6th Transport Research Arena April 18-21, 2016

Risk management at railroad grade crossings:
proposal for a decision support system

Christos Pyrgidis a,* Eleni Papacharitou a, Alexandros Eleftheriadis a

aCivil Engineer, MSc, Aristotle University of Thessaloniki, Civil Engineering Department, 54126, Thessaloniki, Greece

Abstract

Managing accident risk at Railway Level Crossings (RLCs) has been an important issue for both railway and highway infrastructure managers and operators. The term risk management of RLCs includes the process which is followed, the means used and measures taken in order to achieve a specific goal related to the aspect of safety of RLCs. Improvement of the safety level can be reached either by reducing the probability of having an accident or by reducing the consequences of the accidents or by their combination. Safety improvement is costly, however what is not often known is its correlation with the required cost. This paper presents a scientific “tool” for managing the safety of RLCs. A methodology is developed in order to assist the railway infrastructure managers to decide on the type and size of the interventions to be made at a level crossing of the railway network in order to improve its safety. The methodology uses the conventional evaluation indicators of the economic efficiency of an investment/project (NPV; IRR; cost/benefit ratio) as a criterion for the decision making; at the same time it enables the correlation of these indicators to the improvement of the safety level. The methodology is then applied to RLCs with specific constructional and operational characteristics. The proposed methodology may be applied in all incident categories and for various causes subject to appropriate modifications.

© 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: railway level crossings; railway accidents; risk management; accidents’ indicators; safety cost

* Corresponding author. Tel.: +00-30-2310-995795; fax: +00-30-2310-995789.
E-mail address: pyrgidis@civil.auth.gr
1. Objective of the paper & field of application

This paper presents a scientific “tool” for managing the safety of Railway Level Crossings (RLCs). A methodology is developed in order to assist the railway infrastructure managers to decide on the type and size of the interventions to be made at a level crossing of the railway network in order to improve its safety. The methodology uses the conventional evaluation indicators of the economic efficiency of an investment/project (NPV; IRR; cost/benefit ratio) as a criterion for the decision making; at the same time it enables the correlation of these indicators to the improvement of the safety level. The methodology is then applied to RLCs with specific constructional and operational characteristics. The proposed methodology may be applied in all incident categories and for various causes subject to appropriate modifications.

2. The concept of safety management at railway level crossings

The term safety management of RLCs includes the process which is followed, the means used and measures taken in order to achieve a specific goal related to the aspect of safety of RLC.

**Regarding the procedure followed:**

It includes the identification, assessment and hierarchization of risks identified in the RLC.

**Regarding the means used:**

Includes all scientific “tools”, relevant legislation and regulations, manpower, financial resources, equipment. Economic resources include money allocated by the infrastructure manager for the implementation of means/measures to improve safety, but also for equipment operation and maintenance.

**Regarding the measures taken:**

These relate to the constructional and operational characteristics of the RLC. The interventions which may alternatively occur in a RLC are essentially three (Mallet, 1987; George, 1999):

- Elimination of railway level crossings
- Grade separation of the level crossing
- Improvement of railway level crossing’s constructional and operational characteristics.

The removal of a RLC and the shifting of road traffic flow to the next – possibly level- crossing through the adjacent road, means essentially shifting the risk to the next crossing, and results to increased travel time for the road users.

The conversion of an RLC to a non-level crossing is performed by constructing underpasses or flyovers (overpasses).

Finally improving the railway level crossing’s characteristics of a RLC includes:

- conversion of the RLC from passive to active1.
- systematic maintenance of the equipment of the RLC
- upgrading of the existing equipment of an active RLC
- removal of the elements (e.g. advertising boards) that constitute potential distraction for the road vehicles’ drivers and trains’ drivers.
- installation of Closed-Circuit TeleVision (CCTV)
- installation of automatic obstacle detection system

---

1 “Passive level crossing”: level crossing without any form of warning system or protection activated when it is unsafe for the user to traverse the crossing”.  “Active level crossing”: level crossing where the crossing users are protected from or warned of the approaching train by devices activated when it is unsafe for the user to traverse the crossing.”
- improvement of the visibility conditions
- improvement of the lighting
- improvement of the pavement

A parameter that significantly influences the risk level of RLCs is the daily traffic moment\(^2\). It is included among the operational characteristics of a RLC and is the main (if not the only) criterion in many railway networks for the conversion of a passive crossing to an active one.

In figure 1, the number of rail accidents depending on the traffic moment (M) of RLCs is given:
- for the railway network of North Greece
- for the time period 2004-2013
- for a sample of 69 accidents on RLCs of which data were available
- and for various categories of protection

![Fig. 1. Railway network of N. Greece. Period 2004–2013 – number of rail accidents depending on the traffic moment and for various categories of protection of RLCs.](image)

Figure 1 shows that the number of accidents increases in accordance to the increase of traffic moment. It is worth mentioning that in RLCs with a low traffic moment (\(M < 2,000\)), a higher number of accidents is observed than in crossings with \(2,000 < M < 10,000\), because there are many unguarded crossings in this category (\(M < 2,000\)).

Figure 2 provides, for two active RLCs of the examined railway network with the same constructional features but different traffic moment:
- the total number of accidents that occurred in the decade 2004-13,
- the number of deaths and
- the number of injuries

Based on figure 2, it is concluded that the increase in traffic moment is accompanied by an increase in accidents, especially the fatal ones.

\(^2\) “Daily traffic moment”: The number of trains moving on the track in both directions per 24 hours multiplied by the number of passing road vehicles of all types in both directions of the crossing during the same 24-hour period.
Regarding the aspect of safety:
The safety that a railway system provides to its users can be defined using two approaches:

a. Definition according to the risk level

This approach suggests a qualitative assessment of safety. In the case of a railway system the term “safety” describes the guarantee, through the constituents and the components of the railway system, that during operation the risk level is not described as “non permissible”. The classification of the risk is uniquely accrued by the combination of the frequency and the severity of an event. This correlation defines the following four risk levels (Table 1).

In order to classify the various accidents according to the severity of their consequences, CENELEC European Standards adopt specific definitions (catastrophic, severe etc). 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 (Ioannidou & Pyrgidis, 2014).

b. Definition according to incident “indicators”

This approach suggests a quantitative assessment of safety. The safety which a railway system provides is evaluated by the incidents that occurred during a specific time period (e.g. one year) and had consequences on the track, the rolling stock, the passengers, the cargo and the environment.


Table 1. Risk levels based on the frequency and severity of accidents (European Standard EN50126, 2003; EC, 2009)

<table>
<thead>
<tr>
<th>Accident frequency</th>
<th>Risk Levels</th>
<th>Catastrophic</th>
<th>Severe</th>
<th>Minor importance</th>
<th>Negligible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlikely</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>Unimportant</td>
</tr>
<tr>
<td>Rare</td>
<td>Permissible</td>
<td>Permissible</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>Unimportant</td>
</tr>
<tr>
<td>Unusual</td>
<td>Non desirable</td>
<td>Non desirable</td>
<td>Permissible</td>
<td>Unimportant</td>
<td></td>
</tr>
<tr>
<td>Occasional</td>
<td>Non permissible</td>
<td>Non desirable</td>
<td>Non desirable</td>
<td>Permissible</td>
<td></td>
</tr>
<tr>
<td>Possible</td>
<td>Non permissible</td>
<td>Non permissible</td>
<td>Non permissible</td>
<td>Permissible</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>Non permissible</td>
<td>Non permissible</td>
<td>Non permissible</td>
<td>Non desirable</td>
<td></td>
</tr>
</tbody>
</table>
In order to apply the EU Directive 2004/49 for safety and its revision 2009/149/EC (EC, 2009) ERA (European Railway Agency) proposed a series of indicators (ERA, 2013) concerning railway 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.

Indicatively such indicators are:
- 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

Regarding the objectives associated with the aspect of safety:
Based on the first definition given concerning safety, its improvement lies essentially on the adoption of the appropriate measures which will enable, either by increasing the frequency only, or by increasing the severity only, or both simultaneously, to ensure a better than before risk level (e.g. from non permissible to permissible).

Based on the second definition given concerning safety, its improvement lies essentially on the adoption of the appropriate measures which will permit the reduction of a specific indicator which will obtain a lower value than a value that has been set as a target. Indicatively, taking into consideration all fatalities from railway accidents (excluding suicides), the EU “fatality risk indicator” in 2009-2011 had a value of 0.31 fatalities per million train – kilometers (ERA, 2013).

In any case, the safety management of RLCs requires the knowledge of correlation between the cost of interventions and the improvement of safety level. The quantification of this correlation is difficult because it is defined by a number of factors, whose characteristics have not been specified yet (Ioannidou & Pyrgidis, 2014).

3. The concept of safety management at railway level crossings

For the correlation between the interventions’ cost and the anticipated safety improvement two methods can be followed. These two methods are based on the two different definitions of railway safety which were given in paragraph 2. The chart of figure 3 illustrates the first six (6) steps of the proposed methodology which are common to both methods:

As seen in the chart illustrated in figure 3, regardless of the methodology that will be followed, the correlation between interventions’ cost and anticipated safety improvement presupposes the following:
- 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, railway system constituent, etc)
- The approach per accident category and, for each accident category, per accident cause at first level at least (Pyrgidis & Sarafidou, 2007)
- The costing of the accidents’ consequences
- The definition of the type and extend 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.

This paper further develops the second method (method based on the change in the value of accident indicators).
Fig. 3. Proposed methodology for the correlation between interventions’ cost and anticipated safety improvement – first common steps for the two methods.

The correlation between the cost of interventions and safety improvement lies 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 (see figure 3) 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 (number of accidents).

**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 number of accidents is the most difficult task. It can potentially be addressed by one of three ways, namely:

- By appropriate prediction models (Coleman & Stewart, 1976; Morfoulaki et al. 1994; Papaioannou et al., 2015)
- By recording the number of incidents that have taken place or will take place at a particular RLC for at least five years after the implementation of mitigation measures and comparing them with the previous situation
- Based on statistics from other networks with similar functionality (Washington & Oh, 2006; Saccomanno et al., 2006)
4. Case studies

4.1. Individual passive RLC – conversion to active RLC

Incident type: Accident
Accident category: Accident at passive RLC
Special accident category: Collision of a train with a road vehicle
Cause of accident: First level: Railway infrastructure; Second level: 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
Intervention: Improvement of RLC’ constructional characteristics
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% (Morfoulaki et al 1994)
Indicator’s new 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) (ERA, 2009)
Economic life period of barriers = 25 years
Results of cost – benefit analysis: cost-benefit ratio = 4.761069 >> 1 (25 year assessment period, 5.5% discount rate)

4.2. Individual passive RLC – conversion to overpass

Incident type: Accident
Accident category: Accident at passive RLC
Special accident category: Collision of a train with a road vehicle
Cause of accident: First level: Railway infrastructure; Second level: 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
Intervention: Grade separation of the level crossing
Measure: Construction of an overpass
Intervention cost: € 3,200,000 + € 3,500 (Annual maintenance cost)
Impact of measure implementation: Reduction of fatal accidents and, therefore, of the number of fatalities by 100%
Indicator’s new value: 0 fatalities over 25 years = 0.00 fatalities per year
Cost of fatalities: € 836,000 x number of fatalities + € 760,000 per year (fixed premiums) (ERA, 2009)
Economic life period of barriers = 25 years
Results of cost – benefit analysis: cost-benefit ratio = 1.661069 > 1 (25 year assessment period, 5.5% discount rate)
Internal Return Ratio (IRR) = 12%

4.3. Passive level crossings at railway network level

Incident type: Accident
Accident category: Accident at passive RLC
Special accident category: Collision of a train with a road vehicle
Cause of accident: First level: Railway infrastructure; Second level: Poor visibility
Total number of fatalities per year: 10
Total length of track: 2,500 km
Number of passive RLCs = 500
Used indicator: Number of fatalities as a result from accidents at passive RLCs per RLC/track-km = 0.000008 fatalities per year

**Assumption:** The accidents occur in 50 RLCs only (out of 500). Half of these (25) present a total number of 6 accidents during the 25-year period each and the rest (25) present a total number of 4 accidents each.

**Intervention:** Improvement of RLCs’ constructional characteristics

**Measure:** Installation of 50 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)

**Indicator’s new value:** 0.000004

**Cost of fatalities:** 836,000 € \(\times\) number of fatalities + 760,000 € per year (fixed premiums)

**Economic Life period of barriers = 25 years**

**Results of cost–benefit analysis:** cost-benefit ratio = 2.81 > 1 (25 year assessment period, 5.5% discount rate)

Figure 4 depicts the change of the total cost (implementation + maintenance of automatic barriers) and the benefit (reduction of deaths – Present Values in Euros) when we intervene in a growing number of RLCs.

Figure 5 depicts the change of the indicator “fatalities at passive RLCs per RLC/track – km” respectively.

![Cost-Benefit Graph](#)

**Fig. 4.** Change of the total cost and the benefit when we intervene in a growing number of RLCs.

![Fatalities per year Graph](#)

**Fig. 5.** Change of the indicator “fatalities at passive RLCs per RLC/track km” when we intervene in a growing number of RLCs.
5. Conclusions

In this paper, a procedure is developed which allows the correlation between the cost which is required for the application of measures dealing with accidents which occur within a RLC and the improvement of the level of safety as a result from their implementation. The proposed scientific “tool” may assist the railway infrastructure managers to decide on the type and size of the interventions to be made at a level crossing of the railway network in order to improve its safety.

Safety level improvement is expressed quantitatively, with the decrease of a selected safety indicator.

The application of this procedure presupposes the following:

- 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, railway system constituent, etc).
- The approach per accident category and, for each accident category, per accident cause at first level at least.
- The selection of the appropriate indicator and the fixing of its target value to obtain.
- The definition of the type and extend of the measures to be taken and mainly.
- The assessment of the impact that the intervention’s implementation has on the different terms of its mathematical expression (e.g. reduction of number of deaths).

Further research shall include:

- The creation of a database including all possible combinations: Incidents at RLCs – Incident categories at RLCs – First level cause – Second level cause – Safety improvement/consequences reduction measures – Effectiveness of the measures.
- The selection of the appropriate indicator for each incident category.
- A more accurate estimation of the measures’ effectiveness.

References