

Impact of Toll Plazas Road Marking and Signs on Drivers' Behaviour

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Abstract. The paper presents the problem of applying non-typical marking and signs (not included in Polish traffic control guidelines) as a mean to improve traffic performance and safety in Poland. The need for use of such marking and signs was evaluated based on the observed drivers' behaviour supported by literature study. The results of these analyses confirmed that making the correct decisions by drivers can be difficult and may cause safety hazards, especially in the areas of toll plazas on motorways, which are characterized by a high degree of complexity of traffic organization resulting from various payment system (manual and electronic) and high speed. Studies of non-typical road marking and signs were conducted using surveys and empirical research on drivers' behaviour, which can be surrogate measures in assessing road safety. The outcome of research confirmed the usefulness of the developed method of the survey for assessing the non-typical marking and signs. Studies have shown that non-typical signs may lead to cognitive deformations, i.e., interpretation of their meaning which is not always consistent with the sender's intention.

1 Introduction

Measures of improving road safety and traffic performance may include low-cost steps related to the implementation of marking improving the perception and understanding of traffic rules. Such marking can also be non-typical marking, i.e. such which are not included in the guidelines for the organisation of traffic and are not widely used on the roads. The need for the use of such signs is apparent from the observations of drivers' behaviour and the experiences of other countries which implement similar improvement measures. In many countries, non-typical signs are used and the effects of their use are studied [1]. Analyses are most often carried out based on empirical data, research in driving simulators, and surveys of various groups of road users.

The studies of literature and own analyses of non-typical markings in Poland indicate the presence of the following groups of non-typical marking and signs:

- related to the speed management [2]
- alleviating the risk of rear-end crashes [3]
- facilitating the segregation of traffic on the lanes before toll plazas [4–6]

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- informing about the way in which to use additional traffic lanes or other elements in the section of the road [7]

One of the reasons for introducing non-typical marking and signs are the requirements of the dynamic development of ITS services, which may influence: a change in how the infrastructure has been used thus far, drivers' decisions and distraction. This applies particularly to responding to changing conditions in the traffic and preventing disruptions of the traffic flow, as well as eliminating threats to road safety.

The analysis carried out by the Authors have shown that toll plazas on motorways constitute a particularly desired location for non-typical marking. Toll plazas belong to areas with potentially major disruptions to the traffic flow due to having to stop the vehicle and the change in the road section from 2 or 3 lanes to up to 10. Increasing the number of lanes gives drivers the freedom of choosing the toll booth, which can increase the number of lane change manoeuvres during periods of peak traffic. In addition, toll gates on particular lanes can be designed for different groups of motorway users. Traffic conflicts associated with the choice of lane take place especially when drivers can make their payments both manually and in an automated way. Risk in road safety arising in such areas find confirmation in Authors' analyses of data concerning traffic incidents – an increase in the number of collisions (Property Damage Only (PDO)) by ca. 25%, with a lack of a significant effect on the number of accidents.

In literature, only relatively few publications refer to the analysis of the impact of marking and designating lanes in a toll plaza on traffic performance and road safety [4] and, less frequently, to the understanding of signs by drivers [6]. More often these publications provide a description of the impact of different ways of collection on road safety and traffic conditions [5]. Research presented in [4] indicates that the use of auxiliary non-typical markings for electronic toll collections resulted in improved traffic performance and road safety in comparison to the absence of such markings. The average travel time for drivers not using the system of automatic toll collection increased by 30 % (i.e. 8s), whereas for drivers using the system on Sunday it decreased by 18 % (i.e. 2s). The average rate of lane change decreased by 23%, the number of traffic conflicts decreased by 44%, whereas the number of collisions by 38% for drivers using the system of automatic toll collection. In Texas, surveys were carried out [6] to verify the effectiveness of background colours in signs informing about the method of toll collection in a toll plaza. Studies have shown that a change in colour from yellow to purple would be incomprehensible to drivers. The original sign (with a yellow background) was linked to a significantly smaller number of traffic disruptions than in the case of signs where purple substituted yellow.

There are no studies combining the results of surveys on the declared understanding of signs with the research on drivers' real behaviour together with registered road incidents in toll plazas. However, one may point to comprehensive research carried out by Greibe [3], the aim of which was to assess the impact of chevron markings on speed, gap and safety on motorways, and studies conducted by Faheem [8] in order to evaluate the effectiveness of cat-eye reflectors.

Toll plazas with a mixed payment system (manual and electronic) are places where non-typical marking were introduced in Poland. Some of the road users are equipped with electronic devices for paying fees and should make use of dedicated lanes. Such lanes are marked in a non-typical way already prior to the approach to the area of payment collection. Such signs, used in order to facilitate the early segregation of vehicles and the proper choice of the lane before the toll plaza, include (Figure 1):

- marking or pictograms on the roadway indicating the purpose of a given lane (in the form of orange arrows),
- signs informing of the different method of payment above toll booths.

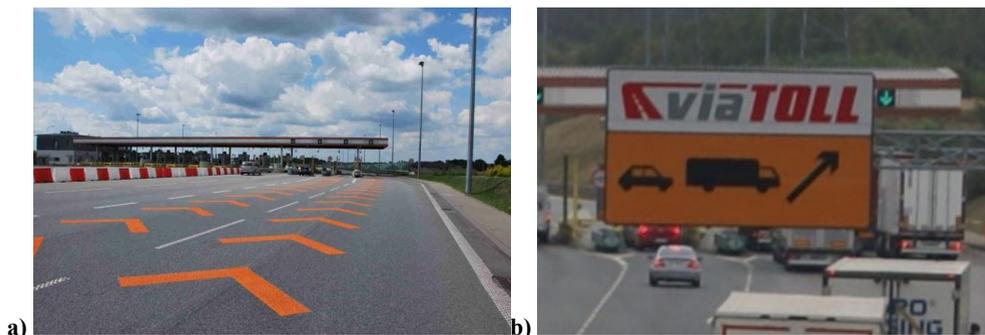


Fig.1. Non-typical marking of a toll plaza (a) and signage of toll booth (b).

To force greater reductions in speed, prior to the approach to the toll plaza additional marking was implemented i.e. transverse strips (Figure 2).



Fig. 2. Transverse strips to reduce speed before toll plaza.

The problem of using lanes in the vicinity of toll plazas is particularly important because of the road users who only use roads with non-typical markings occasionally. Due to the poor road network, a large group of users of motorways in Central and Eastern Europe drives on them only occasionally and thus have no way to "learn" the meaning of non-typical signs. In such cases, it may happen that drivers decipher the meaning of a given sign incorrectly and fail to react in a proper way. Distraction along with an extended time taken to analyse the content of the sign can result in making incorrect decisions. The essence of the problem in question is to assess to what extent the non-typical marking can be effective in the case of toll plazas with respect to different groups of road users.

Having regard to the problem described above, authors' purpose was to assess the influence of non-typical marking introduced on Polish motorways in toll plazas on road safety.

In light of the above-mentioned empirical study results, the assessment of drivers' level of understanding of non-typical marking and signage was considered necessary. Before commencing the research on the understanding of non-typical signs, the assumption was made that the comprehension would depend on two groups of factors:

- related to transport mobility (frequency of using a car, trip length, trip motivation, frequency of using express roads and motorways). The last two variables had significant importance for the research due to the assumed potential cognitive accessibility in memory. Some respondents could have come across the signs, at least theoretically, while driving abroad.
- affecting the understanding of road marking and signage constituted socio-demographic variables, such as: sex, age, a driver's status (amateur or professional), amount of kilometres driven annually and education.

2 Methods

The performed analysis of operating and the reception of marking of the toll plazas included:

- before-after analysis of road accidents (before non-typical marking and signage introduction and after that),
- drivers' behaviour observations,
- surveys aiming at verifying the level of understanding of marking and signage in selected groups of drivers.

The first step of the analysis included a simple comparison of the number of accidents and collisions from the period before and after the implementation of a non-typical marking together with the assessment of the change in the type of incidents and their circumstances. For this reason, the Authors selected equally long before and after periods of 18 months. This comparison allowed the identification of problems related to the operating of a given toll plaza after the introduction of non-typical markings. (Figure 1)

The observation was carried out in 4 toll plazas with the non-typical marking presented in Figure 1. Every measurement lasted 3-4 hours. The observation consisted of the registration of drivers' behaviour on neighbouring lanes "with and without" non-typical marking. It had been assumed that the drivers' errors related to non-typical marking would occur only in the area of neighbouring lanes of different purpose. Incorrect manoeuvres on other lanes were not subject to analysis and were treated as behaviours related to the standard service of vehicles in a toll plaza. Based on observations, a percentage share of a drivers' incorrect behaviours was determined in a group of drivers paying manually with respect to the traffic volume of all vehicles using toll plazas for manual payments and analogically – for vehicles using an electronic system supported by non-typical markings. The following manoeuvres were classified as incorrect:

- a) for drivers paying manually
 - traffic incidents
 - changing of lanes several times, which suggests that the marking was not understood
 - reversing from a booth designed for electronic toll collection
 - taking the lane for electronic toll collection and returning to the lane for manual toll collection
 - taking the lane for electronic toll collection and returning to the lane for manual toll collection just before the toll booth
- b) for drivers' using the electronic system
 - reversing from under a toll booth designed for electronic toll collection
 - entering the lane dedicated to the electronic toll collection just before the booth.

The observations also included the assessment of the reduction in speed before toll plazas caused by transverse strips.

The research into cognitive distortions in the reception of non-typical marking and signs was made based on the survey method (201 drivers). The survey included the frequency of using both a car and express roads and motorways, which helps to assess which group of drivers has come across the non-typical marking and signs for the first time.

3 Analysis and Results

A simple comparison of the number of accidents and collisions for the before and after periods of 18 months, carried out for 4 toll plazas, indicate an increase in the average number of accidents by 20% (respectively 6 and 8 accidents for the before and after period). In statistical terms, this change is not significant. An increase which was statistically significant occurred in the collision group (PDO), where the average number of collisions for all

locations increased by 23.5% (317 and 393 collisions, respectively for the before and after period).

The analysis of the collisions' circumstances fails to show important changes to their structure (Figure 3). The increase in the number of collisions occurs in groups of less numerous circumstances. In the case of accident types (Figure 4), an increase in accidents can be observed for the after period in the group of side impacts and hitting obstacles which may be indicative of drivers' distracted attention due to the impeded understanding of the markings. This was also accompanied by a significant decrease in rear-end collisions. The observed changes in the structure of circumstances and accident types indicate an inconclusive impact of non-typical marking on road safety.

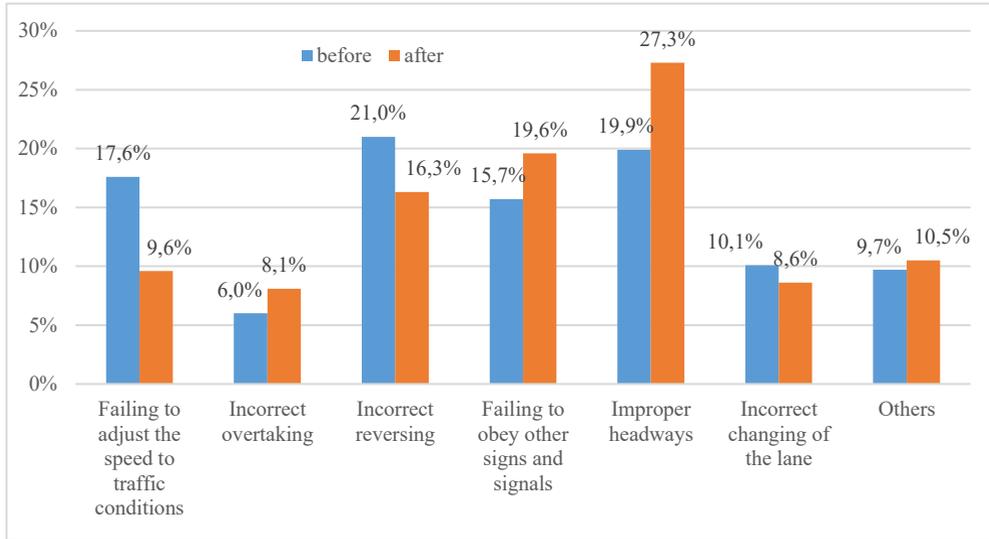


Fig. 3. The percentage share of collision circumstances for the before and after periods.

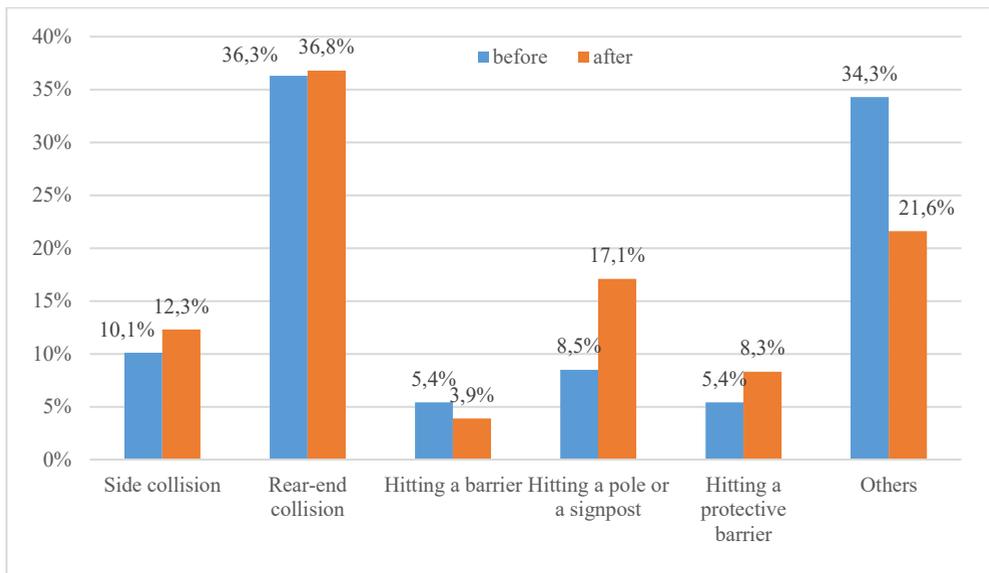


Fig. 4. The percentage share of the collision type for the before and after periods.

The study of drivers' behaviour indicates an insignificant percentage share of incorrect manoeuvres performed by drivers (Figure 5) in relation to traffic volume. The prevailing incorrect behaviours may have to do with non-typical marking which could be misinterpreted by some drivers. What is also surprising is a greater share of incorrect decisions among the users of the electronic toll collection system (or users of the manually toll collection system who use the electronic toll collection booth). Variation of the share of non-typical behavior on marked toll plaza lanes depending on the location, can be caused by frequent users of a given motorway section (multiple use of a given toll booth and "learning" effect)

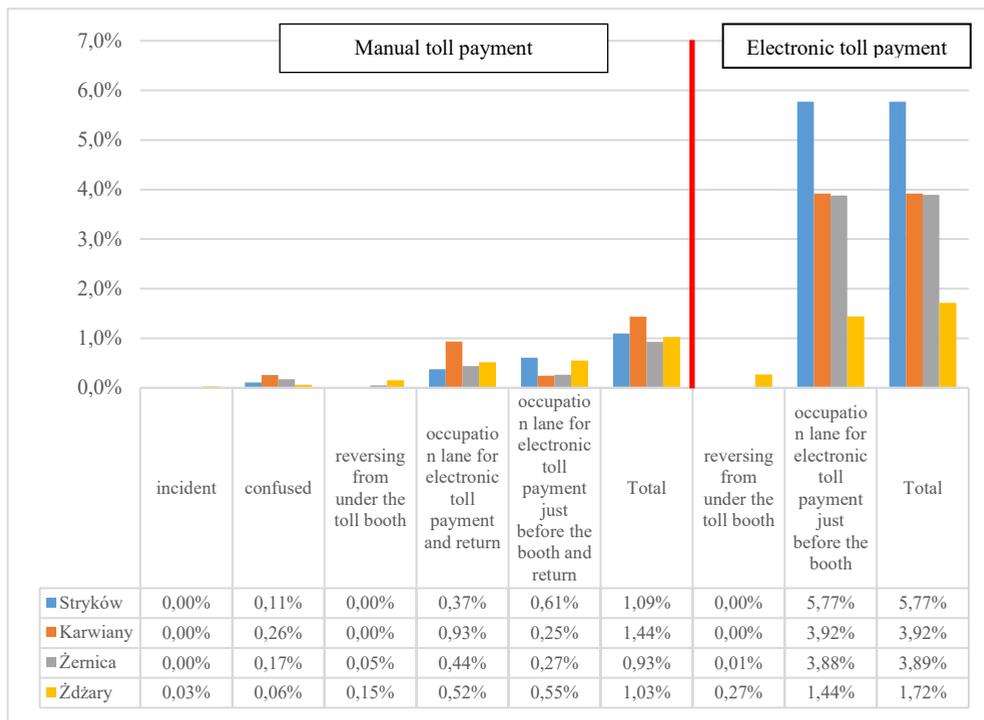


Fig. 5. Percentage share of erroneous manoeuvres with regard to traffic volume on booth manual and electronic gates.

In light of the above-mentioned empirical study results, the assessment of drivers' level of understanding of non-typical marking and signage was considered necessary. Therefore, surveys were carried out. The group of drivers had 201 drivers, within the age limit of 21-65 years (M= 38 years old, SD = 9.7); of primary education (24%), vocational education (31%) secondary education (15%) and higher education (30%); amateur drivers (24%) and professional drivers (76%) including driving instructors (12%); 73 women and 128 men.

The sample questions presented below are those related to the operating of marking informing about electronic toll collection. Percent of answers for each question are included in the bracket.

Have you ever come across this marking while driving?

1. No, never
2. Probably yes, but I don't remember where
3. Yes, several times, on different roads
4. Yes, on the motorway
5. Yes, abroad

What, according to you, can orange arrows on the road mean?

Please select no more than three of the proposed answers or give a new one, your own:

- 1) changing the selected lane is forbidden (**10,48%**),
- 2) marking help driving within the lane (**12,90%**),
- 3) overtaking is forbidden (5,24%),

- 4) constant speed is strongly advised (4,43%),
- 5) speed shall be reduced gradually (**13,71%**),
- 6) be prepared for new important information (3,62%),
- 7) change of traffic organisation because of road works (3,62%),
- 8) follow the arrows (**15,73%**),
- 9) those preferring electronic toll collection should follow these arrows (**7,25%**),
- 10) others, which?..... (4,03%)

The analysis of the data obtained on understanding the horizontal sign leading to a viaTOLL plaza showed that only 7% of all respondents, which is only 18 persons, gave the correct answer showing the right understanding of its meaning. It is worth stressing that many respondents understood the sign differently and a few answers obtained a comparably high number of choices. As many as four answers obtained the highest comparable number of choices a) follow along the arrows (15%); b) reduce the speed steadily (13%); c) keep the vehicle in a traffic lane corridor (13%) d) changing of the lane is forbidden (10%). All four meanings fail to match the intention of the sign, although the meanings a and b are closer to the semantic designate to some extent, despite the fact that they narrow down the intended meaning. In turn, c and d offer a meaning that is contradictory to the intended one.

The introduction of transverse strips located at the approaching to toll plazas results in a greater reduction of speed than in case applying only the typical marking. Average speed at measurement sections was 78 km/h and 89.7 km/h respectively for the section with transverse and non-transverse strips. Presence of transverse strips results in a reduction of average speed 4.4 km/h (5.6%) for the section with transverse strips and 2.9 km/h (3.2%) for the section without transverse strips.

4. Discussion and conclusion

The empirical research has shown that non-typical marking of the toll plaza causes problems to some motorway users who fail to work out the markings' intended meaning. Although the percentage share of traffic incidents caused by the marking is insignificant, it is considerably higher than in the case of incidents registered on the approach to toll plazas without non-typical marking. Manoeuvres involving a sudden change of lane just before the toll gate are considered hazardous. What might be surprising is the fact that incidents described in the paper related to the non-typical marking were registered even after 1.5 years since the introduction of marking. Thus, it was shown that even after a fairly long time of using non-typical marking, drivers still lack a full understanding of its meaning. It is related, among others, to the fact that particular road sections are used by some road users only infrequently. The observation as such is confirmed by surveys on understanding non-typical signs. The share of drivers taking part in the survey and declaring the lack of understanding of the sign leading to the toll plaza equalled 93% and was many times higher than the share of registered traffic incidents resulting from the lack of understanding of the marking meaning (1-2%). The divergences arising from surveys and real-life registration of drivers' behaviour should be interpreted in two ways. First of all, the number of cognitive processes taking place in a driver's mind do not translate into the number of recorded reactions. Behavioural reaction is the last stage in a chain of many cognitive operations preceding the activity. Before a driver makes a decision which leads to the observed behaviour, their mind conducts many complex cognitive analyses. The more difficult and demanding (even incomprehensible) the task is, the greater the number of operations. It was also confirmed by the result of the survey, which showed a great diversification in terms of the understanding of the marking meaning (especially the one leading to the toll plaza). Secondly, it should be stressed here that a driver had to react one way or another. Apart from additional and non-typical marking, drivers are

led to particular booths with the help of the communications displayed above the booth. In such cases, the ignoring of the additional marking may not lead to any traffic conflicts. Traffic conflicts are likely to be linked to attempts to obey the non-typical marking without having a full understanding of its meaning.

The comparison of accidents “before” and “after” the introduction of the non-typical marking results in no uniform trend in the number of accidents and collisions. Beneficial effect of reducing the share of accidents related to the speed adaptation to the traffic conditions was obtained, while the accidents related to the hitting an obstruction were increased. It was not possible to explain the increase in the number of accidents in a different way than the general tendency of the increase of the number of accidents also on other roads.

The application of additional marking in order to reduce speed has proved effective and drivers' reaction time was extended (time for making a decision) in the area where non-typical marking was present. Nonetheless, also cases of incorrect behaviour were registered and linked to the incomplete understanding of the meaning of the marking.

Because the period of using the non-typical marking proved insufficient to achieve a full understanding of the marking's meaning, one should note that non-typical markings and signs should be designed in such a way so as to ensure intuitive understanding. However, this demands extended analyses of the link between the process of content perception and human factors concerning the drivers.

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