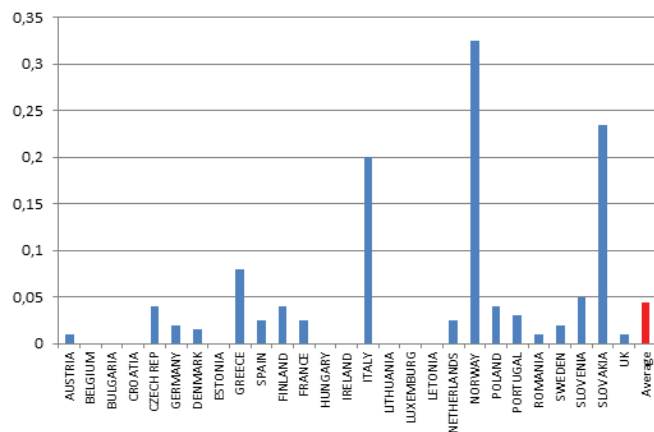


Figure 5: Number of collisions per million train-kilometres, EU-27, 2011

The average number of collisions per million train - km is equal to 0.04 which is considered to be corresponding to the “Occasional” frequency category. The values of the remaining frequency categories are formed based on the percentages defined in Table 3 and are presented in Table 4.

Table 4: Values of frequency categories for collisions per million train-km

Frequency Category	Value
Frequent	0.056
Possible	0.048
Occasional	Average = 0.04
Unusual	0.032
Rare	0.028
Unlikely	0.024

Accidents at Level Crossings (LCs)

The accident indicator used is the “average number of accidents at LCs per LC per track – km”.

In order to form this indicator, the following data are required:

- Number of accidents at LCs
- Number of LCs
- Total length of the track

Figure 6 illustrates the number of accidents that occurred at EU LCs in 2011.

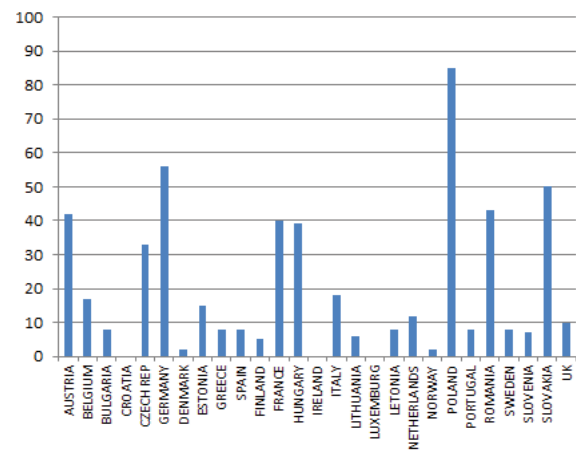


Figure 6: Number of accidents at LCs, EU-27, 2011

Figure 7 shows the number of LCs per track – kilometres for each EU country in 2011. Figure 8 illustrates the number of accidents at LCs per LC per track-km for each EU country and the respective average in 2011.

The average number of accidents at LCs per LC per track-kilometres is equal to 6.6799E-6 which is considered to be corresponding to the “Occasional”

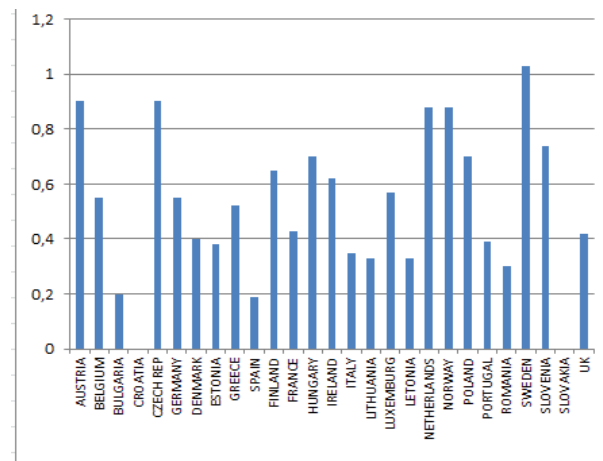


Figure 7: Number of LCs per track – kilometres, 2011

frequency category. The values of the remaining frequency categories are formed based on the percentages defined in Table 3 and are presented in Table 5.

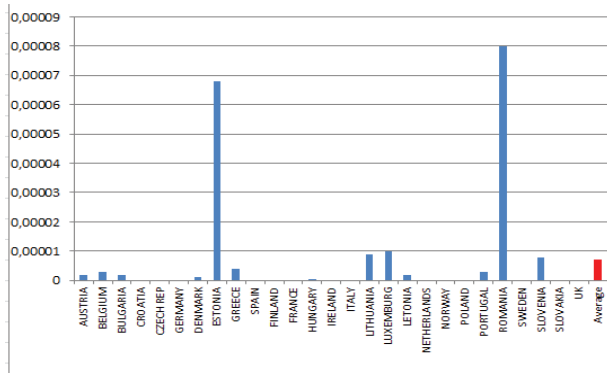


Figure 8: Number of accidents at LCs per LC per track-kilometres, EU-27, 2011

Table 5: Values of frequency categories for accidents occurring at LCs per LC per track – km

Frequency Category	Values (10 ⁻⁶)
Frequent	9.35186
Possible	8.01588
Occasional	Average = 6.6799
Unusual	5.34392
Rare	4.67593
Unlikely	4.00794

5.1.2 Classification of a specific accident’s severity

Various European studies have attempted to classify an accident’s severity while as the EU, through the Standards Committee, has introduced a common ground of reference for these efforts [1]. More specifically, it proposes the following categories of classification:

- Catastrophic: Fatalities and / or multiple severe injuries and / or severe environmental impact and / or extensive material damage.
- Severe: One (1) fatality and / or serious injury, and / or significant environmental impact, and / or limited severe material damage.
- Low severity: Light injury, and / or significant threat (or low impact) on the environment, and / or limited damage.
- Negligible: Possible light injury, and / or minor material damage.

However there is no precise definition of each category by the EU, and therefore the above classification is applied at will by initiatives of railway

safety stakeholders. Thus, according to the British Railtrack, the equivalence between fatalities and injuries is defined as follows:

- 1 fatality = 10 severe injuries
- 1 severe injury = 20 minor injuries

The EU by adopting standards and by forming the appropriate legislative framework has managed to approach some of the issues. For example: As extensive damages are considered "those for which the Accident Investigation Body can directly estimate that a minimum of € 2,000,000 are required for their restoration" (Directive 2004/49) [6].

In this paper, accident severity is approached in two (2) ways.

The first approach involves the accident category (as defined in paragraph 2) with its usual consequences. More specifically, it is considered that some accident categories have, in most cases, catastrophic consequences, such as loss of human lives. The classification of severity proposed in this research based on the accidents categories listed in Table 6.

Table 6: classification of severity based on the accidents categories

Severity Categories	Accident Categories
Catastrophic	Derailment of trains Collision of trains Level-crossings accidents
Severe	Accidents to person caused by rolling stock in motion
Low severity	Fires in rolling stock
Negligible	Other accidents

Derailments and collisions are two accidents categories which, regardless of the cause of their occurrence, in many cases, cause fatal accidents and / or multiple severe injuries and / or severe environmental impact, and / or extensive material damage, hence they are classified in the "Catastrophic" severity category. Accidents at LCs and accidents caused by moving rolling stock usually cause those impacts recorded in the "Severe" accident category, and are classified in the "Severe" category. For the same reasons, fires are classified in the "Low severity" category although in some cases their consequences can be catastrophic.

The second approach regarding severity, involves its quantification based of the actual consequences of accidents that have occurred. A key indicator in order to form the values for each severity category of each accident category is the average of their consequences

(at national level or for a set of networks). Depending on the average of their consequences, accidents are classified in one of four (4) categories, namely catastrophic, severe, low severity and negligible as already defined in the above.

5.2 Case studies

One (1) case study is examined, regarding the total of LCs of a railway network. It is assumed that the selected preventive measure results in a decrease in accidents occurrence by 50% [8].

Level Crossings (LCs) at network level

Incident type: Accident

Accident category: Accident at level crossing

Total number of accidents per year = 40

Total number of level crossings = 1,275

Total Length of track = 2,500 km

Accident frequency: Used indicator: Number of accidents at LCs per LC per track –km = $12.5E-6$ accidents per year

Classification of frequency: **Possible**

Classification of severity: Severe

Risk level: Non permissible

Measure: Installation of 500 Automatic barriers

Intervention Cost (per gate): 570,000 € (Installation of Automatic barriers) + 5,000 € (Annual maintenance cost)

Impact of measure implementation: Reduction of accidents by 50 % (4 per year)

New accident frequency: New indicator's value: $6.2743E-6$

New frequency category: Occasional

New severity category: Severe

New risk level: Non desirable

6. Conclusions

This research paper is a first attempt to provide answers in an important research field for railway companies, as many issues should be further explored. More specifically, further research shall include:

- With respect to the approach based on the change in the “risk level”: definition of the values of each frequency and severity category, for each incident and cause category
- With respect to the approach based on the indicators: selection of an appropriate indicator for each incident category (definition of indicator, measurement units)

It should be noted that it is necessary to create a database for the complete recording of statistical data regarding incidents per incident category and their causes. This tool will assist towards the direct recognition of the frequency category of a particular accident and the selection of the necessary measures.

At the same time, it is necessary to check the data so that the produced results are accurate and reliable. In order to improve safety based on the collected statistical data and the results produced based on those data, it is necessary to conduct a feasibility study prior to deciding to proceed with an investment.

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