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Evaluation of the Levels of Safety at Railway Level Crossings Using Data Envelopment Analysis (DEA) Method: A Case Study on Slovenian Railways

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Abstract

Railway level crossings (RLXs) are intersections where road crosses the railway at the same level. As such, RLXs represent conflict points for accidents which include trains and road users. Improving safety at RLXs remains an important social concern within the European Union, as well as in other parts of the world. Significant past research have considered improvement of safety at RLXs focusing on relationships between vehicle accidents and geometric design and operation of road sections, accident frequency analysis, factors that cause accidents, different effects of alternative intelligent transportation systems (ITS) interventions, as well as safety benefits of countermeasures. However, relatively little research has been done on safety performance and safety evaluation at RLXs. This paper proposes Data Envelopment Analysis (DEA) method for monitoring the changes in terms of safety performance at RLXs and evaluating efficiency of railways in improving RLXs safety. In order to demonstrate the application of DEA method for enhancement of safety level at RLX, Slovenian railways are used as a case study.

*Keywords:*railway level crossings; RLX; DEA; railway;railway safety; efficiency evaluation.

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1. Introduction

Railway level crossings (RLXs) represent a weak point of railway and road infrastructure intersection as a large number of accidents take place every year. In the European Union (EU) accidents at RLXs are more numerous and account for more fatalities than fatal train collisions and derailments (Evans, 2011a). Namely, RLXs represent about 27% accidents and 28% fatalities of all significant accidents and fatalities at railway, respectively. Approximately, around 400 people die in accidents at RLXs in EU. Beside these fatalities, accidents at RLXs entail enormous human and financial cost to society. The cost of accidents at RLXs is at least 100 million EUR per year in the EU (Khoudour et al. 2009).

Within the EU there are about 1.2 million RLXs, and about five of them at every 10 line-km. In terms of equipment, half of them are active RLXs, while others are passive

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RLXs. Haleem(2016) classified RLXs as public and private. Differences between them is in the fact that private RLXs are not open to public travel or maintained by a public authority. According to Evans(2013) active RLXs involve automatic and railway-controlled RLXs. RLXs are commonly interlocked with railway signaling, so the proper functioning crossing has impact on train forward movement. Automatic RLXs are activated by the passage the trains over the track circuit without the intervention of railway staff and imply a “combination of flashing lights, audible warnings, and barriers, which operate only when a train is approaching or is on the crossing” (Evans, 2013). Railway-controlled crossing implies control of crossing operation by a member of the staff i.e. signaler or crossing-keeper. This type of crossing used to have large swinging gates, but today it has full lifting barriers, either operated by a signaler at the site, or remotely supervised by Closed Circuit Television. These are the safest crossings because they are fully protected. However, they require staff and they tend to impose longer delays on road users (Evans 2013). Passive crossings include footpath crossings that do not have ‘‘active’’ warning devices to inform the road user whether a train is approaching. This type of RLXs “consists of a static array of signs that remain unchanged at all times” (Wigglesworth, 2001) or “fixed warning signs (typically a St Andrew’s Cross or ‘crossbucks’)” (Evans, 2013).

Improving safety at RLXs is important field of research and causes concern among road and railway authority, as well as public and other stakeholders. In order to improve safety at RLXs, decision makers (DMs) may require to know the state of safety i.e. level of safety at RLXs based on safety history and know how the level of safety will change when different types of countermeasures are introduced. Although the safety at RLXs is attractive topic in literature, consideration of application of DEA method in that field is missing. Therefore, the aim of this paper is to present a new approach i.e. the application of DEA method in monitoring the changes in terms of safety performance at RLXs and evaluation of railway efficiency related to level of safety at RLXs. DEA method is employed on a case study of Slovenian railway. Beside the application on the overall railway network, this method can be used for different levels i.e. for particular RLXs.

The next section of the paper represents literature review related to RLXs. Description of DEA method and its application to the case study are illustrated in Sections 3 and 4. Section 5 presents conclusions and the plan for future work.

2. Literature Review

Literature implies papers that (i) analyze the rates of accidents at RLXs, (ii) evaluate the major factors that cause accidents at RLXs, (iii) propose and consider countermeasures for improvement safety at RLXs, as well as (iv) examine the behavior of road users according to different device systems of RLXs.

(i) Regarding the accidents, Evans (2011a, 2011) investigated the fatal accidents and fatalities from 1946 to 2009 in Great Britain. The development of railway safety in Finland from 1959 to 2008 was represented by Silla andKallberg (2012). Furthermore, the fatal train-pedestrian collisions in the Chicago metropolitan area between 2004 and 2012 were analyzed by Savage(2016). According to Evans (2011) the number of fatal accidents and fatalities per year substantially decreased from 1946 to 1975, after which it remained more constant at about 11 fatal accidents and 12 fatalities per year. The reason why fatal accidents and fatalities did not decrease in the second half of the period was the increase of the number of automatic crossings and removal of safer railway-controlled crossings on some public roads. In terms of Finland, the number of accidents at RLXs gradually decreased from the late 1960s to the mid-1990s, and increased with the rapid growth of motor vehicle fleet. The number of accidents was decreased after the removal of RLXs, "the construction of overpasses or underpasses at crossings with dense traffic" where maximum speed was over 140 km/h and "on railway sections where dangerous goods were frequently transported, the installation of barriers and the improvement of conditions such as visibility at crossings".

(ii) Understanding significant factors that affect crash injury severity at public RLXs is essential to define countermeasures to reduce deaths and injuries at these locations (Haleem and Gan 2015). Investigation of relationships between major factors that cause accidents and accidents could be found in(Austin and Carson 2002, Davey et al. 2008, Yan et al. 2010, Lu and Tolliver 2016, Haleem 2016).The factors that influence injury severity of drivers have been presented by (Hu et al.2010, Eluru et al. 2012, Hao and Daniel 2014,Hao et al. 2015, Hao et al. 2016, 2016a). The main factors that are responsible for accident could be categorized as traffic characteristics, roadway characteristics, and crossing characteristics (Lu andTolliver, 2016). Basically, all of the above papers have mentioned that crossing warning devices, highway traffic, rail traffic, maximum train speed, number of tracks, appearance of paved highway are significant factors which contribute to RLXs accident likelihood. Major factors that influence injury severity include "driver age, time of the accident, presence of snow and/or rain, vehicle role in the crash and motorist action prior to the crash" (Eluru et al. 2012). In the evaluation the mentioned factors, statistical models such as Poisson models, negative binomial (NB) regression model as a special case of Poisson, 'zero-inflated' Poisson model, gamma probability model, Conway–Maxwell–Poisson (CMP) model, Bernoulli distribution model, hurdle Poisson model, were used.

(iii) In order to improve the level of safety at RLXs, the literature has proposed countermeasures and examined their effects. Washington and Oh (2006) have evaluated the safety benefits of countermeasures and illustrated it on 18 countermeasures. The top three performing countermeasures for reducing accidents are in-vehicle warning systems, obstacle detection systems, and constant warning time systems. According to Saccomanno et al. (2007) the strongest countermeasure effect in reducing RLXs "is an upgrade in warning device from 2- to 4-Quadrant Gates and the installation of Photo/Video enforcement", while the weakest is "introduction of yield signs ahead" of RLXs. Silmon and Roberts (2010) have presented potential benefits of introducing obstacle detection system on automatic half-barrier level crossing (AHB) and overall improvement safety at RLXs. In order to reduce accidents at RLXs Salmane et al. (2014) have implemented intelligent video surveillance system with automatic recognition and evaluation of potentially dangerous situations at RLXs in both cases - open and closed barriers. Moreover, decision support system (DSS) (Forgionne 2002), Adaptive Neuro Fuzzy Inference System (ANFIS)(Ćirović and Pamučar 2013), and cost and benefit analysis(Rezvani et al. 2015) have been proposed as tools for identification, selection and prioritization RLXs for upgrading in order to increase their level of safety.

(iv) Drivers' behaviour is one of the major accident factors at RLXs (Tey et al. 2011). Examination of effectiveness of warning devices at RLXs to drivers' behaviour is presented in (Meeker et al. 1997, Wigglesworth 2001, Lenné et al. 2011, Tey et al. 2011, Tey et al. 2013, Tey et al. 2014, Laure et al. 2015). All the papers conclude that RLXs with active protection have lower crash risks than those with passive protection.

3. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a linear programming based method for efficiency measurement based on Farrell(1957) original work that was later popularized by Charnes et al. (1978). DEA is a non-parametric approach, which means that input-output function does not have to be assessed. DEA is used for evaluating performance of comparable set of units able to transform multiple inputs into multiple outputs. Relative efficiency of decision making units (DMUs) is measured against DEA efficient frontier which is formed as piecewise linear combination that connects the set of best practice observations of the examined sample. Hence, DEA method is used for evaluating sufficiency of similar DMUs. This method offers DMs information on efficient and non-efficient DMUs. Additionally, the method does not require prior definition of weights of criteria for input and output by DMs, as all weights are determined after solving DEA model, which eliminates subjective decision-making. A major stated advantage of DEA is that it does not require any prior assumptions on underlying functional relationships between inputs and outputs. The basic CCR (Charnes, Cooper and Rhodes) model, i.e. traditional DEA model has been design by Charnes et al. (1978). Since the beginning of DEA method study, various different models have been proposed (Cooper et al. 2006) in addition to basic CCR model such as Banker, Chames and Cooper (BCC) model, additive model, a slack-based measure of efficiency, Russell measure models. DEA method has been extensively applied in various fields of economics. However, it has not been used in safety measurement and related fields.

Assuming that there are n DMUs, m outputs and s inputs, efficiency score is usually calculated based on one of the basic DEA models, Charnes, Cooper and Rhodes (CCR) DEA model (Cooper et al. 2006), and for our purpose we have used input oriented CCR dual problem of linear programming that can be written as:

$$\begin{gathered} \min \theta \\ s.t\ X\lambda \leq \theta x_i, (1) \\ Y\lambda \geq y_i, \\ \lambda \geq 0 \end{gathered}$$

The dual problem of linear programming is different from primal in terms of variables and constraints. In the model (1), X and Y represent set of vectors of inputs and outputs, respectively. θrepresents indicator of technical efficiency where $\theta \in [0,1]$ and indicates how much evaluated entity could potentially reduce its input vector while holding the output constant. The presented CCR model exhibits the constant returns to scale (CSR), but with additional constraint $\sum \lambda = 1$, CCR model becomes the classical BCC model that allows variant to return to scale (VRS) (Banker et al. 1984).

4. Case Study

Input oriented CCR DEA model is applied to the evaluation efficiency of Slovenian railway in terms of level of safety at RLXs for the period from 2001 to 2013. The above presented CCR model is conducted based on the selected inputs and outputs (**Errore. L'origine riferimento non è stata trovata.**) with the *Excel Solver*. Since the selection of inputs and outputs is a heavy task, it is based on the critical factors that contribute to accidents, mentioned in Section 2.

Table 1:Variables employed in CCR model.

Inputs/Outputs	*Unit*	*Source of data*
Number of railway level crossings	Number	Slovenian Traffic Safety Agency
Number of assets	Number	Statistical Office of the Republic of Slovenia
Railway passenger volume	Million passenger-kilometer	Statistical Office of the Republic of Slovenia
Railway freight volume	Million tonne kilometer	Statistical Office of the Republic of Slovenia
Number of accidents at RLXs	Number	Slovenian Traffic Safety Agency

Source: Authors

Actually, the selected inputs are number of RLXs and number of assets at Slovenian railway, as well as number of accidents at RLXs (**Errore. L'origine riferimento non è stata trovata.**). Number of RLXs implies the total number of passive and active RLXs at Slovenian railway and present potential site/place of accidents (Lu and Tolliver, 2016), while due to the lack of data for number of trains at network that influence accidents at RLXs (Hu et al. 2010), the number of assets represents the number of locomotives and railcars under assumptions that have been used for forming garniture of trains. It should be noted that, due to unavailability of data related to roadway characteristics such as volume of road traffic, our evaluation is based only on railway viewpoint i.e. railway data.

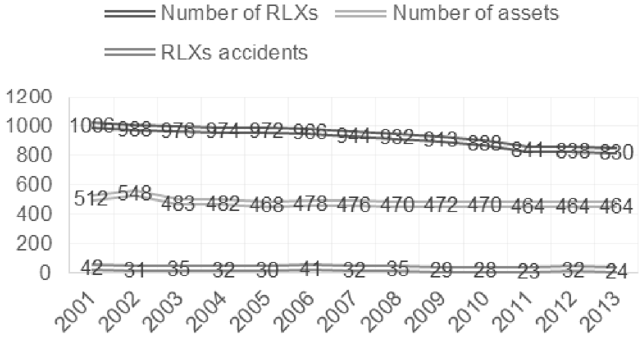

Figure 1: Inputs used in CCR model.
Source: Authors

The railway passenger volume and the railway freight volume at Slovenian railway represent the *outputs* for CCR DEA model (Figure 2). These volumes of realized kilometers are helpful for consideration because DMs are able to detect the best practices (i.e. year) which have the lowest range of accidents for the given level of volume of transport. The data used for conduction of CCR model are from Statistical Office of the Republic of Slovenia [1] and Slovenian Traffic Safety Agency (Prometa, 2014).

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[1] http://pxweb.stat.si/pxweb/Database/Ekonomsko/Ekonomsko.asp#22

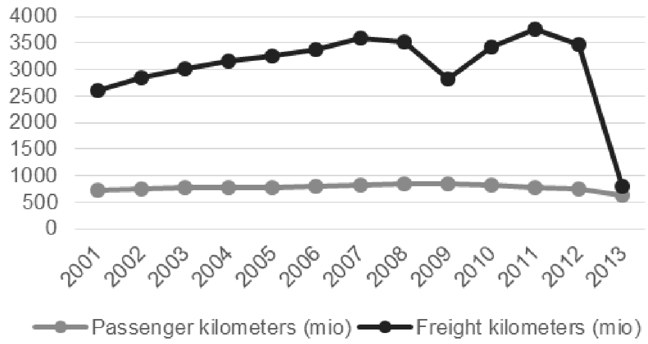

Figure 2: Outputs used in CCR model.
Source: Authors

The results of efficiency of Slovenian railway related to the level of safety at RLXs for selected time period could be seen in Figure 3. Slovenian railway was the most efficient between 2008 and 2011. Before and after that period the efficiency of Slovenian railway was lower. After considering the used data, it could be seen that the values of all input variables decreased for the given level of transport volume (i.e. passenger and freight kilometers) in the period 2008-2011. This resulted in exceptional efficiency of Slovenian railways regarding the level of safety at RLXs.

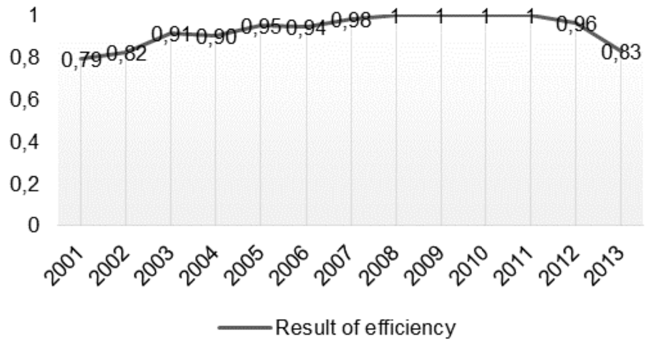

Figure 3: Results of efficiency of Slovenian railway related to level of safety at RLXs.
Source: Authors

5. Conclusions

This paper was focused on the suggestion of using DEA method for the evaluation of railway efficiency in terms of the level of safety at RLXs. Input-oriented CCR DEA model was used for evaluation of efficiency of Slovenian railway in terms of level of safety at RLXs. The results of efficiency for level of safety at RLXs were represented for the period from 2001 to 2013. The evaluation of level of safety at RLXs was conducted with relevant inputs and outputs. After the application on a case study, conclusion is that CCR model can be used for the evaluation of efficiency regarding this and similar purposes. The advantage of this approach is that it requires no assumptions and enables adding the necessary limitations, all in accordance with research requirements. Based on that model, DMs could be able to find the best practices i.e. year for which the railway has been most efficient. Slovenian railway was the most efficient from 2008 to 2011. Moreover, CCR DEA model could be observed as useful technique and used for evaluation of efficiency of particular RLXs and some countermeasures before and after implementation. Furthermore, in case of data availability, CCR model could be employed for evaluation which involves different inputs and outputs that represent factors which cause accidents at RLXs.

Evaluation in this paper is based only on railway viewpoint i.e. data for railway transport. Due to data unavailability, the limitation of this paper is in the fact that characteristics of roadway, such as roadway volume, is not considered. Therefore, the proposal for future work implies evaluation of the level of safety at RLXs with roadway transport data. Moreover, consideration of some variables as undesirable factors in evaluating efficiency of railway regarding the level of safety at RLXs with DEA method, could be a part of future work.

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