



ROAD SAFETY IMPROVEMENT ON AT-GRADE INTERSECTIONS

Nemunas Abukauskas¹, Henrikas Sivilevičius², Virgaudas Puodžiukas³, Ineta Lingytė⁴✉^{1,3}Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania²Dept of Transport Technological Equipment, Vilnius Gediminas Technical University, Plytinės g. 27, 10105 Vilnius, Lithuania⁴Road Research Institute, Vilnius Gediminas Technical University, Linkmenų g. 28, 08217 Vilnius, LithuaniaE-mails: ¹nemunas.abukauskas@vgtu.lt; ²henrikas.sivilevicius@vgtu.lt; ³virgaudas.puodziukas@vgtu.lt;⁴ineta.lingyte@vgtu.lt

Abstract. Engineering improvement of roads is in many cases inseparable from the improvement of at-grade intersections, as one of the most hazardous engineering structures. At-grade intersections in Lithuania are currently subjected to intensive installation of different traffic engineering and safety measures. More and more often, to ensure road safety the measures of experimental nature are used the effect of which has not been specified yet. Therefore, for the research object three intersections were selected provided with safety islands with flexible plastic reflective posts. The research was carried out within the zone of conventional intersections with the left-turn deceleration and waiting lanes on the main roads of Lithuania. During the research the driving speeds were measured in three different locations and the changes in the speeds and in the frequency of traffic conflicts were determined. Using an analogical comparison of similar traffic engineering measures, a preliminary effect of the study measures was identified.

Keywords: safety islands, road safety, at-grade intersection, driving speed, traffic conflict.

1. Introduction

Engineering activity aimed at improving and assuring safety on the roads of Lithuania has been progressing on a large scale. Consistent and purposeful engineering activity has already given positive results in eliminating the most dangerous locations from the road safety point of view, the so-called black spots (Keršys *et al.* 2011; Meuleners *et al.* 2008; Prentkovskis *et al.* 2010). Over the last 6 years the number of black spots on the Lithuanian roads has been constantly decreasing. In 2006, 267 black spots were identified, whereas, in 2007 – 247, in 2008 – 225, in 2009 – 178, in 2010 – 135, in 2011 – 87, in 2012 – 58 (Fig. 1).

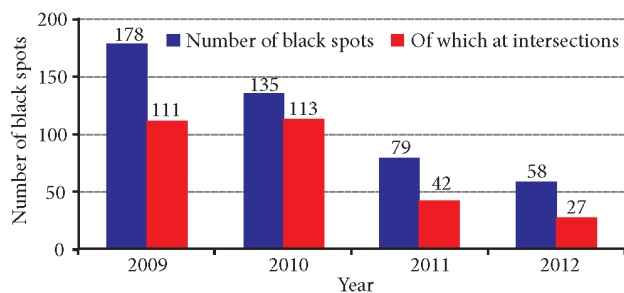


Fig. 1. The change in the number of black spots on the roads of national significance of Lithuania, 2009–2012

Analysis of the currently implemented engineering activity on high-accident locations has determined that more than half of all solutions are related to the engineering improvement of at-grade intersections (Čygas *et al.* 2009; Montella *et al.* 2011; Kulmala 1994) since intersections is often the main factor influencing the occurrence of black spot. The diagram data shows that the percentage of black spots (Gregoriades, Mouskos 2013) the occurrence of which was caused by the accidents on intersections amounts to about 50% of the total number of black spots.

Accident risk on intersections is explained by the crossing traffic flows and a large difference in their driving speeds. All these factors initiate the occurrence of traffic conflicts (Sayed, Zein 1999; Wang *et al.* 2011).

Based on the experience of USA, Sweden and Germany, segregation of traffic lanes reduces the occurrence of conflict zones, the risk of collisions, facilitates the drivers' orientation at the intersection, directs traffic flows to a necessary direction. The properly segregated traffic lanes increase road capacity, whereas, improperly segregated lanes may cause opposite effect and do even more harm to traffic than the absence of a separate lane.

Additional deceleration lanes for the left-turning vehicles reduce the number of rear-end collisions but



Fig. 2. Intersection with the minor road equipped with the left-turn deceleration and waiting lane



increase the driving comfort on the main road due to which the drivers may exceed the speed limit (Zhou *et al.* 2010). Thus, engineering measures to be installed must not only increase driving comfort for the vehicles moving on the main road but also to ensure that they use safe and permissible speed (Gomes, Cardoso 2012). Also, it is necessary to seek for more innovative, cheaper and shortly implemented measures, often those of experimental nature, which do not yield in their efficiency to the conventional, the earlier studied solutions.

2. Construction of the left-turn lanes in the intersection zone

At-grade three-way or four-way with the left-turn deceleration and waiting lane (Fig. 2). This engineering solution requires minimum investments, creates comfortable conditions for the drivers waiting to turn left, and ensures uninterrupted traffic on the main road (Chen *et al.* 2012; Kim, Washington 2006; Wang, Abdel-Aty 2008) The solution could be called conventional for the intersections of main and national roads in Lithuania when the amount of vehicles making turning manoeuvres at the intersection is sufficient (at least 1% of the total flow), though it is also necessary to ensure that the vehicles turning left would create no direct obstacle for the vehicles going straight ahead.

Intersection with the left-turn deceleration and waiting lane can be a safe enough solution if the drivers follow the horizontal marking requirements, however, in many cases this is difficult to achieve and this solution has no effect on the reduction of accidents (Elvik, Vaa 2004). Frequently, the zone of such intersections represents inobservance of horizontal marking requirements where inadmissible manoeuvres are made within the intersection zone (overtaking, increase of turning radii when entering or exiting the minor road) (Levinson *et al.* 2005). Due to a widening formed in the intersection zone, intended for the left turn, the island is used for overtaking slower vehicles (Fig. 2) and during the overtaking the speed limit is highly exceeded (Čygas *et al.* 2009).

Rumble strips painted with red colour. In order to improve road safety situation a perimeter of islands was started to be painted with red colour and additionally equipped with rumble strips (the strips are milled into asphalt pavement and cause strong vibrations and unpleasant



Fig. 3. Rumble strips in the intersection zone

audible rumbling) (Fig. 3). The aim of these measures is to prevent the drivers from driving on the island and, thus, to eliminate the most hazardous overtaking manoeuvres in the intersection zone. However, it was determined that the drivers nevertheless drive on a rough pavement surface in the island zone and, therefore no positive effect was achieved.

Raised splitter islands on the main road. The research has found that the intersections of this type show considerable reduction in accident rate (Elvik, Vaa 2004). The first two intersections of this type in Lithuania were built in 47.88 km and 61.14 km of the main road A11 Šiauliai–Palanga at the end of 2006 (Fig. 4).

The increased safety of intersections was affected by: elimination of overtaking manoeuvres in the intersection zone, reduced speeds due to narrowed and clearly segregated traffic lanes, more careful driving manner when getting sight of direct obstacle on the road. This measure directs the drivers to the proper driving trajectories and prevents them from departing, the contours of the island remain of good visibility under unfavourable climatic conditions, and therefore the intersection is early observed and recognized. With the reduced speeds on the main road more favourable and safe conditions are created for the vehicles entering from the minor roads – with the lower speeds on the main road the drivers on the minor road have more time to rationally assess traffic conditions on the main road.

The best practice was successful, however, these intersections has also some disadvantages:

- remaining probability of running on the island (in case of running on the island the vehicle chassis and tyres can be damaged, and this can cause



Fig. 4. Raised splitter islands in 47.88 km and 61.14 km of the main road A11 Šiauliai–Palanga



Fig. 5. Plastic reflective posts on the intersection of the road A16 Vilnius–Marijampolė

sudden and unpredictable change in the driving direction (Elvik, Vaa 2004);

- construction of this type of intersection is rather expensive due to the intervention into road pavement structure, the use of large amount of building materials and the need of large working power resources;
- when constructing single intersections of this type the un-expectancy effect is possible where the drivers used to the prevailing solutions on the road (mostly to the left-turn lanes delineated by horizontal markings) can drive on the raised islands and cause accident situations.

Safety islands with flexible plastic reflective posts. This type of islands in three-way and four-way intersections with the left-turn deceleration and waiting lane aimed at a full channelization of intersection was started to be used due to the fact that the raised islands in the intersection zone are effective but rather costly measures and a mass use of this measure on roads is hard to be implemented.

On Lithuanian roads the reflective posts were decided to be experimentally used also for the delineation of perimeters of un-raised islands. Installation of this measure was based on the assumption that the posts should accentuate perimeter of the islands and create an impression that of a raised engineering measure (the effect of full channelization). To ensure a satisfactory effect of experimental solutions one of the main tasks is to identify the impact of experimental measures on road safety.

3. The object and methods of research

The object of research is the experimental solution – raised safety island with flexible plastic reflective posts (Fig. 5). The origin of this experimental solution – the best practice example of foreign countries where the perimeter of raised traffic control measures (islands) in case of snow cover is additionally accentuated by 1 m high bright-colour posts (North European countries: Sweden, Norway). Thus, in case of even a thick snow cover the location and the perimeter of engineering measure are clearly seen.

The posts create an impression of solid raised obstacle. A visually realistic impression of a stationary engineering measure was even strengthened in winter period: the island zone with a snow cover has formed a naturally raised island surface (Hääl, Sürje 2006) (Fig. 6).

The site inspections have determined that due to an impression of stationary obstacle in these intersections the drivers try to avoid driving into the opposite traffic lane, no overtaking manoeuvres take place in the island zone. Such traffic changes create preconditions for the improvement of safety situation at this intersection (Elvik, Vaa 2004). However, seeking to accurately assess the effect of this measure, the following investigations were carried out:

- the change in driving speeds;
- the change in traffic conflicts;
- comparison of similar traffic engineering measures using an analogue method.

3.1. The change in driving speeds

For speed measurements on the main roads A5 Kaunas–Marijampolė–Suvalkai, A8 Panevėžys–Aristava–Sitkūnai and A16 Vilnius–Marijampolė three intersections of identical structure were selected (one on each road).

Speeds on the selected intersections were measured prior to the installation of measures and after a certain time of their installation. The days for the measurements were chosen with the prevailing similar weather conditions (creating identical traffic conditions for the drivers). Speed measurements on each of the intersections lasted for 1 hour before and after installation of measures.

Speed measurements were taken using the counters-classifiers Marksman 400. This equipment is intended for determining traffic volume, classifying vehicles and

recording driving speeds. The speed measuring error is less than 2. Two measuring sections were selected to measure driving speeds on the intersections (Fig. 7).

Speeds were measured in one driving direction.

3.2. The change in traffic conflicts

Investigation of traffic conflicts comprises: the identified “near miss” situations, also situations where a probability for the accident occurrence was identified but one of the conflict parties had taken precautionary actions. Based on Road safety manual traffic conflicts also include inadmissible manoeuvres, overtaking manoeuvre in the intersection zone, the cases of exceeding the speed limit, increase in driving speed before the intersection.

3.3. Comparison of similar traffic engineering measures using an analogue method

Comparison of similar traffic engineering measures is a reliable means to compare the effect of similar engineering solutions in respect of road safety. When implementing this comparison it is very important that traffic engineering measures were as similar as possible by their structure and operation, i.e. they are used in the same infrastructure objects (in this case – in at-grade intersections), they are intended for serving the same traffic organization assurance function and realized by the road users as a measure of the same type. The measures can differ in their installation materials, specific features and nature of technological installation.



Fig. 6. A naturally formed snow cover island of the road A16 Vilnius–Marijampolė

4. Analysis of research results

Essential data on the study intersections is given in Table 1.

Speed measurements on the selected intersections before installation of engineering measures showed that:

- the intersection of the road A5 Kaunas–Marijampolė–Suvalkai was passed by 428 vehicles over the study period. Compared to the other selected road sections the road A5 section represented an especially high traffic volume of heavy vehicles (more than 30% of the total traffic). With the prevailing high heavy traffic the heavy vehicles decrease the speed of vehicles moving behind. Due to such traffic pattern a further research of the intersection makes no sense since the essence of the

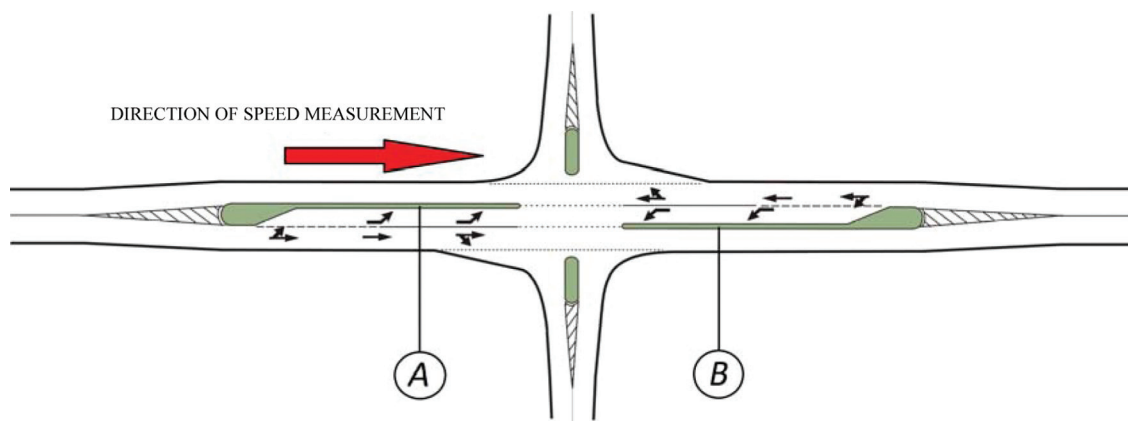


Fig. 7. Speed measuring scheme

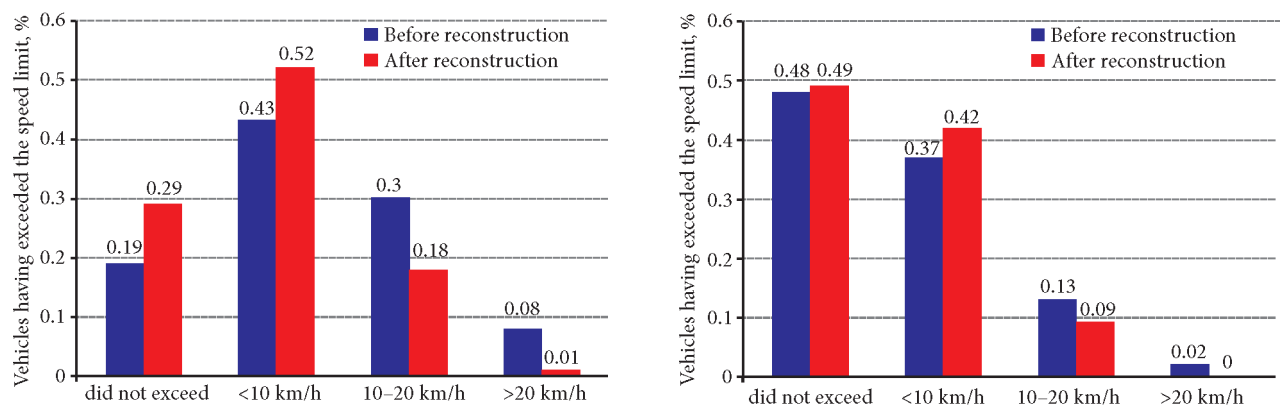
where section A – speed measuring post before the intersection. The post was erected at a 20–30 m distance to the intersection; section B – speed measuring post aimed at recording vehicles that passed the intersection or made a turn in it. The post was erected at a 20–30 m distance behind the intersection

Table 1. Data on the study intersections

Road No.	Measuring site, km	AADT, vpd	Type of intersection	The date of measure installation, year/month	$V_{permissible}$ in intersection zone,		Weather conditions and pavement condition during measurement	
					before, km/h	after, km/h	before	after
A5	25.76	10 326	Four-way	2010/12	90	70	Sunny, dry	–
A8	79.94	6 197	Four-way	2010/12	70	70	Sunny, dry	Overcast, dry
A16	18.09	10 309	Four-way	2010/01	70	70	Overcast, dry	Overcast, dry

Table 2. Measuring results on the intersections of the main roads A5, A8 and A16

Road No.	Measuring date and time, year/month/day hour:minutes	Measuring duration, hour	Vehicles eliminated from the research	Number of vehicles having taken for the research, vph
A5	2010.11.13 11:00–12:00	1 hour	3 vehicles having made the turning manoeuvres and 1 slow-speed vehicle	424
A8	2010.11.13 14:30–15:30	1 hour	5 vehicles having made the turning manoeuvres and 3 slow-speed vehicles	210
	2011.05.05 14:30–15:30	1 hour	4 vehicles having made the turning manoeuvres and 2 slow-speed vehicles	210
A16	2009.11.03 11:00–12:00	1 hour	No	311
	2010.11.14 11:30–12:30	1 hour	2 slow-speed vehicles	296

**Fig. 8.** Distribution scheme of prevailing speeds in the intersection zone of roads A8 (on the left) and A16 (on the right)

research lies in the change of speeds, the decrease or increase of which is caused not by traffic volume but by installation of engineering measure. Also, on the road A5 intersection after installation of posts the speed limit has changed (from 90 to 70 km/h), therefore it is impossible to identify the effect of each measure separately. Due to the above reasons, the road A5 intersection was eliminated from further research;

- the intersection of the road A8 Panevėžys–Aristava–Sitkūnai was passed by 218 vehicles over the study period. 8 vehicles were eliminated from the research, of which 5 vehicles having made the turning manoeuvres in the intersection and 3 low-speed vehicles,
- the intersection of the road A16 Vilnius–Marijampolė was passed by 311 vehicles over the study period.

Having taken additional speed measurements (after implementation of measures), on the road A8 Panevėžys–Aristava–Sitkūnai intersection 6 vehicles were eliminated from the research: 4 of them having made the turning manoeuvres in the intersection and 2 slow-speed vehicles. On the road A16 Vilnius–Marijampolė intersection 2

slow-speed vehicles were eliminated from the research. Table 2 gives the research data.

Speed measurements on the selected intersections have determined that after implementation of measures the speed regime at the intersections of both roads has significantly changed (Fig. 8).

One of the most important changes – reduction in the number of vehicles driving at especially high speed: on the road A8 Panevėžys–Aristava–Sitkūnai such vehicles made 1% of the total traffic after implementation of measures (8% before), and on the road A16 Vilnius–Marijampolė no cases of especially high speeds were recorded after implementation of measures (2% of the total traffic before). Analysis of the research data has determined that after implementation of measures the actual speed of vehicles on the intersections has decreased, the number of cases of violent exceeding of speed limit has dropped, the average driving speed has decreased (Table 3).

Analysis of the change in speeds has determined that the average driving speed on the road A8 Panevėžys–Aristava–Sitkūnai decreased by 4% (4 km/h), on the road A16 Vilnius–Marijampolė – by 2.7% (2 km/h).

Besides the actual decrease in speeds an important criterion is the decrease in the difference of driving

Table 3. Data on measuring the change in speeds

Road No.	Number of passing vehicles		The largest determined driving speed		Vehicles exceeding the speed limit,		Average driving speed,		Average decrease in speeds,		
	before	after	before	after	before	after	before	after			
	unit		unit		%		km/h		%		km/h
A8	210	210	102	98	81	71	78	75	4		4
A16	311	296	92	84	52	51	73.3	71.3	2.7		2

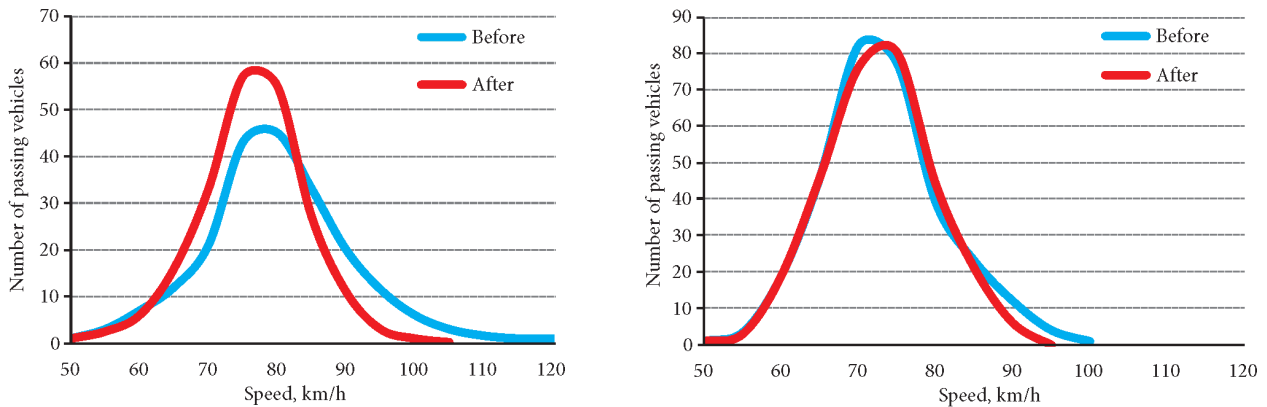


Fig. 9. Diagrams of the change in speeds (the road A8 – on the left, the road A16 – on the right)

speeds (with more uniform speed of the moving vehicles the amount of conflicts is proportionally decreasing). Before installation of intersections on the road A8 Panevėžys–Aristava–Sitkūnai 77.1% of the total traffic travelled within the speed limits of 70–90 km/h, whereas, after implementation of measures 87.1% of the total traffic travelled within the speed limits of 70–90 km/h. Respectively, on the road A16 Vilnius–Marijampolė – 74.9% before and 76.7 – after installation of intersection. Diagrams of the change in speeds are given in Fig. 9.

Analysis of the change in speeds has identified obvious differences between separate roads: on the road A16 Vilnius–Marijampolė percentage of vehicles not exceeding the speed limit after installation of posts was 49%, whereas, on the road A8 Panevėžys–Aristava–Sitkūnai – only 29% of the total traffic. After implementation of measures on the road A16 Vilnius–Marijampolė no violent cases of exceeding the speed limit were recorded, whereas, on the road A8 Panevėžys–Aristava–Sitkūnai such cases still remained (Fig. 9). The speed difference on the roads of identical technical category is explained by different local conditions (road A8 Panevėžys–Aristava–Sitkūnai environment – rural area, road A16 Vilnius–Marijampolė environment – the suburbs), also by a higher traffic volume on the road A16 Vilnius–Marijampolė. An important change in speed distribution after implementation of measures is the increased number of vehicles exceeding the speed limit up to 10 km/h. The increase could be caused by the decrease of cases of exceeding the speed limit (vehicles exceeding the speed limit by more than 10 km/h before installation of intersections, exceeded it less after their installation, i.e. up to 10 km/h).

Having made a research of traffic conflicts on the selected intersections it was determined that: before

implementation of measures in the intersection zone of road A8 Panevėžys–Aristava–Sitkūnai during the study hour two overtaking cases took place. In one case, the overtaking was made under oncoming traffic: the vehicle to be overtaken, the vehicle that overtook and the upcoming vehicle were found in one cross-section of the road at the same time. This traffic situation is assessed as especially dangerous. On the road A16 Vilnius–Marijampolė intersection during the study hour one overtaking case was recorded using the left-turn deceleration and waiting lane.

During the site inspection of intersections after implementation of measures no overtaking cases were recorded. Also, there were no outrageous cases where the island is circuited not from the left but from the right side. When assessing traffic conditions for the vehicles driving on the minor road, it was determined that due to the reduced speeds on the main road more comfortable and safe conditions are created for the vehicles on the minor to enter (cross) the main road.

For the comparison the analogue method was used. In this instance, similar traffic engineering measures are compared having identical structural and operational solutions:

- installation of raised splitter islands on the main road (full channelization of intersection);
- installation of flexible reflective posts on the main road (full channelization of intersection).

For the comparison the most important parameters were determined the change of which can result in a positive or negative impact on the traffic in the intersection zone. Table 4 gives the impact of analogical measures on the change in traffic indices. “Positive” refers to the traffic indices the impact of which on road safety situation is positive, and vice versa.

Table 4. The impact of analogical measures on the change in traffic indices

Criterion	At the intersection	
	Stationary splitter island	Flexible reflective posts
Decrease in driving speeds	Positive	Positive
Elimination of overtaking manoeuvres	Positive	Positive
Improvement of visibility and recognisability of intersection	Positive	Positive
Possible sudden departure of vehicle from the route in case of running on the measure	Negative	Positive
Damage to the vehicle structural components in case of running on the measure	Negative	Positive
Durability of measure	Positive	Negative

The comparison results show that in case of installation of both measures a positive change in traffic indices is achieved: the driving speeds are decreased, hazardous manoeuvres are eliminated (especially the overtaking), visibility and recognisability of the intersection are improved. It was determined that on the intersections with flexible reflective posts the reduction of accident rate is of similar level to that on the intersections with stationary splitter islands. Several essential differences have been also determined during the analogical comparison: durability of the above measures is different in respect of consequences in case of running on the measure.

5. Conclusions

1. Seeking to accelerate a road safety improvement process it is necessary to look for the most cost-effective, cheap and shortly implemented measures. For this purpose the research on the installation of flexible reflective posts in the island zone was carried out. The effect of measure was determined based on the decrease in driving speeds and the change in the frequency of traffic conflicts.

2. Speed measurements have determined that after implementation of measures the speed regime at the intersections has significantly changed: the actual driving speed decreased from 2.7% (2 km/h) on the road A16 Vilnius–Marijampolė to 4% (4 km/h) on the road A8 Panevėžys–Aristava–Sitkūnai, the average driving speed decreased from 15.2% on the road A16 Vilnius–Marijampolė to 15.5% on the road A8 Panevėžys–Aristava–Sitkūnai.

3. Research on the change in traffic conflicts has determined that after implementation of measures when the most hazardous turning manoeuvres were eliminated and the actual driving speeds were decreased a probability of the occurrence of traffic conflicts in the intersection zone has been considerably reduced.

4. With the help of the analogue method, where similar traffic engineering measures are compared, it was determined that in many cases the flexible reflective posts do not yield in their efficiency to the stationary splitter islands and in some positions the effect is even higher.

5. Installation of flexible reflective posts is a cheaper traffic engineering measure than stationary splitter islands (costly construction works are avoided, less material is

needed), therefore the effect of this measure was assessed as economically positive.

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