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Preliminary communication

Safety Calculation Model of Grade Crossings with Automatic Barrier System

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Abstract: Rail transportation systems are among the types of transportation that are used extensively for reasons such as transportation safety and efficient structure. One of the most important parameters in rail transportation systems is the infrastructure systems used. Infrastructure systems used in areas where rail system lines intersect with highway systems can be listed as underpasses, overpasses, and grade crossings (GC). Although their use is risky, grade crossings continue to be used because underpasses and overpasses cannot be established for all intersections. Among the grade crossings, automatic barrier grade crossings appear as the safest structures. When grade crossings with automatic barriers are examined, it is observed that different parameters affect safety, and it is possible to make predictions for crossing safety. It has been observed that basic grade crossing features, location, physical structure, human and environmental factors, and signboards are effective while performing the safety assessment. In this study, the safety calculation model created for the safety calculation of grade crossings with automatic barriers has been transferred.

Keywords: automatic barrier system; grade crossing; rail systems; safety calculation; safety calculation model

1 INTRODUCTION

With the development of transportation, rail transportation systems and highway systems have started to use common ways. These common ways are called grade crossings. The ways to serve rail transportation systems basically consist of infrastructure and superstructure systems. Grade crossing: It consists of guarded-barrier grade crossings, automatic barrier system grade crossings, and uncontrolled (free) grade crossings [1]. Grade crossings are areas that directly affect the safety of property and life and where serious accidents can occur [2]. In this respect, many studies are carried out in the world and in our country to ensure the safety of grade crossings. Due to the problems that may be experienced using the grade crossings, they are kept as small as possible and transportation with the lower and overpass structures is tried to be provided. Grade crossings continue to be used due to the costs and implementation difficulties of underpasses and overpasses [3].

To ensure safety in grade crossings, a complex structure with many components should be created [4, 5]. While calculating a grade crossing safety, the physical location, the interaction of the railway and the highway, the warning and warning signs to be used, and the level of awareness are examined [6-13]. While determining the grade crossing types to be established, train speed (v < 120 km/h, 120 km/h < v < 160 km/h, v > 160 km/h) and cruising moment value (the number of trains passing through the daily grade crossing multiplied by the number of road vehicles) are considered.

During the implementation of grade crossings, various standards, arrangements, application models and reports have been published by different institutions to explain certain basic situations [14-22]. In our study, the models examined and the safety calculation model for the grade crossing with automatic barrier applied in Turkey will be transferred. The safety calculation model will be evaluated under 5 different subheadings.

2 METHOD

In this section, the details of grade crossings, which are an important infrastructure system in rail transport, will be explained. The factors affecting safety at grade crossings and the safety calculation model will be explained.

2.1 Grade Crossing

Infrastructure systems include all kinds of studies to ensure the safe course of the existing natural floor structure of the rail system vehicle. Infrastructure systems consist mainly of tunnels, bridges, passages and support structures [23]. At the intersection of the railway with the highway, the structures that provide passage from one side to the other are called passages. In the railways, underpass, overpass, and grade crossing structures are provided [24]. They consist of guarded-barrier grade crossings, automatic barrier system grade crossings, and uncontrolled (free) grade crossings. 1-lane and 2-lane highway grade crossings that intersect with the railway are shown in Fig. 1.

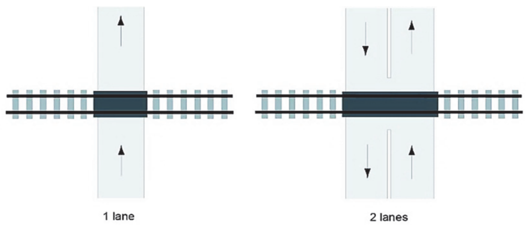

Figure 1 Grade crossing: 1 lane and 2 lanes road and railroad [6]

While designing grade crossings, designs are made according to train speed and cruising moment value (the number of trains passing through the daily grade crossing multiplied by the number of road vehicles). Grade crossing type selection according to train speed and cruising moment value is shown in Tab. 1 [25].

Table 1 Grade crossing type selection [25]

Train Speed	Grade Crossing (GC) Moment	GC Type
Train Speed < 120 km/h	Moment < 3000	Uncontrolled (Free)
Train Speed < 120 km/h	3000 < Moment < 30000	Automatic Barrier
120 km/h < Train Speed < 160 km/h	Moment < 3000	Automatic Barrier
120 km/h < Train Speed < 160 km/h	3000 < Moment < 30000	Automatic Barrier
Train Speed > 160 km/h	Moment < 3000	GC is not Suitable
Train Speed < 160 km/h	Moment > 30000	GC is not Suitable

2.2 General Safety Assessment in Grade Crossings

Different sub-headings are examined when making a safety assessment at grade crossings with automatic barriers. The examined topics are listed as basic definitions, location evaluation, physical condition evaluation, human and environmental assessment, signboard evaluation. The general safety assessment at grade crossing structure is shown in Fig. 2.

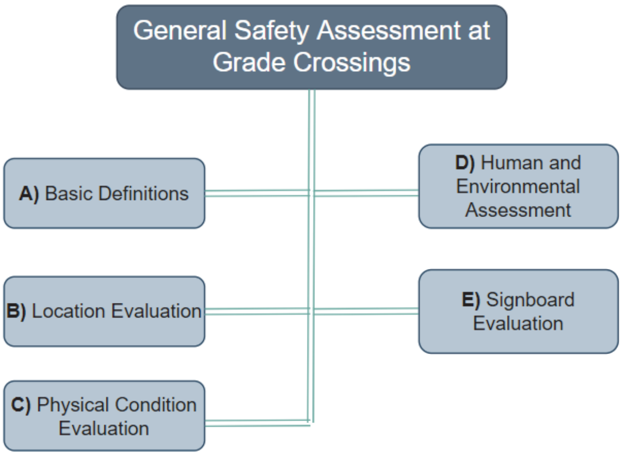

Figure 2 General safety assessment at grade crossings

Factors evaluated under different headings and calculations related to these factors will be explained under the relevant sections. The total safety value obtained because of the evaluations made according to the calculations explained in the relevant sub-headings is calculated. The grand total safety value for the grade crossing is shown in Eq. (1).

$$\sum General = \sum A + \sum B + \sum C + \sum D + \sum E \tag{1}$$

The general total grade crossing safety value result obtained in Eq. (1) is evaluated according to the color scale indicated in Fig. 3. In the colour scale evaluation, the red colour indicates a high-risk level, and the green color indicates a low-risk level. While going from red to green, the risk level decreases, and it reveals that it is a safer system.

Colour Scale	0	100	200	300	400	500	600	700	800
	50	150	250	350	450	550	650	750	

Figure 3 Grade crossing safety value color scale

2.2.1 Basic Definitions Section (*A*)

The first section that is evaluated while calculating safety at grade crossings is the basic definitions section. While safety calculations are made for grade crossings with automatic barriers, evaluations are made according to the moment value, train speed, and signalling system. As stated in Tab. 1, the opening of the grade crossing or the type of grade crossing that is opened is made according to the basic definitions evaluations. Different intervals are considered when calculating the safety value (A_1) for the moment value. Within these ranges, there are cases where the moment value is less than 7500, in the range of 7500 - 15000, in the range of 15000 - 22500 and in the range of 22500 - 30000. With this evaluation, the safety value can be 24, 16, 8 or 0. When calculating the safety value for the train speed (A_2), different intervals are considered. Within these ranges, there are cases where the train speed is less than 30 km/h, in the range of 30 - 60 km/h, in the range of 60 - 90 km/h and in the range of 90 - 160 km/h. With this evaluation, the safety value can be 24, 16, 8 or 0. While calculating the safety value (A_3) according to the signalization status, the presence or absence of signalization in the system is checked. With this evaluation, the safety value can be 4 or 0. Basic definitions parameters are shown in Tab. 2.

Table 2 Basic definitions parameter

Parameter	Describing	Safety Value
(A_1) Moment Value	Moment < 7500	24
	7500 < Moment < 15000	16
	15000 < Moment < 22500	8
	22500 < Moment < 30000	0
(A_2) Train Speed / km/h	Speed < 30	24
	30 < Speed < 60	16
	60 < Speed < 90	8
	90 < Speed < 160	0
(A_3) Signalization	Yes	4
	None	0

The calculation of total security value calculated according to the parameters of the basic function is shown in Eq. (2).

$$\sum A = A_1 + A_2 + A_3 \tag{2}$$

2.2.2 Location Evaluation Section (*B*)

The second part that is evaluated while calculating safety at grade crossings is the location evaluation part. While making the location evaluation section examinations, highway vehicle vision, railroad vehicle vision, curve radius, intersection angle, and railroad slope state of being on parabola headings are examined. While providing highway vehicle vision (B_1) and railroad vehicle vision (B_2) inspection, the regions of highway and railway vehicles are considered in the grade crossing region. The regions of highway and railway vehicles are shown in Fig. 4.

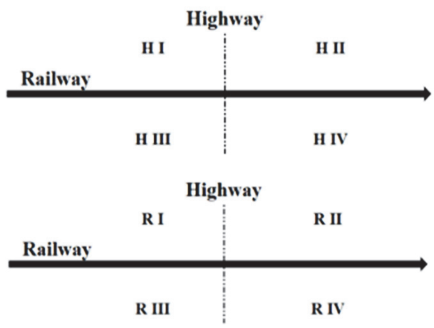

Figure 4 Zones of highway and railway vehicles

When calculating the safety value for the curve radius (B_3), different intervals are considered. Within these ranges, If the curve radius is 0 m, the safety value will be 15, if it is less than 300 m, the safety value will be 0, and if it is in the range of 300 - 500 m, the safety value will be taken as 5. When calculating the safety value for the insertion angle (B_4), different ranges are considered. Within these ranges, if it is equal to 90° the safety value is calculated as 50, if it is in the range of 45° - 70° the safety value is 15, if it is in the range of 30° - 45° the safety value is calculated as 4. If it is less than 30° the safety value is calculated as 0. The Highway and Railroad Intersection Angle structure is shown Fig. 5.

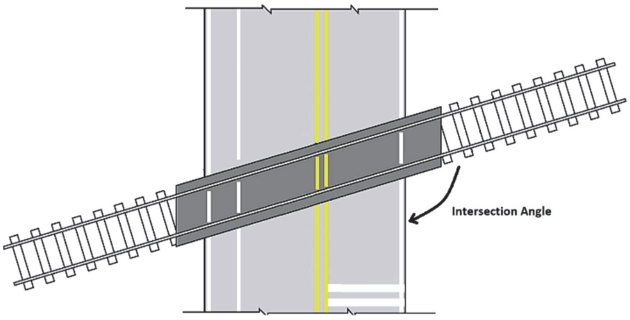

Figure 5 Rail intersection angle by highway [6]

Different intervals are considered when calculating the safety value (B_4) for the railroad slope. Within these ranges, if it is in the range of 0.000 - 0.005, the safety value is calculated as 25, if it is in the range of 0.005 - 0.01, the safety value is 10, and if it is greater than 0.01, the safety value 0 is calculated. If it is on the parabola, the safety value is 0, otherwise it is 2. The location evaluation parameters are shown in Tab. 3.

Table 3 Location evaluation parameter

Parameter	Describing	Safety Value
(B_1) Highway Vehicle Vision (500 m)	HI > Speed	3
	HII > Speed	3
	HIII > Speed	3
	HIV > Speed	3
	HI < Speed	0
	HII < Speed	0
	HIII < Speed	0
	HIV < Speed	0
(B_2) Railroad Vehicle Vision (750 m)	RI > Speed	3
	RII > Speed	3
	RIII > Speed	3
	RIV > Speed	3
	RI < Speed	0
	RII < Speed	0
	RIII < Speed	0
	RIV < Speed	0
(B_3) Curve Radius (m)	$R = 0$	15
	$R < 300$	0
	$300 < R < 500$	5
(B_4) Instersection Angle	Angle = 90°	50
	45° < Angle < 70°	15
	30° < Angle < 45°	4
	Angle < 30°	0
(B_5) Railroad Slope	0.000 < Slope < 0.005	25
	0.005 < Slope < 0.01	10
	0.01 < Slope	0
(B_6) State of Being On Parabola	Yes	0
	No	2

The calculation of total security value calculated according to the location evaluation parameters is shown in Eq. (3).

$$\sum B = B_1 + B_2 + B_3 + B_4 + B_5 + B_6 \tag{3}$$

2.2.3 Physical Condition Evaluation Section (*C*)

The third section, which is evaluated while calculating safety at grade crossings, is the physical condition evaluation section. During the physical condition evaluation, highway slope, highway length, side road length, highway coating, cant of the track, drainage, and grade crossing coating headings are examined.

Different ranges are considered when calculating the safety value for the highway slope (C_1, C_2). Within these ranges, if it is in the range of 0 - 0.03, the safety value is 18, if it is in the range of 0.03 - 0.05, the safety value is 5, if it is in the range of 0.05 - 0.07, the safety value is 2, if it is in the greater than 0.07 the safety value is 0. Different intervals are considered when calculating the highway length (m) safety value (C_3, C_4). If it is greater than 50 m within these ranges, the security value is 5, if it is between 30 - 50 m, the security value is 3, if it is between 10 - 30 m, the security value is 2, and if it is less than 10 m, the security value is 0.

When calculating the side road length (m) safety value (C_5, C_6) different intervals are considered. Within these ranges, if the length is greater than 30 m, the safety value is 6, if it is in the range of 10 - 30 m, the safety value is 3, and if it is less than 10 m the safety value 0 is calculated. Different ranges are considered when calculating the highway coating safety value (C_7, C_8) In the case of a highway pavement, the security value is calculated as 15, in the absence of it, the security value is calculated as 0. Different ranges are considered when calculating the Cant of the track safety value (C_9). Within these ranges, if it is less than or equal to 50, the safety value is 17, if it is in the range of 50 - 90, the safety value is 10, if it is in the range of 90 - 105 the safety value is 5, if it is greater than 105 the safety value 0 is calculated. The cant of the track structure is shown in Fig. 6.

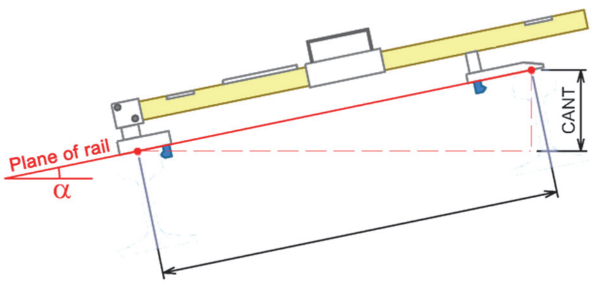

Figure 6 Cant of the track application in rail systems

Different intervals are considered when calculating the Drainage safety value (C_{10}). In case of Drainage structure, safety value is calculated as 10, if not, safety value is calculated as 0. Different ranges are considered when calculating the grade crossing coating safety value (C_{11}). While making the evaluations, the coating structure: length, width, height, surface, connection, and flange space elements are examined. The physical condition evaluation parameters are shown in Tab. 4.

The calculation of the total safety value calculated according to the physical condition evaluation parameters is shown in Eq. (4).

$$\sum C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + \\ + C_7 + C_8 + C_9 + C_{10} + C_{11} \quad (4)$$

Table 4 Physical condition evaluation parameter

Parameter		Describing	Safety Value
(C_1) Highway Slope (Right Railroad)		0 < slope < 0.03	18
		0.03 < slope < 0.05	5
		0.05 < slope < 0.07	2
		0.07 < slope	0
(C_2) Highway Slope (Left Railroad)		0 < slope < 0.03	18
		0.03 < slope < 0.05	5
		0.05 < slope < 0.07	2
		0.07 < slope	0
(C_3) Highway Length / m, (Right Railroad)		50 < length	5
		30 < length < 50	3
		10 < length < 30	2
		length < 10	0
(C_4) Highway Length / m, (Left Railroad)		50 < length	5
		30 < length < 50	3
		10 < length < 30	2
		length < 10	0
(C_5) Side Road Length / m, (Right Railroad)		30 < length	6
		10 < length < 30	3
		length < 10	0
(C_6) Side Road Length /m, (Left Railroad)		30 < length	6
		10 < length < 30	3
		length < 10	0
(C_7) Highway Coating (Right Railroad)		Yes	15
		No	0
(C_8) Highway Coating (Left Railroad)		Yes	15
		No	0
(C_9) Cant of the Track		cant <= 50	17
		50 < cant < 90	10
		90 < cant < 105	5
		105 < cant	0
(C_{10}) Drainage		Yes	10
		No	0
(C_{11}) Grade Crossing Coating	Length	Very Good	15
		Good	10
		Middle	5
		Bad	0
	Width	Very Good	15
		Good	10
		Middle	5
		Bad	0
	Height	Very Good	15
		Good	10
		Middle	5
		Bad	0
	Surface	Very Good	15
		Good	10
		Middle	5
		Bad	0
	Connection	Very Good	5
		Good	3
		Middle	2
		Bad	0
	Flange Space	Very Good	5
		Good	3
		Middle	2
		Bad	0

2.2.4 Human and Environmental Assessment Section (*D*)

The fourth section, which is evaluated while calculating safety at grade crossings, is the human and environmental assessment section. While conducting human and environmental assessments, the headings of human environmental conditions, grade crossing users assessment, environmental lighting, past accident status, and opinion of the evaluation team are examined. Different situations are considered when calculating the human-environmental conditions safety value (D_1). In these situations: Is there a school around? Is there a market around? Is there an entertainment center in the area are found? Different ranges are considered when calculating the grade crossing users assessment safety value (D_2). In these situations: Are Highway Drivers Experienced? Are Highway Drivers Sensitive to the Rules Are found?

Different ranges are considered when calculating the Environmental lighting safety value (D_3). In case of environmental lighting, safety value is calculated as 0, if not, safety value is calculated as −15. Different intervals are considered when calculating the Past Accident Status safety value (D_4). If there is a Past Accident Status, the safety value is calculated as −40, otherwise the safety value is calculated as 0. Different ranges are considered when calculating the Opinion of the Evaluation Team safety value (D_5). If Opinion of the Evaluation Team is positive, the safety value is calculated as 0, and if it is negative, the safety value is calculated as −40. Human and environmental assessment parameters are shown in Tab. 5.

Table 5 Human and environmental assessment parameter

Parameter		Describing	Safety Value
(D_1) Human Environmental Conditions	Is there a school around?	Yes	−20
		No	0
	Is there a market around?	Yes	−20
		No	0
	Is there an entertainment center in the area?	Yes	−20
		No	0
(D_2) Grade Crossing Users Assessment	Are Highway Drivers Experienced?	Yes	0
		No	−20
	Are Highway Drivers Sensitive to the Rules?	Yes	0
		No	−20
(D_3) Environmental Lighting		Yes	0
		No	−20
(D_4) Past Accident Status		Yes	−40
		No	0
(D_5) Opinion of the Evaluation Team		Positive	0
		Negative	−40

The calculation of total safety value calculated according to the human and environmental assessment parameters is shown in Eq. (5).

$$\sum D = D_1 + D_2 + D_3 + D_4 + D_5 \quad (5)$$

2.2.5 Signboard Evaluation Section (*E*)

The 5th section that is evaluated while calculating safety at grade crossings is the signboard evaluation section. Signboard evaluation is examined by the signs on the railroad, and signs on the highway. The signboard evaluation parameters are shown in Tab. 6.

The calculation of total security value calculated according to the signboard evaluation parameters is shown in Eq. (6).

$$\sum E = E_1 + E_2 \quad (6)$$

Table 6 Signboard evaluation parameter

Section	Parameter	Sign	Describing	Safety Value
(E_1) Signs on the Railroad	Machinist Whistle Blow (Right Railroad), Before GC 750 m		Yes	23
			No	0
	Machinist Whistle Blow (Left Railroad), Before GC 750 m		Yes	23
			No	0
(E_2) Signs on the Highway	Go Right Sign (Right Railroad) TT-36a		Yes	1
			No	0
	Go Right Sign (Left Railroad) TT-36a		Yes	1
			No	0
	Median Attachment Plate (Right Railroad) T-34b		Yes	1
			No	0
	Median Attachment Plate (Left Railroad) T-34b		Yes	1
			No	0
	Uncontrolled Railway Crossing (Right Railroad) T-27a		Yes	1.5
			No	0
	Uncontrolled Railway Crossing (Left Railroad) T-27a		Yes	1.5
			No	0
	Stop Sign (Right Railroad) TT-2		Yes	1.5
			No	0
	Stop Sign (Left Railroad) TT-2		Yes	1.5
			No	0
	Flasher (Right Railroad)		Yes	45
			No	0
	Flasher (Left Railroad)		Yes	45
			No	0
	Bell (Right Railroad)		Yes	45
			No	0
	Bell (Left Railroad)		Yes	45
			No	0
	Barrier (Right Railroad)		Yes	45
			No	0
	Barrier (Left Railroad)		Yes	45
			No	0

3 CONCLUSIONS

With the developments in rail transportation systems, the number of crossings that intersect with the highway has increased. Grade crossings, which are the most frequently used system among these crossings, have been identified as an area where serious studies are carried out due to accident risks and the effects of these accidents. The geometric designs and risk prevention applications of grade crossings used in the world are specially designed according to the geographical location of the region where the system is used, line capacities, awareness levels and technology levels of the systems used.

In the study, the standards, regulations, application models, and reports put forward by many different countries were examined. In addition to all the study, the risk assessment system used in Turkey has been examined. In the study, while safety calculations were made in grade crossings, evaluations were made under the headings of basic definitions, location evaluation, physical condition evaluation, human and environmental assessment, and signboard evaluation. It includes moment value and train speed (km/h) headings in basic definitions, which is the most important main heading for determining the grade crossing type in the whole system.

While making the location evaluation section examinations, highway vehicle vision, railroad vehicle vision, curve radius, intersection angle, and railroad slope state of being on parabola headings are examined. During the physical condition evaluation, highway slope, highway length, side road length, highway coating, cant of the track, drainage, and grade crossing coating headings are examined. While conducting human and environmental assessments, the headings of human environmental conditions, grade crossing users assessment, environmental lighting, past accident status, and opinion of the evaluation team, are examined. Signboard evaluation is examined by the signs on the railroad, and signs on the highway. With the study, the safety model, which is suitable for the grade crossings with an automatic barrier, was transferred and all the titles required to make location-based evaluations were transferred.

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