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Evaluation of Safety Performance of Level Crossings in Turkey with Data Envelopment Analysis

(Penilaian Prestasi Keselamatan Lintasan Kereta Api di Turki dengan Analisis Penyampulan Data)

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ABSTRACT

Level crossing, also known as railroad and highway crossings, pose a risk to those who use both modes of transport due to collisions that may occur. This risk associated with level crossings is of great importance both in Turkey and in the world. In this study, data envelopment analysis was performed on the accident data occurring on five types of level crossings in Turkey and a measurement of safety performances of level crossings in Turkey was provided. As a result of the analysis, the most efficient three-level crossings were found to be Hilal-Bandırma in Manisa, Samsun-Kalın in Amasya_1, and Samsun-Kalın in Amasya_2. In addition, a linear regression model that serves with the variables which are the components of level crossing and the number of accidents is established. In this model, it is seen that the ratio of independent variables to dependent variables was statistically significant.

Keywords: Accident; data envelopment analysis; level crossing; safety performance

ABSTRAK

Lintasan kereta api, juga dikenali sebagai landasan kereta api dan lintasan lebuh raya, dapat menimbulkan risiko kepada mereka yang menggunakan kaedah pengangkutan ini atas sebab wujudnya kemungkinan pelanggaran yang akan berlaku. Risiko ini dikaitkan apabila lintasan kereta api adalah amat penting bagi negara Turki dan dunia. Daripada analisis kajian ini, analisis penyampulan data dijalankan pada data kemalangan yang berlaku pada lima jenis lintasan kereta api di Turki dan satu ukuran prestasi keselamatan lintasan kereta api di Turki telah disediakan. Hasil analisis menunjukkan terdapat tiga kaedah yang didapati paling cekap dalam lintasan kereta api iaitu Hilal-Bandırma di Manisa, Samsun-Kalin di Amasya_1 dan Samsun-Kalin di Amasya_2. Sebagai tambahan, model regresi linear telah dihasilkan yang mempunyai beberapa pemboleh ubah komponen lintasan kereta api dan jumlah kemalangan. Model ini memperlihatkan bahawa julat pemboleh ubah tidak bersandar kepada pemboleh ubah bersandar daripada statistik adalah amat ketara.

Kata kunci: Analisis penyampulan data; kemalangan; lintasan kereta api; prestasi keselamatan

INTRODUCTION

The level crossing can be defined as the field which is located at the intersection of a railway and a highway. The accidents in the level crossing not only cause many deaths and injuries but also lead to disruption in both modes of transport. This failure also brings some financial losses. Many academic studies have been carried out in diverse fields such as social sciences, cultural studies, economics, and engineering, with the aim of preventing accidents in level crossings. In order to prevent accidents in the level crossings, first of all, the background of risks must be determined. In a study conducted by European Railway Agency (ERA), after determining the railroad lines and the number of level crossings on these lines, the mortality rates at the level crossings were determined for European countries. The results indicated that Ireland was the lowest-level risk country with the eleven per billion and Greece was the highest-level risk country with the five hundred and fifty per billion. Such studies play an important role in determining the accident risk root causes (ERA 2014). Although the determination of the risk background is very important, each region has its own specific risk parameters. The risk assessments based on accident risk parameters have been tried to be estimated by mathematical models and some statistical methods (Ghazel 2009; Liang et al. 2018). Based on the accidents in level crossings, a financial simulation study was carried out for a more secure level crossing and it was stated that there is a financial loss of

110 million Euros per year for the accidents occurring at the level crossing (Khoudour et al. 2009). In addition, it has been stated that 90% of level crossing accidents occur in rail freight and passenger transportation. These statistical data on level crossing have not only attracted the attention of transport authorities but have also become the focus of several academic studies (Djordjević et al. 2018).

Considering these information and related studies, it can be seen that the analysis of the accidents occurring at level crossings can be performed by data envelopment analysis (DEA) method. DEA is a nonparametric method that evaluates multiple inputs and outputs simultaneously. An extensive bibliography of the DEA has been provided by Liu et al. (2013). This method has been applied in various fields in Turkey. One of these studies aimed to determine the port capacity efficiency at seven ports connected to the Turkish State Railways (TCDD) by determining the efficient and inefficient ports, and offered suggestions for inefficient ports (Baysal et al. 2004). In this study, the safety performance of level crossings in Turkey is evaluated by DEA with six inputs and an output.

MATERIALS AND METHODS

DATA ENVELOPMENT ANALYSIS

Data envelopment analysis (DEA) can be defined as the ratio of the output to the input in the simplest way, it can also be defined as the efficient use of the resources. Any sample including team players, ports, logistics centers, and European countries, are determined as a decision-making unit (DMU).

The main objective of DMUs is to reach the maximum output value with the existing inputs. When this situation is considered in terms of academic studies, every engineering phenomenon that has input and output can be the subject of DEA. The DMU may contain some abstract data or concrete data. Regardless of the type of data, according to the performance criteria determined by DEA, in terms of the event of interest, a frontier is established by determining the best in practice. This is called as the efficiency frontier, and other DMUs are evaluated according to this frontier. Thus, the DMUs are divided into two groups as efficient and inefficient. The results obtained here provide the advantage of suggesting inefficient DMUs to be efficient. With the DEA, it is possible to calculate the change in the efficiency of DMUs over time in a certain period, thus enabling dynamic evaluation. The first model, which was the basis for this analysis, was proposed by Charnes et al. (1978), and the model was named the CCR (Charnes, Cooper, Rhodes) model by combining the first letters of the names of the scientists who proposed the model. Since then, a great number of studies have been carried out on DEA. Some of these studies consist of the elimination of the problems arising from the model, adaptation to other methods or innovations within the model. These examples are Acarlar et al. (2014), Bal al. (2010), Banker et al. (1984), Fare et al. (1996), Lovell and Pastor (1999), Malekmohammadi et al. (2010), Olesen and Petersen (1995) and Thanassoulis and Dyson (1992). Besides, the application studies in the literature of DEA are of great importance and the application area of DEA is very wide. DEA can be applied in fields where there is at least one of the inputs or outputs, such as education, health, sport, judiciary, energy, and finance. A few examples of the application studies mentioned are Alp (2006), Avkiran (2001), Bal and Gölcükcü (2002), Cui and Li (2015), Fare et al. (1995), Ray (1991), and Sözen et al. (2010).

The CCR model (1), which forms the basis of the DEA methodology and whose number of studies increases per year, has been given herewith. This model assumes constant return to scale. This is because the efficiency frontier obtained by the model is fixed slope.

$$\max vy_o \tag{1}$$

$$\begin{aligned} ux_o &= 1 \\ uY - vX &\leq 0 \\ v,u &\geq 0 \end{aligned}$$

x_o is the input of the o. DMU, y_o is the value of the o. DMU output. While v corresponds to the outputs, u corresponds to the inputs. This model is also called the multiplicative form. The dual of the model given in (1) is as follows and this model is also called enveloping form.

$$\min \theta \tag{2}$$

$$\begin{aligned} \theta x_o - X\lambda &\geq 0 \\ Y\lambda &\geq y_o \\ \lambda &\geq 0 \end{aligned}$$

θ, is the efficiency score belonging to o. DEA, X and Y are the input and output matrices, x_o and y_o are the input and output vectors that belong to o. DEA, and the λ is the weighting vector.

According to model (2), if o. DMU provides to conditions $\theta = 1$, $\lambda_o = 1$ and $\lambda_j = 0(j \neq o)$, it is classified as efficient. Each DMU providing all these conditions is considered efficient. Also, the model is given in model (2) is called input-oriented CCR model. This model achieves efficiency scores of DMUs with minimized inputs while outputs are fixed. Another case for the CCR model is output-oriented. In contrast to the input oriented CCR model, the inputs are kept constant and the outputs are maximized. In model (3), the output oriented CCR model is given.

$$\begin{aligned} &\max \eta \\ &x_o - X\mu \geq 0 \\ &\eta y_o - Y\mu \leq 0 \\ &\mu \geq 0 \end{aligned} \tag{3}$$

where $\mu = \lambda/\theta$ and $\eta = 1/\theta$. The efficiency frontier obtained by the CCR model is a line that passes through the origin.

Accordingly, the DMU on the efficiency frontier is efficient. The region below the efficiency frontier is called the production likelihood cluster, and all of its inefficient DMUs are included in this cluster. In other words, since the efficiency frontier, on which the efficient DMUs are located, is enveloping all other inefficient DMUs on the outside. The term enveloping has been used and the general name of the method is called data envelopment analysis. Based on this model, the other basic model of the DEA methodology is the BCC model. This model by Banker et al. (1984), which is proposed by combining the initials of the authors' names, allows variable returns to scale. The reason for this is that the efficiency frontier created by the model has a variable slope. Input-oriented BBC model and output-oriented BBC model are given in (4) and (5), respectively.

$$\begin{aligned} &\min \theta \\ &\theta x_o - X\lambda \geq 0 \\ &Y\lambda \geq y_o \\ &\sum \lambda = 1 \\ &\lambda \geq 0 \end{aligned} \tag{4}$$

$$\begin{aligned} &\max \eta \\ &y_o - Y\lambda \leq 0 \\ &X\lambda \leq x_o \\ &\sum \lambda = 1 \\ &\lambda \geq 0 \end{aligned} \tag{5}$$

The number of efficient DMUs obtained with the BCC model is greater than or equal to the efficient DMU number obtained with the CCR model. Apart from CCR and BCC efficiency, another type of efficiency encountered in application articles is scale efficiency. This is achieved as a ratio of the CCR efficiency score to the BCC efficiency score.

RESULTS

Some of the studies carried out in the field of transportation are composed of DEA studies. Karlaftis (2004) examined the efficiency of urban transportation and used labor, fuel, and capital variables as inputs; passenger miles and passenger boarding variables as outputs. Von Hirschhausen and Cullmann (2010) also analyzed the activities of public transport companies in Germany by using labor and busses as input variables, and seat kilometers or bus kilometers as output variables. Sampaio et al. (2008) investigated public transport systems activities in Brazilian and some European cities by using the number of passengers transported as input variables. Karlaftis and Tsamboulas (2012) evaluated the efficiency of fifteen European transport systems for ten years by using vehicle-miles, passenger miles or passenger boarding as input variables of labor, fuel and capital. Boame (2004) examined the fleet by using vehicle kilometers, passenger kilometers and network kilometers as the input variable for the efficiency of Canada city transportation systems.

It is possible to give more examples of similar works. Besides, there are studies evaluating the efficiency of facilities such as port and airport. Unlike the studies given previously, Djordjević et al. (2018) evaluated the DEA model and the safety level of the railway level crossing in the EU as an input-output variable using the number of railway level crossings, number of assets, railway passenger volume, railway freight volume and number of accidents at RLCs. In this study, the safety performance of the level crossings for seven regional offices connected to TCDD is evaluated by DEA method. Here, six inputs including Flight Momentum (FM), Train Sight Distance (TSD), Vehicle Sight Distance (VSD), Aperture (A), Skew Angle (SA) and Railway Slope (RS) and one output, Number of Accidents (NA), are used as variables.

THE DEFINITIONS OF INPUTS AND OUTPUT OF THE LEVEL CROSSING

Flight Momentum It is defined as the number obtained by multiplying the annual average daily value of the number of trains passing through the railway level crossing in the last year and the annual average daily traffic value of the number of road vehicles (U.S. Department of Transportation).

Train Sight Distance The minimum distance from the railway vehicle to the level of the level crossing from both directions must be 750 m (Figure 1).

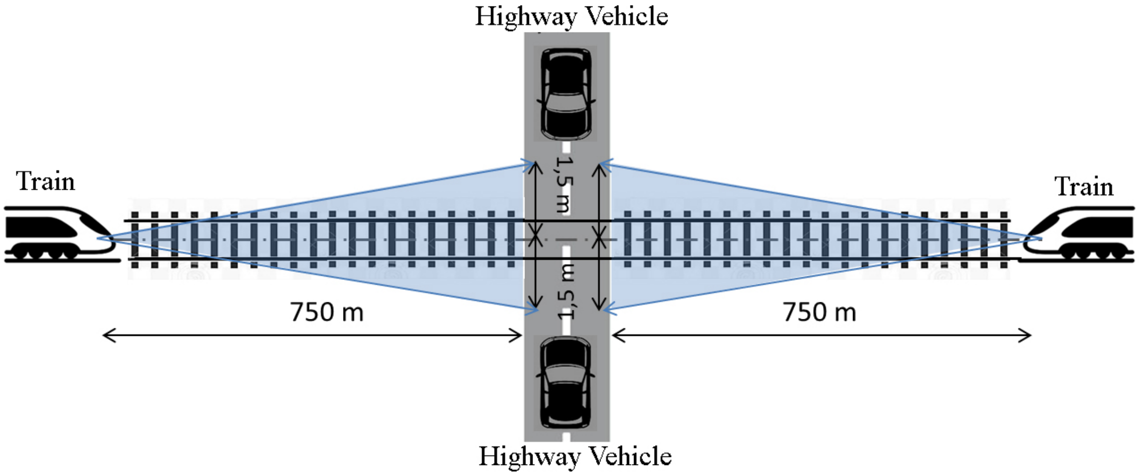

FIGURE 1. Railway sight distance

Vehicle Sight Distance The distance from the highway car to the railway is five meters away and the distance of both sides of the railway should be at least 500 m (Figure 2).

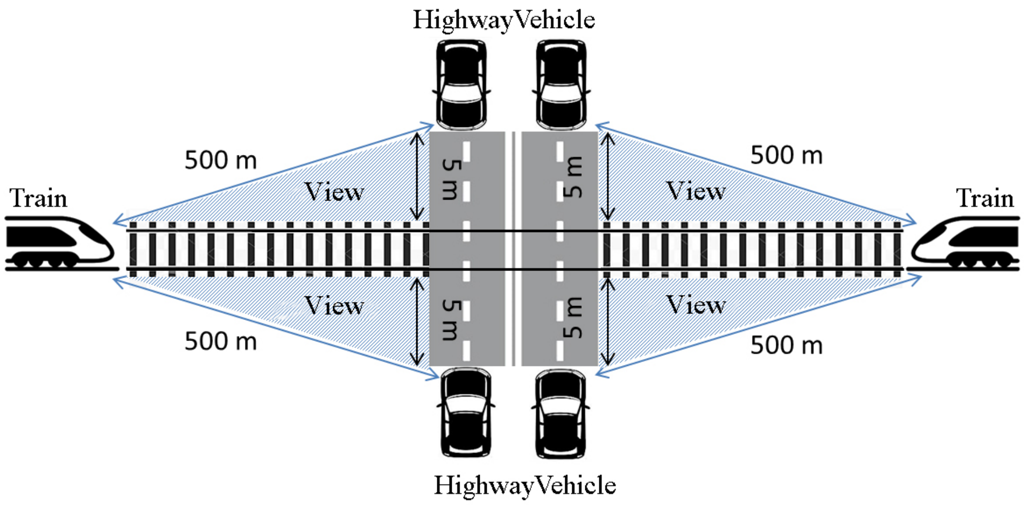

FIGURE 2. Vehicle sight distance

Skew Angle The intersection angle of the vehicle road and railway is less than 70 degrees and the angle of intersection is greater than 110 degrees (Figure 3).

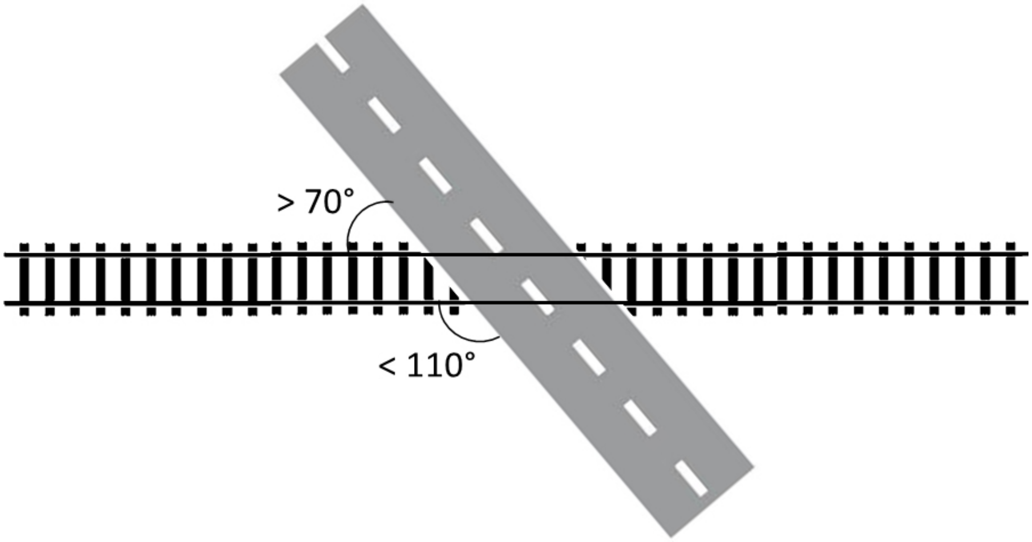

FIGURE 3. Skew angles

Railway Slope It is the value of the slope of the railway where the level crossing is located.

Aperture Identifies the width of the highway on the railway.

RESULTS

Descriptive statistics for the variables used are presented in Table 1.

TABLE 1. Descriptive statistics of the variables

	Minimum	Maximum	Mean	Std. Deviation
NA	.33	1.00	.95	.15
FM	5.00	690,000.00	27686.72	83315.29
TSD	.00	2,00000	493.72	363.74
VSD	.00	1.500.00	344.44	312.27
A	2.00	35.00	7.19	5.18
SA	40.00	90.00	84.62	10.56
RS	.00	29.00	5.37	5.34

Super efficiency scores of the CCR model are applied for 180 level crossing of 5 types (Type 1: Guarded barrier, Type 2: Automatic barrier, Type 3: Flasher + banner + barrier-free, Type 4: Free (cross-signed) and Type 5: Flasher + belled automatic + barrier). In Table 2, only the efficiency scores of the efficient DMUs are given. According to this, the three most efficient levels are Hilal-Bandırma in Manisa, Samsun-Kalın in Amasya_1, Samsun-Kalın in Amasya_2. Super efficiency scores for inefficient DMUs are not included here because the table is too large.

TABLE 2. Super efficiency scores

Rank	Efficiency score (%)	Region	Railway line	Province
1	Big	3	Hilal-Bandırma	Manisa
1	Big	4	Samsun Kalın	Amasya_1
3	4,000.00	4	Samsun Kalın	Amasya_2
4	777.78	3	Manisa-(Dumlupınar)Afyon	Manisa_1
5	640.00	6	Gaziantep - Karkamış	Gaziantep
6	480.10	6	Adana - Toprakkale	Adana
7	250.55	7	Manisa(Dumlupınar)-Afyon	Afyon
8	200.57	5	Narlı-Malatya	Adıyaman
9	178.71	4	Kayseri Hudut	Erzincan
10	173.94	4	Kayseri Hudut	Erzurum
11	161.02	4	Kayseri Hudut	Kars
12	154.23	7	Enveriye-Konya	Konya
13	145.43	3	Hilal-Bandırma	Balıkesir
14	143.76	1	Pehlivanköy-Kapıkule	Edirne
15	141.70	6	Sudurağı – Ereğli	Karaman
16	141.58	5	Malatya-Diyarbakır	Malatya
17	136.37	6	Fevzipaşa – Narlı	K.Maraş
18	131.91	5	Narlı-Malatya	K.Maraş_1
19	126.32	7	Alayunt-Balıkesir	Balıkesir
20	123.14	7	Goncalı-Eğirdir	Isparta_1
21	121.80	7	Goncalı-Eğirdir	Isparta_2
22	120.00	4	Samsun Kalın	Amasya_3
23	114.58	3	Manisa-(Dumlupınar)Afyon	İzmir
24	114.16	4	Samsun Kalın	Samsun
25	112.23	3	Manisa-(Dumlupınar)Afyon	Manisa_2
26	111.66	3	Manisa-(Dumlupınar)Afyon	Uşak
27	111.06	2	Irmak-Zonguldak	Karabük
28	110.99	5	Malatya-Çetinkaya	Malatya
29	109.86	2	Irmak-Zonguldak	Çankırı
30	107.92	7	Alayunt-Balıkesir	Kütahya
31	102.75	5	Narlı-Malatya	K.Maraş_2

The mean efficiency score for 180 level crossing was 73.79. The minimum efficiency score is 24.6.

TABLE 3. The distribution of the efficiency type of the level crossing

Type of level crossing	Number of level crossing	Percentage of level crossing	Number of efficient level crossing	Percentage of efficient level crossing
Type 1	15	0.08	4	0.13
Type 2	45	0.25	9	0.29
Type3	24	0.13	2	0.06
Type 4	83	0.46	16	0.51
Type 5	13	0.07	0	0.00
Total	180	1.00	31	1.00

According to Table 3, 31 of the 180 level crossing passages are found to be safe. 0.08 of the level crossing are Type 1 and 0.25 is Type 2. 0.51 of Type 1 and 0.29 of Type 2 are efficient in terms of safety. In addition, 0.27, 0.20, 0.08, 0.19, and 0.00% of Level 1-2-3-4-5 level crossing were found to be efficient, respectively. From this point of view, it is possible to conclude that the most ideal type for safety is Type 1 and the non-ideal type is Type 5. The efficiency frontier obtained by the CCR model is a line in the first region that passes through the origin in the coordinate plane. Both CCR and BCC models are linear programming models. Therefore, to support the accuracy of the established CCR model, the number of cases were used in the model (output) as dependent variable, and flight momentum, train sight distance, vehicle sight distance, skew angle, aperture, and slope (inputs) variables were carried out as non-constant linear regression analysis. With this analysis, the *p-value* obtained from the F test, which examines the model significance, was found to be 0.00 and the model was interpreted as meaningful. Also, the R^2 value of the dependent variable was found to be 0.92. This value shows that the model is quite proper. In addition, the efficiency scores obtained from the CCR model and the correlation values of the other variables used in the model are given in Table 4.

TABLE 4. Correlation coefficients between efficiency scores (ES) and variables

	NA	SM	TSD	VSM	A	SA	RS
ES	.600**	-.226**	-.322**	-.240**	-.307**	-.234**	-.101

**Correlation is significant at the 0.01 level

According to Table 4, there is a significant relationship between ES and other variables RS, FM, TSD, VSM, A, SA are negatively correlated, the NA is also positively related and has the highest relationship among them. Here, the positive correlation between NA and ES is interpreted as follows: when the ES value increases, NA value increase, as well. However, this interpretation contradicts the established model. The reason for this is that the NA values are taken to the CCR model by 1 ratio.

Conclusion

In this study, the safety level of 180 level crossings located in the 7 regions of Turkey with 5 different types were analyzed by DEA method, and the efficient and inefficient level crossings were determined. Super efficiency scores were also calculated to rank among efficient level crossings and are given in Table 2. In this way, the safety of the existing level crossings was compared relatively. This exemplifies some sort of information on the application studies for the safety level of the level crossings. Besides, to be efficient, DEA and inefficient level crossing should be informed about which variable should be changed. Because the subject of the study is to compare the safety levels of the existing level crossings, the study does not serve such kind of identification. This can be the subject of another study. In this study, a model which analyzes the components of level crossings, the number of accidents and the performance of the ground passages was employed. However, the data used here consists of an annual data of a three-year interval of a grade crossing. By keeping the recorded data for years of all levels, or any period, or for a data set held in this way, the time-dependent variation of the security activity may also be obtained. In addition, panel data analysis can be performed in case of the required number of period data. This will allow for a more detailed analysis of the safety situation analysis of the intersection of the road and railroad as well as level crossings.

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