

Study of effectiveness of experimental marking and signs in speed management

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Abstract. The paper presents the evaluation of effectiveness of non-standard road marking and signs (ES) in speed management. Transverse strips, speed limit signs dedicated to selected lanes, non-standard sign, which inform about slippery pavement at motorway curve during the rain. were analysed. Based on survey, degree of understanding of the content of analysed marking and signs by road users was assessed. Empirical studies allowed for evaluation of change in speed caused by non-standard marking and signs implementation. Results show that non-standard marking and signs can be effective speed management measures. The paper also point out problems in evaluation of ES implementation.

1 Introduction

Decisions made by road users, including the choice of speed, are determined mainly by the perception of the road space and additional information provided by the marking and signs. The occurrence of non-typical traffic situations as well as the low effectiveness of typical marking and signs in such situations, result in the search for new tools of influencing the behaviour of road users. One of the ways is to use experimental marking and signs (ES) which absorb the attention of road users better than typical marking and signs, including these used in speed management.

The paper is focused on the study of the impact of ES on the drivers' choice of speed. However, the wider use of ES requires a prior check to what extent this type of marking and signs will be understandable to the road users and cause the expected effects, i.e. making the right decisions by the drivers. Very often the expected effect of ES implementation is the choice of proper speeds, which is adequate to the actual level of road safety on a given road section.

Characteristic feature of ES is its occasional occurrence on the road. Therefore, research on its effectiveness in speed management involves the following dilemmas and findings answers to the following questions:

- to what extent rare used marking and signs can be understood by road users?
- in the case of incomplete understanding of ES, can it perform, apart from the warning function, also the functions of prohibitory and mandatory signs?
- how to evaluate the effectiveness of ES if the test sample is very small?

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- can ES have greater impact on choice of speed by drivers than standard marking and signs?

The aim of the research was the assessment of the impact of ES on the drivers' choice of speed in sites, where special attention is required. Toll plazas, interchange ramps, hazardous motorway curves and approaches to crosswalks were analyzed. In those localizations ES were implemented, which are: transverse strips, speed limit signs dedicated to selected lanes (located above the lanes), non-standard sign, which inform about slippery pavement at motorway curve during the rain.

2 Literature review

Frequently used research methods of non-standard marking and signs are surveys and analysis in driving simulators [1]. The main purpose of surveys is to evaluate the level of understanding of ES. The surveys also collect information on the potential reactions to the tested marking and signs, declared by the respondents [2]. Research methods mentioned above eliminate the risk of using marking and signs, which could cause negative effects in real traffic. Only in cases of positive results of surveys or in driving simulators, ES are tested in real traffic conditions.

Impact of transverse strips on drivers behavior in driving simulators was analyzed e.g. in [3,4]. In [3] it was shown that such marking causes speed reduction by up to 11 km/h, both when passing through a hazardous locations and when approaching it. The results show that effectiveness of the marking does not depend on the distance between transverse strips. Other conclusions were drawn by the authors of [4]. In this case, it has been found that it is possible to influence the vehicle speeds by changing the distance between strips. In this case, transverse strips caused speed reduced by 10-20 km/h.

Transverse strips were also analyzed in real traffic [5,6]. Implementation of transverse rumble strips in the approach to yield sign-control intersection resulted in a reduction of vehicle speeds average by 1.6 km/h (the maximum speed reduction was 3-5km/h) [5]. The same type of marking implemented on railway crossing with "STOP" sign caused speed reduction by 5 km/h [6].

Research on the drivers' reaction to speed limit signs is extremely broad and clearly confirms the speed reduction in the zone of such sign. The level of speed reduction depends strongly on local conditions, including the location of the road section [7,8]. However, there are no analysis of speed limit signs dedicated to selected lanes.

An important observation in many previous studies of ES is its decreasing impact on drivers' behavior over the time [9]. However, such statement can not be applied to all cases of non-standard marking and signs implementation. Indication of marking and signs with decreasing impact on drivers' behavior over the time should be the subject of further research, taking into account the characteristics of road users and road parameters.

3 Method

To evaluate of the effectiveness of ES, both research methods survey and empirical studies were used. The purpose of the survey was to evaluate the degree of understanding of ES by road users, which determines making correct decisions. The survey also looked for links between the degree of understanding of the analyzed marking and signs and the characteristics of the respondents. In the survey 7-10 responses were proposed to the question about the meaning of a given marking or sign, from which maximum 3 could be chosen by respondent. Responses were additionally ranked by the respondents from the most to the less likely as correct. An important question was whether respondent had already met with an

analyzed marking or sign. In the survey took part 381 respondents, in different age groups and with different experience in driving.

In the empirical studies, the effectiveness of ES was assessed on the basis of differences in speed at locations with ES implemented and control group (with similar characteristics but with no ES). Speed measurements using both techniques image technique analyses and pneumatic detectors were made. The video technique was used on motorways and expressways, while pneumatic detectors were used on the roads with lower speed.

The following non-standard marking and signs were tested:

- transverse strips located on approaches to two toll plazas “Strykow” and “Zdzary” on A2 motorway (marking is located on the pavement in the approach to toll plaza, Fig. 1a);
- transverse strips combined with speed limit signs dedicated to selected lanes (located above the lanes) in the approach to interchange ramp on A1 motorway (Fig. 1b);
- non-standard sign of hazardous curve on A4 motorway (Fig. 1c);
- red transverse strips on approach to crosswalk in Biorkow Maly and Poskwitow villages (Fig. 1d).



Fig. 1. Analysed non-standard road marking and signs: a) transverse strips on approach to toll plaza; b) speed limit signs dedicated to selected lanes (located above the lanes); c) non-standard sign of hazardous curve; d) red transverse strips on approach to crosswalk.

In analysis of effectiveness of transverse strips located on approaches to toll plazas, toll plaza "Zernica" on A4 motorway was chosen as a control group. The traffic organization is the same at all 3 toll plazas (the same perception of toll plaza by road users, a similar number of lanes and toll booths for electronic toll collection with additional marking and signs).

The non-standard sign of hazardous curve is located only on carriageway in one direction. The use of this sign results from improper drainage of the carriageway. The large radius of the curve (2400 m) does not require limitation of vehicles speed below the general limit of 140 km/h. As a control location, a curve on carriageway for opposite direction was chosen.

The impact of red transverse strips located on approach to crosswalk on drivers' behavior was estimated by comparison of changes in vehicles speed on this approach with changes in

speed on approach to standard marked and signed crosswalk (without transverse strips) determined in national research [10].

In all empirical studies, the sample size was greater than the required minimum sample size with the assumption of 95% confidence interval. To eliminate the impact of other variables on drivers' behavior, measurements were carried out in good weather and lighting conditions in free flow traffic.

4 Results

The selected results of non-standard marking and signs effectiveness, which were taken about 36-44 months after their implementation, are described below. Thus, the presented results show the impact of ES, which should not change significantly in the following months (expected permanent effect). It can be assumed that some of the road users already know analysed marking and signs and their meaning better. However, ES are implemented very rarely and therefore the presented results should be considered as a case study. Broader interpretations can only be made to the results of survey on understanding of non-standard marking and signs.

Level of understanding of ES declared in the survey was varied:

- for transverse strips: 62% of correct answers. Cluster analysis of survey responses showed that the marking is correctly interpreted mainly by people who have already met such marking, including a large sample of truck drivers traveling over 40,000 km per year. Wrong answers were made mainly by drivers at the age of 36-45 traveling less than 20,000 km per year;
- for speed limit signs dedicated to selected lanes: 24% of answers were corrected. This is a surprisingly low value, because it refers to standard speed limit sign, but used in non-typical way.

Non-standard sign of hazardous curve consists of a few standard signs. Only the background of the sign is changed, therefore that sign was not the subject of the survey. It was assumed that sign shown in Fig. 1c should be understood by the drivers.

Empirical studies of transverse strips located at the approaching to toll plazas confirmed the positive impact of this type of marking on drivers' behavior. It was found that the presence of transverse strips results in a greater mean speed decrease than for the control group. Vehicles speed at a length of 70 m before toll plazas was estimated. This is a distance that speed limit can be perceived as reasonably for drivers. In measurement section, the speed limit was up to 70 km/h and 40 km/h. The average speed and speed difference between the beginning and the end of the measurement section were estimated (table 1).

Table 1. Speed on the approach to toll plazas with transverse strips and for control group.

	Approaching to toll plazas with transverse strips	Control group (no transverse strips)
Average speed at the beginning of measurement section [km/h]	78.0	89.7
Standard deviation of speed at the beginning of measurement section [km/h]	17.7	17.2
Average speed reduction on measurement section [km/h]	4.4	2.9
Change in average speed [%]	5.6	3.2

The average speed reduction in locations with transverse strips was 5.6% and in control locations 3.2%. However, attention should be paid to the impact of transverse strips on

vehicles speed in approaching to the measurement section. In locations with ES, average speed at the beginning of the measurement section was lower by 11.7 km/h (13%) in relation to the control group. This is a significant difference in speed with a large potential impact on reducing accidents risk at toll plazas.

Empirical studies of transverse strips combined with speed limit sign dedicated to selected lanes implemented on interchange ramp fully confirmed the positive effect of such ES on vehicles speed (table 2).

Table 2. Speeds on approach to interchange ramp with transverse strips combined with speed limit sign dedicated to selected lanes and control group.

	Treated location (with transverse strips and speed limit sign)				Control group – approach to interchange ramp	
	Approach to interchange ramp with ES		Through lanes with no ES		Left lane	Right lane
	Left lane	Right lane	Left lane	Right lane		
Average speed [km/h]	97.3	88.6	120.9	107.4	113.3	92.9
85th percentile of speed [km/h]	112.7	105.4	140.5	124.1	142.8	105.9
Standard deviation [km/h]	20.01	18.63	25.84	23.15	28.73	19.03

The average speed on lanes with a dedicated speed limit of 90 km/h and transverse strips was lower than average speed on lanes without ES by 22.6 km/h (19.5%) on the left lane and 18.8 km/h (17.6%) on the right lane. This speed difference can be partially related to the function of lanes (through lanes - no marking, interchange ramp lanes – with ES) and therefore an additional comparison was made with the control group with the same parameters but without ES. This comparison shows that the average speed on lanes with ES is lower than speed on control lanes by 16 km/h (14%) and 4.3 km/h (4.6%) respectively on the left and right lane. Results confirm the positive effect of ES implementation. However, on the lanes with a dedicated speed limit of 90 km/h, the 85th percentile of speed is significantly greater than the speed limit (by 22.7 km/h and 15.4 km/h respectively on the left and right lane).

The effectiveness of the non-standard sign of hazardous curve was estimated by comparing the speeds recorded "before" and "behind" the sign and speeds at the control curve without additional marking. Due to the function of non-standard marking (warning about hazard during the rain), the speed measurements were made in different weather conditions (table 3). Free flow speed of light vehicles on the left lane of the carriageway was tested, because of higher speeds on that lane in comparison to the right lane.

Table 3. Speeds at hazardous curve with non-standard sign and control curve in different weather conditions.

Weather conditions	Curve with additional non-standard sign			Control curve at curve	Speed difference**)
	„before” sign on tangent	„behind” sign at curve	speed difference*)		
Dry pavement	135.3	133.8	1.5	134.1	0.3
Rain	128.3	128.4	-0.1	134.0	5.6
Wet pavement (no rain)	133.4	129.0	4.4	134.4	5.4

*) difference between speed „behind” sign and „before” sign

***) difference between speed „behind” sign at treated curve and speed at control curve

Results show that presence of a non-standard sign in the area of a hazardous curve cause the speed reduction. It was found that on dry pavement average speed at the curve with non-standard sign do not differ significantly (0.2%) in comparison to speed for control curve. In case of rain and wet pavement (directly after rainfall) this difference is around 4%. The lack of a significant difference between the average speed "before" and "behind" sign during the rain can be result of speed reduction already before the sign. Such reduction can be the effect of simultaneous interaction of a sign perceived from a large distance and deterioration of visibility conditions due to the rain.

The impact of red transverse strip on approaches to crosswalks was analyzed based on free flow speed distributions at the following sections: "before" transverse strips; "in the middle" of transverse strips; at crosswalk (Fig. 2).

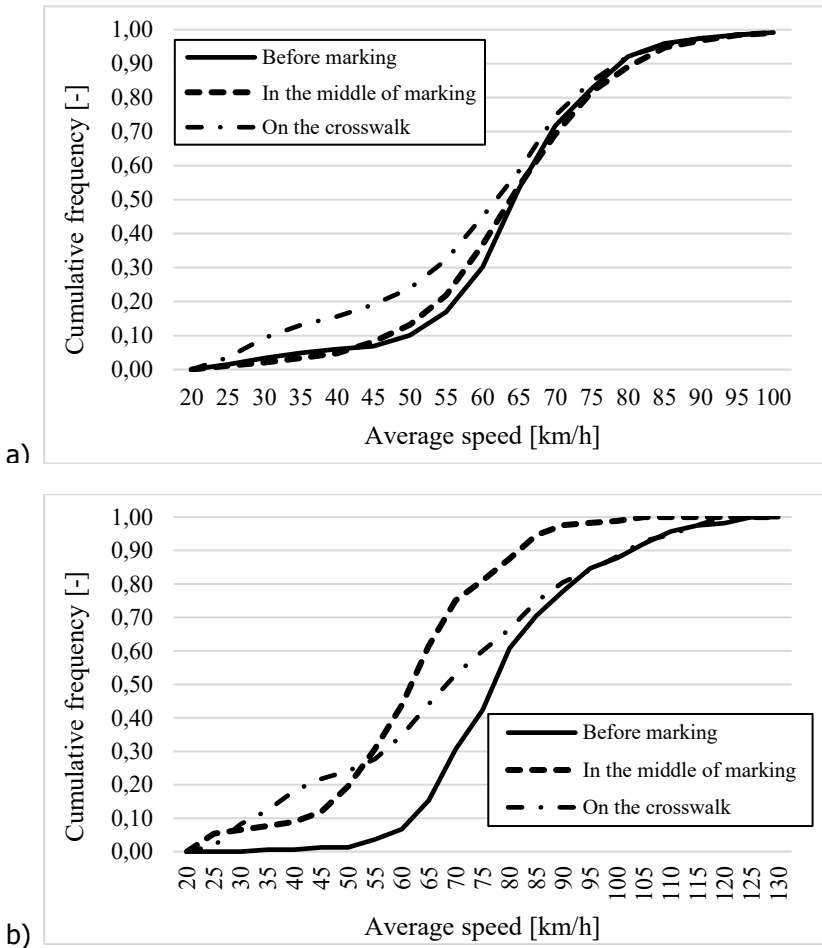


Fig. 2. Speed distributions on approaches to crosswalks with red transverse strip: a) Biorkow Maly city; b) Poskwitow villages.

Results show a statistically significant difference in average speed at crosswalks in comparison to the average speed "before" transverse strips. Average speed decreased by 15,5-27,5km/h (29-43%). At control crosswalks speed increased by 3,5km/h (6%) [10]. Despite the reduction of the average speed, the share of drivers exceeding the speed limit (50km/h) is 87-99% in section "before" transverse strips and 76% at crosswalks. Described results

show that red transverse strips can improve pedestrian safety. However, refuge island implementation is much more effective in vehicle speed reduction at crosswalks [11].

5 Summary and conclusion

The results of survey of ES indicate a varied degree of their understanding. The level of understanding declared by the respondents (including signs not analysed in the paper) varied from 23% (general speed limit sign of 90 km/h on rural roads) to 73% (speed limit marking on pavement). Surprising low level of understanding of the sign (44%) was obtained for the speed limit sign located above the lanes. The given examples indicate an important role of the pre-warning information on the applied ES to achieve the desired effect of such marking and signs. The results confirm that form of ES, frequency of its presence and drivers experience from other countries have impact on level of understanding the ES. However, the declared level of understanding the ES does not always mean the desired behavior in traffic.

The results of speed measurements confirm the impact of ES on the choice of speed by drivers. However, the degree of this impact varies and depends on its type and locations. Reduction of average speed by 4-16 km/h was statistically significant, especially in locations with greater accident risk. The impact of ES on the choice of speed by drivers was greater than for the standard marking, but still the desired level of speed was not obtained.

Non-standard road marking and signs are used very rarely and empirical studies of their impact on road users' behavior have the character of a case study. Therefore, it is necessary to combine different assessment methods (surveys, empirical studies, analysis in driving simulators) in order to better explain the mechanism of impact of the tested marking on road users' behavior.

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