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NEW APPROACH TO DETERMINING VISIBILITY LENGTH ON PASSIVE PROTECTED LEVEL RAILROAD CROSSINGS

ABSTRACT

The paper is based on the question whether the existing (legislation determined) method for determining the visibility length on passive protected level railroad crossings insures the relevant level of traffic safety. It has been recognised that using of such method does not provide stopping of road driver vehicles in front of railroad crossing in all conditions. Based on such conclusion a new approach to determining visibility length on passive protected level railroad crossing is proposed. The new approach is based on the assumption that it is necessary, primarily on level railroad crossings with local roads to recognize the worst possible and expected road and weather conditions. The testing of the proposed method in the real environment has shown that at lower speeds of road vehicles there is almost no difference, and that important benefits are recognised for the speeds of 30 and 50km/h where longer stopping distances of road vehicles have been detected (road vehicle can stop safely in front of a rail crossing) with almost the same visibility lengths. The use of the proposed method could have important impact on the increase of traffic safety on passive protected level railroad crossings.

KEYWORDS

traffic safety, visibility field, level railroad crossings

1. INTRODUCTION

Slovenian regulations of safety on road and rail defines that a train or other means of transport which moves by the rail have total priority over all other road users. A driver approaching a level railroad crossing must drive with caution and at such a speed that they can safely stop before a barrier. In case of approaching a level railroad crossing, passively protected only with signs and marked with St. Andrew's cross or saltire, the drivers should make sure that they can safely drive across the railroad tracks. However, in reality many of those level crossings do not assure the driver the nec-

essary visibility for safe crossing of the rail tracks, due to environmental or other obstacles.

Level railroad crossing is "an intersection of a road and railway on the same level, where roads and rail include different operators and responsibilities". As a result, level railroad crossing protection is the common task of all those involved in the operation and control of roads and railways. Level crossings come under the purview of laws, regulations, administrative provisions and directives. Two basic classifications of level crossings are recognized by the European Rail Agency [1]:

- passive protected level crossings: These always appear to the road user in the same way, irrespective of whether or not there is a train approaching. Therefore, the road users have to look for the train themselves.
- active protected level crossings: These indicate to the road user whether a train is approaching or not.

In the paper we will focus on the visibility field only on passive level crossings which are marked, since those level crossings are most dangerous and most numerous in Slovenia railway system. As presented in Figure 1, over the past sixteen years, at level crossings across the railway lines in Slovenia 646 traffic accidents occurred in which 147 people were killed and 274 were injured. The majority of accidents happened on the passive protected level crossings, but it is surprising that 20% of accidents happen at active protected level crossings secured with automatic or manual gates (official data of Slovenian Railways).

Traffic safety on the passive protected level railroad crossings strictly depends on the driver's possibility to control activities on the rail when approaching the railroad crossings.

To insure the possibility to control the activities on the rail tracks from the roadway the visibility field is established. Beside traffic signs the visibility field is the only and crucial measure to assure traffic safety on the passive protected road rail level crossings. The visibility field design contains defining of the sight dis-

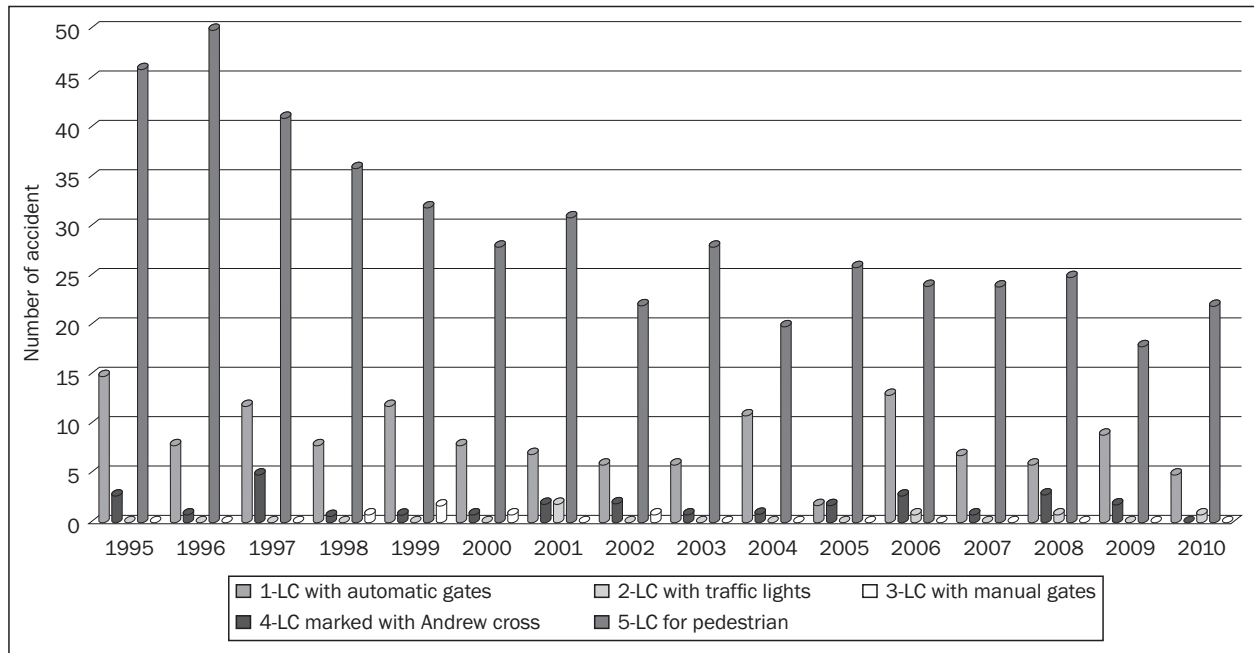


Figure 1 - Number of accidents by type of level crossings

Source: official data of Slovenian Railways

tance, view points on the road and visibility points on the track – all these depend on the driving speed (on the road and on the rail) and are derived from driving dynamics and kinematics [2, 3, 4]. Although the mentioned domain has been analysed in the recent scientific literature in general, on such base the legislation rule about level crossings (Pravilnik o nivojskih prehodih) [5, 6, 7] was prepared in the year 2008. The legislation rule (“legislation” method) defines also that:

- on the passive protected level crossings first it should be checked if from the viewpoint of the speed of road vehicles of 5km/h based on the maximal rail track speed the relevant visibility is assured and after that, if so, whether the visibility field for the speed of road vehicles of 15, 30 and 50km/h is checked, and
- the view point from where visibility must be assured is defined depending on the expected stopping distance of the road vehicle and it is shown in the table where stopping distances for the road driving speed of 5, 15, 30 and 50km/h are 5, 10, 22 and 41m, respectively.

The subject of research in the recent paper is the method to define the relevant stopping distance in the methodology for visibility field design because traffic safety of the road vehicle drivers on the passive protected railroad level crossings depends strictly on the possibility that the driver of road vehicle should perceive on time the obstacle (train) and to undertake relevant activities upon such perception.

The aim of research is to analyse the crucial parameters which affect the relevant stopping distance

definition which indirectly affects the scale of visibility field of the passive protected level railroad crossings.

The objective of research is to contribute to a higher level of traffic safety on the level road rail crossings.

The research hypothesis is established as. “Traffic safety level on the passive protected level railroad crossings should be increased by using the relevant and improved method for defining the driver stopping distance”.

2. THEORETICAL BASIS

To determine the visibility on level crossing we must first identify the visibility field used for ensuring safety on the level railroad crossings. The visibility field is the land or/and limited space above and near the road transport infrastructure, which is determined by the visibility triangle. The visibility triangle is the land by the road infrastructure whose use is limited to ensure the required transparency in the level crossing.

The size of the visibility triangle is determined on the basis of kinematic features and assumptions of vehicle movement on the road and rail infrastructure. The following assumptions are made:

- given a certain maximum speed of road vehicles the perception of the train on the rail must be possible in a way that the road vehicle can safely stop - stopping distance of a road vehicle;
- crossing time of road vehicles over the railway line must be shorter than the time of train approaching.

Interdependence between length of stopping distance ISDR and path length of rail vehicle IT is presented in Figure 2 and by Equation 1 [7].

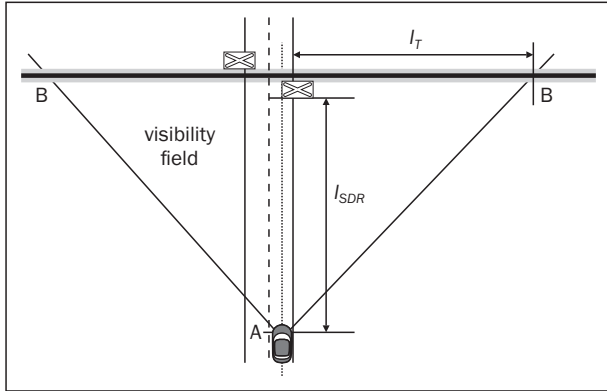


Figure 2 - Visibility triangle on level railroad crossing

$$I_T \geq v_{Tmax} \left(\frac{I_{SDR} + I_{CA} + I_{RV}}{V_R} + 6 \right) \quad (1)$$

where:

- I_T – path length of rail vehicle in time of approaching train from visibility point (B) to the level crossing (m);
- v_{Tmax} – maximum speed of rail vehicle (m/s);
- I_{SDR} – length of stopping distance of road vehicle (m). It is a distance from safe stopping to St. Andrew's cross to the viewing point (A). Road vehicle driver with the assumption of maximum speed limit should be ensured a smooth and uninterrupted view to the visibility point B;
- I_{CA} – length from the stopping position to the end of the conflict area of the level crossing (m), measured parallel with the axis of the road and determined by the cross section of the rail line (example: one way track = rail gauge + 2 × width of rail);
- I_{RV} – length of road vehicle (m);
- V_R – speed of road vehicle (m/s).

Based on Equation 1 relevant diagrams are prepared to assist the engineers in their professional work. An example of diagrams is presented in Figure 3.

The following questions are asked:

- Question 1: With which average deceleration should a road vehicle drive for safe stopping before the rail tracks, and
- Question 2: Is the proposed and prescribed distance of stopping length (as in [7]) sufficient for safe stopping of the road vehicle in all possible conditions?

The answer to the first question is easy to find using the basic kinematic equations of regularly decelerating movement.

The second question should be answered by defining the *relevant driving speed*. The relevant driving speed is used when the answer is required to the question if the driver had the possibility to stop before the obstacle with hard and aggressive deceleration.

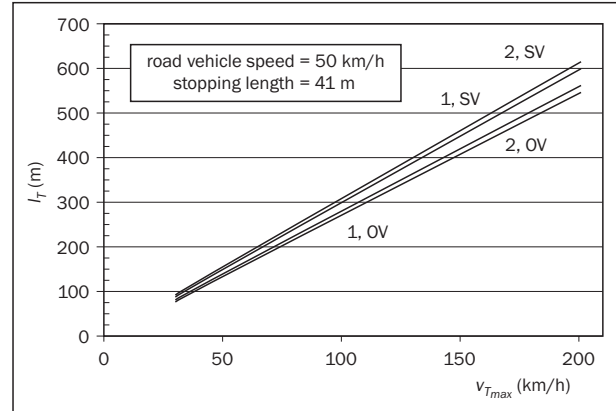


Figure 3 - Length to visibility point in accordance with maximum speed of rail vehicle with assumption of road vehicle speed 50km/h, where OV is a personal vehicle, SV a group of vehicles, 1 or 2 means number of rail tracks

The relevant driving speed is derived from knowing the stopping distance, deceleration and reaction time

$$I_{SDR} = v_0 \left(t_1 + \frac{t_2}{2} \right) + \frac{v_0^2 - v_n^2}{2a_{max}} - \frac{a_{max} \cdot t_2^2}{24} \quad (2)$$

where:

- v_0 – speed of road vehicle before braking (m/s);
- v_n – speed of road vehicle after braking (m/s);
- t_1 – driver perception - reaction time (s) – normally 0.8 s;
- t_2 – time to start breaking (s) – normally 0.2 s;
- a_{max} – maximal possible deceleration depends on friction and slope grade of the road (m/s²).

Rearranged equation 2 can be written in the form of quadratic equation:

$$\frac{v_0^2}{2a_{max}} + v_0 \left(t_1 + \frac{t_2}{2} \right) - \left(I_{SDR} + \frac{a_{max} \cdot t_2^2}{24} \right) = 0 \quad (3)$$

with the following solution:

$$v_0 = \sqrt{2a_{max} \cdot I_{SDR} + a_{max}^2 \left[\left(t_1 + \frac{t_2}{2} \right)^2 + \frac{t_2^2}{12} \right]} - a_{max} \left(t_1 + \frac{t_2}{2} \right) \quad (4)$$

where only positive solutions are possible.

Proposed in the prescribed stopping sight distance [8] also some other general known theoretical bases should be checked, which are used for assuring safety in road traffic as follows:

Related to Juvanc [8] the *stopping sight distance* is defined by

$$I_{SDR} = \frac{v_{pr}^2}{2 \cdot g \cdot f} + 7 \quad (5)$$

where:

- v_{pr} – project speed (m/s);
- g – roadway grade in decimal;
- f – pavement coefficient of friction.

Stopping sight distance is related to ASHTOO [9, 10] defined as distance where the vehicle must decelerate to stop at an acceptable rate to avoid the clearly

discernible object or obstacles presented on the roadway.

$$I_{SDR} = 0.278 \cdot V \cdot t_1 + \frac{V^2}{254 \cdot (f \pm g)} \quad (6)$$

where:

- V – speed (km/h);
- t₁ – driver perception - reaction time (s) – normally 2.5 – 3.0 s;
- f – pavement coefficient of friction typically for poor, wet pavement.

When conflicts are numerous, conditions are complex, the driver expectancies may vary or visibility to traffic control or design features is impaired the *decision sight distance* should apply.

3. ANALYSES AND RESULTS

A moving road vehicle approaching the level railroad crossing is taken into consideration. The road vehicle driver receives the very first information about the possible dangerous side when they are about 240m before the crossing (traffic sign “Approaching to passive protected railroad crossing” – if it exists). Inside the approaching area the speed limit of 50km/h is valid, but normally there is no regular speed limitation traffic sign. The second and the third signs are normally located at the distances of 160 and 80m before the crossing. When a vehicle driving at a continuous speed of 50km/h arrives at view point A at a distance of 41m (related to [7]) from the crossing, at that point the visibility field for such speed must be established.

Using kinematic equations for continuous deceleration movement it is possible to calculate that a vehicle could stop before the tracks when the average deceleration is at least 2.35m/s². Under the mentioned condition the deceleration and stopping are safe in almost all weather and road conditions, and the problems could be expected on incompact dry snow (average deceleration of 1.0 to 2.5m/s² is possible) and on ice (average deceleration of 0.5 to 1.0 m/s² is possible).

Introducing the driver’s perception-reaction time into the mentioned model the available stopping distance decreases and the average deceleration should be at least 3.5m/s² when the driver’s reaction time of 1s is taken into consideration, and should be at least 13.5m/s² (1.35g) when the driver’s perception-reaction time of 2.5s is taken into consideration. When the driver’s perception-reaction time of 1s is taken into consideration the deceleration and stopping are safe in almost all weather and road conditions, and the problems could be expected on snowy and on icy pavement. All the results of modelling average deceleration of road vehicle depend on the driving speed and the available stopping distance is presented in *Table 1*.

Answer 1: Based on different models, the road vehicle should realise the average deceleration for safe stopping before rail between 2.35 and 3.5m/s² when the driving speed of 50km/h is taken into consideration and between 1.65 and 2.5m/s² when driving speed of 30 km/h is taken into consideration.

From the aspect of engineering practice the accuracy of the model takes usable results. The deceleration increases with involving additional details into road vehicle movement modelling when available braking time and braking distances decrease.

The relevant driving speed (Equation 4) at which the driver of road vehicle could safely stop before the tracks on the basis of different possible maximum deceleration (it depends on the pavement quality) is also taken into consideration. It is easy to recognise that a road vehicle driving at a speed of 50km/h could safely stop before the tracks at a stopping distance of 41m (perception-reaction time of 1s is valid) when the sum of pavement friction coefficient and slope grade of the road is greater than 0.35 (*Figure 4*). When the pavement friction decreases, a lower driving speed makes safe stopping possible.

Answer 2: Analysing the required average deceleration of road vehicles in view of possible safe stopping in front of rail tracks when legislation requirement of road vehicle speed and available stopping distance is taking into consideration, it is recognised that safe stopping is not possible on all roads and in all weather

Table 1 - Modelling average deceleration of road vehicle depends on relevant speed and available stopping distance for safe stopping before rail tracks

Speed of road vehicle (km/h)	Avail. stop dist. (m)	Model of deceleration					
		Continuous decel. movement		Add perception-reaction time			
		a (m/s ²)	*	t ₁ = 1s		t ₁ = 2.5s	
		a (m/s ²)	*	a (m/s ²)	*	a (m/s ²)	*
50	41	2.35	dry snow, ice	3.5	snow, ice	13.5	**
30	22	1.65		2.5		16.5	
10	10	0.38	-	0.55	ice	1.5	dry snow, ice

* different road pavements where hazards could be expected

** it is not possible to stop under any conditions

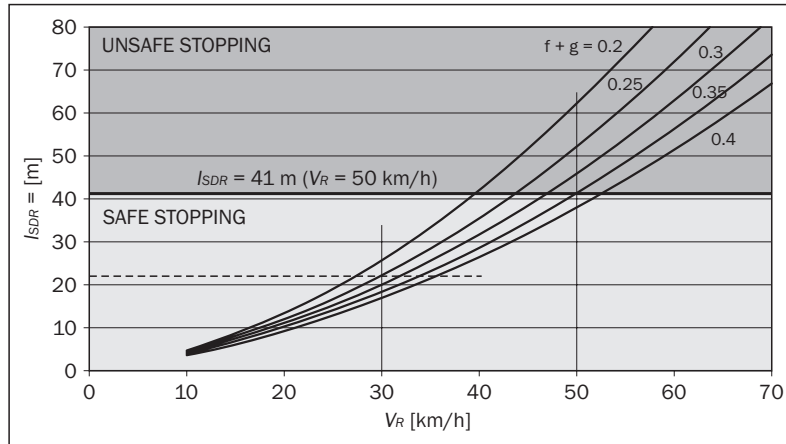


Figure 4 - Safe and unsafe stopping area by different possible sums of pavement friction coefficient and slope grade of the road for stopping distance of 41m ($V_R = 50\text{km/h}$) and perception-reaction time of 1s

condition. Special problem is recognised in winter conditions because local roads are generally macadam ones and have no great importance for winter maintenance.

4. NEW APPROACH TO DETERMINING VISIBILITY LENGTH ON PASSIVE PROTECTED LEVEL RAILROAD CROSSINGS

In previous chapter it was clearly shown that procedures defined by the Slovenian national railway legislation on determining the required visibility on passive protected level railroad crossings do not assure safe stopping of road vehicles in all road and weather conditions. Special problems could be expected on local low-level roads normally macadam, where winter maintenance service depends on local providers.

The following suggestions have to be included in legislation renewals:

- defining of the visibility field must depend on the real dynamics of road vehicle driving, and
- the stopping distance must be defined related to real road and the worst expected weather conditions with the perception-reaction time of at least 2s taken into consideration.

Based on such predispositions interdependence between length of stopping distance l_{SDR} and path

length of rail vehicle l_T (Equation 1, Figure 2) could be written as:

$$l_T \geq v_{Tmax} \left(\frac{l_{SDR} + l_{CA} + l_{RV}}{V_R} + 6 \right)$$

where:

$$l_{SDR} = 2 \cdot V_R + \frac{V_R^2}{19.6 \cdot (0.3 \pm g)} \tag{7}$$

In Equation 7 the perception-reaction time of 2s and pavement friction coefficient of 0.3 (snow) is observed.

The very important difference between “legislation” and the proposed method is in the way of application – the proposed method is adapted to road vehicle dynamics while the “legislation” method demands first checking for road driver speed of 5km/h and then increasing it, if possible, although the required time for crossing the passive protected railroad crossing at higher speeds of road vehicles is shorter (also the required visibility distance is smaller).

The comparison of the results of both methods is impossible in general because both methods have no same predispositions. The comparison of results shows that at lower speed of road vehicle there is almost no difference, and important benefits are recognised for the speeds of 30 and 50km/h where the longer stopping distance of road vehicle is detected (road vehicle can stop safely in front of the railroad crossing) with almost the same visibility length.

Table 2 - Comparison between “legislation” and suggested method for defining the visibility field on passive protected level railroad crossings

V_R [km/h]	l_{SDR} [m]			l_T [m]		
	“leg.”	new	ratio	“leg.”	new	ratio
5	5	3	0.60	647	368	0.57
15	10	11	1.10	331	255	0.77
30	22	28	1.27	264	240	0.9
50	41	61	1.49	241	249	1.03

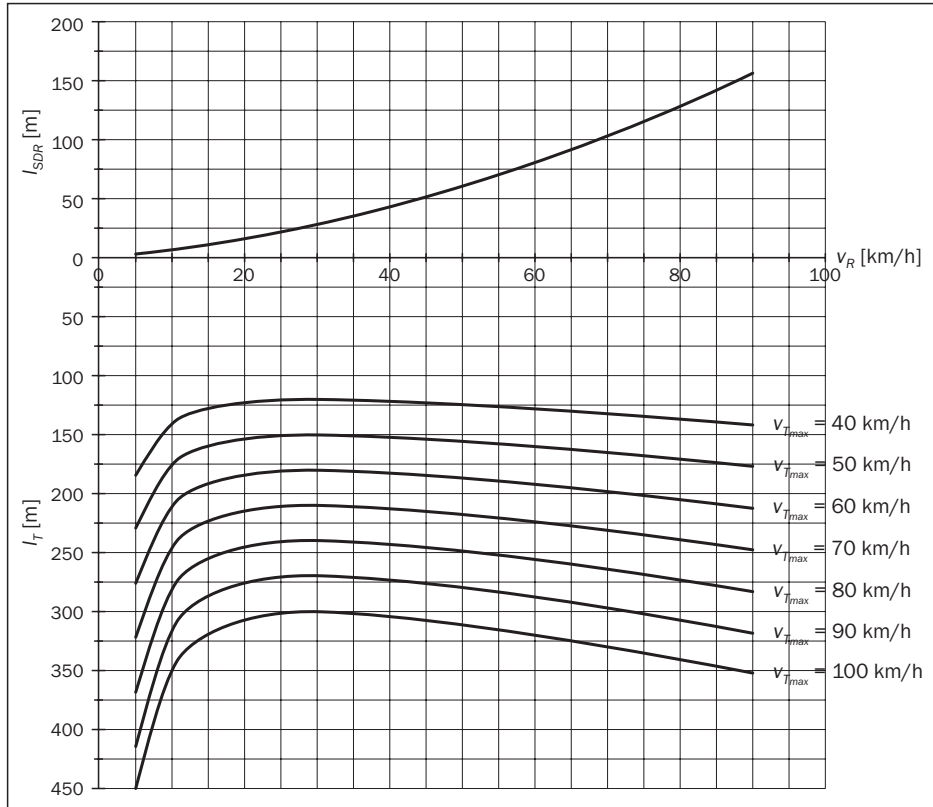


Figure 5 - Interdependence between the length of the stopping distance I_{SDR} and the path length of the rail vehicle I_r related to relevant road vehicle speed and maximum allowed speed on rail (ICA of 6.575m, IRV of 5m and g of 0 is observed)



Figure 6 - Comparison between "legislation" and suggested method for defining the visibility field on passive protected level railroad crossings (brighter: suggested method, darker: "legislation" method, left: $V_R = 50$ km/h, right: $V_R = 30$ km/h)

The use of the proposed method in comparison to the "legislation" method was tested on many passive protected level railroad crossings in Slovenia. Further, a real example of a passive protected level railroad crossing is given: No. 394, Libanja 4 the main railway 41 G Ormož – Ivanjkovci (Slovenia) in stationary 6 + 785.90 ($V_{\max} = 80\text{km/h}$) uncategorised public way (macadam) crossing at an angle of 70 degrees.

Figure 6 shows a comparison with the "legislation" and a suggested method in real environment. The numerical comparison between the mentioned methods is shown in Table 2.

5. CONCLUSION

In passive protected level railroad crossings, the road user is responsible for observing the railway line and recognising an approaching train directly. The most important measure to ensure the perception of the train is to keep the visibility field - triangle clear of all obstacles.

Based on the checked inadequacy of the existing "legislation" method a new one is proposed. The new suggested method is based on road vehicle dynamics and made with respect to the natural way of driving (and stopping in front of the obstacles) and expected road and weather conditions. The usage of the proposed method guarantees that the road driver will have sufficient time for stopping in front of the rail crossing independent of road and weather condition.

Using the proposed method where the relevant distance of stopping the road vehicle in all conditions is taken into consideration could guarantee that the number and consequences of traffic accidents on passive protected level railroad crossings could decrease, thus increasing the level of traffic safety in this segment. The last conclusion confirms the research hypothesis of the presented paper.

Although present article deals with a very limited segment which has great impact on traffic safety on passive protected level railroad crossings it is important to mention that it is a part of complex research made on traffic safety of passive protected level railroad crossings at the University of Maribor. The results of this research affect:

- the method of modelling visibility field on passive protected level railroad crossings [11, 12],
- establishing a common level railroad crossings database,
- establishing a common method for categorisation, labelling and equipment on passive protected level railroad crossings etc.

All mentioned could have an important impact on saving people on passive protected level railroad crossings with help of adequate management and promotion.

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POVZETEK

NOV PRISTOP K DOLOČEVANJU DOLŽINE PREGLEDNOSTI PASIVNO ZAŠČITENIH NIVOJSKIH ŽELEZNIŠKIH PREHODOV

Pričujoči prispevek temelji na vprašanju, če obstoječa zakonsko določena metoda za določevanje dolžine preglednosti na pasivno zaščitene železniške prehode zagotavlja ustrezni nivo prometne varnosti. Ugotovljeno je, da uporaba obstoječe metode ne omogoča vozniku motornega vozila zaustavitve vozila v vseh pogojih. Na osnovi takšne ugotovitve je predlagan nov pristop k določevanju dolžine preglednosti na pasivno zaščitene nivojskih železniških prehodih. Nov pristop temelji na predpostavki, da je nujno, predvsem na nivojskih železniških prehodih lokalnih cest, upoštevati najslabše možne in pričakovane cestne in vremenske pogoje. Preizkus predlagane metode v realnem prometnem okolju je pokazal, da pri nižjih hitrosti cestnih vozil skoraj ni razlike, pomembnejše prednosti se pokažejo pri hitrostih 30 in 50 km/h, kjer so ugotovljene večje dolžine zaustavljanja cestnega vozila (cestno vozila se lahko varno zaustavi pred nivojskim železniškim preodom) pri skoraj enakih dolžinah preglednega polja. Uporaba predlagane metode lahko pomembno prispeva k povečanju prometne varnosti na nivojskih železniških prehodih zaščiteni samo z Andrejevim križem.

KLJUČNE BESEDE

prometna varnost, polje preglednosti, nivojski železniški prehod

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