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INVESTIGATING DRIVERS' BEHAVIOUR AT NON-SIGNALISED PEDESTRIAN CROSSINGS

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Abstract. Pedestrian safety is one of the most serious problems in Estonian traffic. Thus every third person killed on the roads is a pedestrian. The main goal of this paper was to find which factors could affect drivers' attitude to give way to pedestrians at non-signalised crossings. By the obtained data we could follow up that the main factor influencing drivers willingness to give way at non-signalised urban crossings was motor vehicle traffic volume.
The second part of the study involves drivers speed choice at pedestrian crossings. Here we considered that:
1. The driving speeds at crossings are rather high. At almost 60 % of runs the speed was higher than a speed limit.
2. The change in speed at the vicinity of zebra crossing is minor. The situation is especially critical at the crossings with speed limit of 70 km/h. On these sites an average speed is dangerously high at the whole vicinity of zebra crossing and does not allow breaking safely when driver occurs the pedestrian waiting at the roadside.

Keywords: road safety, pedestrian safety, non-signalised pedestrian crossing, drivers' behaviour.

1. Introduction

Road accidents and their consequences are a significant social problem, as well as one of the indicators of the sustainable development of urban systems. More than 10 000 pedestrians and cyclists are killed every year in EU countries, representing more than 20 % of all road deaths. The small proportion of pedestrian and cyclist casualties that occur in rural areas are relatively severe and should be not forgotten, but this review is concerned with the majority, which occur in urban areas.

Pedestrian safety is also one of the most serious problems in Estonian traffic, especially in urban areas. If one compares Estonia's figures with those of the neighbouring country Finland, the pedestrian road traffic risk in Estonia is 2–4 times higher. The situation is extremely alarming in urban areas, which share about 85 % of all pedestrian accidents in Estonia. It is documented that every fourth urban pedestrian accident occurs at non-signalised pedestrian crossings, often referred as zebra crossing or in their vicinity.

It is a well studied fact that the road traffic risk of pedestrian fatality or injury is related to drivers' behaviour aspects, such as choice of speed when approaching a crossing and also the driver's willingness to yield to pedestrians at non-signalised crossings.

2. International comparison

After establishing the independence, during last 15 years the motorisation level rose rapidly in Estonia – from 154 (2000) to 367 (2005) registered cars per 1000 inhabitants. Such a rate of motorisation has caused a number of negative consequences, like pollution and road accidents. Even if the safety development characteristics during the last decade have been generally positive, the differences in road safety situation between the old EU member states and Estonia are remained rather big. Even if Estonia has had a visible progress in road safety, the country remains among the countries with poorest road safety data in the EU. One of the alarming issues in Estonian road safety is the safety of pedestrians.

The per capita risk of death of pedestrians in EU-15 countries in 1996 is shown in Table 1. Data is from IRTAD

(International Road Traffic and Accident Database – http://www.bast.de/htdocs/fachthemen/irtad/english/irtadlan.htm) and Estonian Road Administration annual statistics. These figures represent the pedestrians per capita risk. To obtain a better understanding of the risk to pedestrians, each country needs to collect information on the amount of walking which is not available today.

Due to the data of Estonian Road Administration during 1998–2002 the police reported 1142 fatalities on Estonian roads. Of these, pedestrians accounted for 361 fatalities (Table 2). Thus every third person killed on roads is a pedestrian. In Estonia, the police only record pedestrian accidents in which at least one vehicle was also involved. The police do not record single pedestrian accidents, such as falls or collisions with bicyclists.

Thus taking into account the risk data of old EU countries in 1996 and then comparing the pedestrian risk indicators with the Estonian ones, we can get that the pedestrian fatality risk is somehow three times higher than in old EU on average and even 7–8 times higher than in countries with the best safety characteristics, like the Netherlands and Sweden.

Pedestrian risk is especially high in urban areas, where pedestrian accidents obtain almost half of all registered injury or fatality accidents. But the biggest city, capital Tallinn, with the population of 400,000 inhabitants, shows the share of pedestrian fatalities of all fatal road accidents even as 63 % (Table 3).

The problems associated with pedestrian safety are far greater than they are reflected by the official safety statis-

Table 1. Per capita risk of death of pedestrians in EU-15 countries in 1996 and Estonia (average of 1998–2003)*

Country	Population, mln	Number of fatalities		Fatalities per million of population		Percentage of fatalities with pedestrians involved
		Total	Pedestrians	Total	Pedestrians	
Austria	8,02	1 027	157	128	20	15
Belgium	10,18	1 336	155	131	15	11
Germany	81,91	8 758	1 178	107	14	14
Denmark	5,29	514	68	97	13	13
Spain	39,68	5 483	960	138	24	18
France	58,21	8 541	1 043	147	18	12
Finland	5,13	404	70	79	14	17
Greece	10,48	2 063	469	197	45	23
Italy	57,25	6 688	987	117	17	15
Ireland	3,58	453	113	127	32	25
The Netherlands	15,60	1 180	109	76	7	9
Portugal	9,82	2 730	624	278	64	23
Sweden	8,82	537	74	61	8	14
UK	58,29	3 740	1 039	64	18	28
Estonia*	1,35	228	72	169	53	32

Table 2. Pedestrian accidents, Estonia 1998–2002

		All 1998–2002	Pedestrian 1998–2002	Share of pedestrian accidents, %
Total		1 142	361	32
Total urban		323	160	50
Total signalised crossing		23	22	96
Urban	non signalised crossing	15	14	93
	intersections	43	17	40
	road sections	300	138	46
Rural	Total rural roads	818	201	25
	signalised crossing	0	0	–
	non-signalised crossing	0	0	–
	intersections	41	9	22
	road sections	777	192	25

Table 3. Road accidents in the City of Tallinn, Estonia (1999–2002)

	Road accidents, 1999-2002			Percentage, %		
	Accidents	Fatalities	Injuries	Accidents	Fatalities	Injuries
Tallinn:	1853	97	2109	100	100	100
Pedestrian accident	1056	61	1035	56	63	49
Cycle accident	158	3	158	9	3	8
Other accident types	639	33	916	35	34	43

tics. This is one reason why analyses of the pedestrian safety are necessary.

3. Pedestrian risk and motor vehicle speed

The choice of exposure is crucial to any comparison of own risk across different modes of transport. The reason is that the speed and duration of the individual trips differ between the various modes of transport.

Walking and cycling are about 7–8 times more dangerous per person kilometre than is a travel by private car, whereas travel by private car is more dangerous per trip than walking. Cycling is twice as dangerous per person hour travelled relative to walking and private car travel. If trips of less than 300 metres are included, the number of casualties per million pedestrian trips drops to 1,1 (instead of 1,7). The other figures of the table do not change significantly if trips of less than 300 are included [1]. About 70–75 % of all pedestrian casualties are falls.

Fig 1 illustrates how the fatality and injury risk of pedestrians is depending on motor vehicle speed at a collision situation. It could be obtained that the pedestrian fatality and injury risks are highly depending on collision speed. Thus the probability of staying alive in collision is about 6 times higher when collision speed is 30 km/h instead of 50 km/h. At 70 km/h collision speed the probability of being killed in accident is almost 95 %, when only 15 % at collision speed of 40 km/h [2]. But all these speeds are common on zebra crossings, as speed limits and the actual speeds of individual motor vehicles could be even much higher.

4. International risk evaluation of zebra crossings

According to the Estonian Road Traffic Act, a zebra crossing is a part of the road, which is provided for pedestrians when crossing the carriageway and which is specially marked. If there is a zebra crossing in the vicinity, pedestrians must use it when crossing carriageways. Drivers approaching a non-signalised zebra crossing must adapt their speed so as they can stop in order to give way to pedestrians who are just entering the crossing. If necessary, drivers shall stop to allow pedestrians to pass. Drivers approaching a zebra crossing must not overtake or pass another vehicle if that vehicle obstructs a full view of the crossing.

In Estonia like in many other countries, zebra crossings consist of broad stripes which are parallel to the direction of the road. There are no special regulations where non-signalised zebra crossings could be established on roads with certain speed limit. Thus the most of zebra crossings are located in urban streets with regular speed limit of 50 km/h, but sometimes we can found them also on streets or roads with a special speed limit of 70 km/h. Also there is a usual practice to mark zebra crossings at intersections.

The risk to pedestrians crossing roads at various points in traffic systems has been studied in a series of studies from England [3, 4], Norway and Sweden [5]. The same method was used in all these studies. The number of accidents in which crossing pedestrians was involved was compared to the number of pedestrians crossing with a fixed period (12 min counts outside the rush hour were used). One study found that the risk involved in crossing road sections at up to 45,7 m from a zebra crossing including the crossing itself was 30 % higher than that at over 45,7 m from a zebra crossing, whereas three other studies found that the risk was up to 50 % lower. Three studies found that the risk involved in crossing roads at or near non-signalised junctions, at distances of up to 18,3 m from the junctions and up to 45,7 m from a zebra crossing was up to 127 % higher in comparison with that at non-signalised junctions lacking zebra crossings, although two other studies found that the risk was up to 35 % lower. The effects of other circumstances, such as central islands, road lighting and road width were not eliminated in the studies.

In New Zealand, the risk to crossing pedestrians has been found to be 15 % lower at non-signalised zebra crossings, in comparison to crossing roads at any other point. Pedestrian exposure was estimated through interviews. No allowance was made for possible differences in the occurrence of other measures, quantities of car traffic and speed of car traffic [6]. A before-and-after study of the construction of 62 zebra crossings in London showed that the safety effects of the crossings was dependent on the accident rate (all accidents) during an earlier period. At places where there had been fewer than 2 accidents per year in a 100 m section with the crossings located at the section centres, the number of pedestrian accidents increased significantly by 50 %. In contrast, the number of pedestrian accidents dropped by 50 %, where there had been more than 3 accidents per year. There was an attempt to reduce the effects of bias in the results [7].

An American with/without accident study of pedestrian crossings marked with 2 continuous white lines (parallel to the stop lines, but without zebra stripes) at 400 non-signalised junctions showed that the risk to crossing pedestrians was about twice as high at the pedestrian crossings in comparison to unmarked crossings. The pedestrian crossings at the 400 junctions were marked only on one arm of the primary road, whereas the other arm was unmarked. Only pedestrian accidents occurring at the crossings themselves were included in the study, which is critical, as the location of the unmarked crossings must therefore be determined and accidents occurring in the vicinities of the crossings are important in a risk assessment. The traffic was counted for 24 h at 40 systematically-selected junctions. At these junctions, the risk to crossing pedestrians was only by 40 % higher than at crossings in comparison to the unmarked ones [8].

Draskóczy and Hydén [9] point out that the give-way rules possibly influenced the effect of the pedestrian crossings. Even though most studies indicate a negative safety effect of pedestrian crossings, there are exceptions, eg from England and Norway. England and Norway have clear give-way rules which require vehicles to give way to pedestrians, whereas other countries, such as Sweden, had no such rules. Draskóczy and Hydén thus suggest introducing clear give-way rules in the Swedish Road Traffic Act, so that zebra crossings should reduce the number of accidents in which crossing pedestrians are involved.

Swiss traffic regulations were amended in 1994, so that vehicles must give way when the behaviour of a pedestrian clearly indicates that he or she intends to use a zebra crossing. Earlier, pedestrians needed to signal to drivers that they wished to cross the road. It was possible to conclude on the basis of behaviour studies that the average number of vehicles that drove past before waiting pedestrians crossed the road dropped from 2,6 in the before period, to 1,5 in the after period. The proportion of motorists who stopped/braked and allowed pedestrians to cross the road increased from 12 % in the before period, to 32 % in the after period, one year after amendment of the give-way rules [10]. Based on literature, Varhelyi [11] notes about non-signalised zebra crossings:

1. The presence of pedestrians at zebra crossings has little or no influence on the speed of approaching vehicles.
2. Between 4 and 30 % of vehicle drivers give way to pedestrians at zebra crossings.
3. Drivers are more willing to slow down or stop for crossing pedestrians when the vehicle approach speed is low.

A Swedish interview survey showed that crossing pedestrians feel safer at zebra crossings than they are away from them [12]. This should possibly be considered in the context that pedestrians walk about 10 % faster when crossing a road away from a zebra crossing than they do at such crossings [13].

5. Motor vehicle user's behaviour in the vicinity of zebra crossings

In the context of the provision being made for them and the changes in behaviour being required and asked of drivers and pedestrians themselves need to be educated and encouraged to take steps that are open to them to reduce their own exposure to risk in the course of the increasing use they are being encouraged to make of walking and cycling as means of transport. They need to be fully consulted and informed about the routes being developed for them, and especially of any situations in which, for the sake of safety, any route is made somewhat less attractive or convenient in some other respects. Both pedestrians and cyclists also need to be encouraged to use reflective clothing and devices that increase their conspicuity to drivers. In all these ways it should be possible to achieve considerable increases in the use of healthier and more environmentally friendly means of transport and still reduce the numbers of deaths and injuries among pedestrians, and thus to contribute to sustainable safety.

Because of differences in design, behaviour patterns, knowledge of safety design and planning, concerning zebra crossings, it is difficult to assess the rapid safety effect of reconstructing zebra crossings in Estonia. Effects of up to ±50 % in the number of accidents involving crossing pedestrians have been attained or estimated through the construction of zebra crossings on road sections. These sections should be marked at the point safest for pedestrians to cross the road. Also at junctions, zebra crossings give the best safety effect for pedestrians when they are carefully planned. When located and redesigned optimally, these crossings should be considered by pedestrians to be "guides to the safest route".

5.1. Motorists' observance of their obligation to give way at zebra crossings

The idea behind zebra crossings is to reduce the risk for pedestrians crossing and to reduce their waiting time. Technical approaches that can increase the proportion of motorists who do observe pedestrian rights of way should be investigated more closely. In this research we were interested in drivers' behavioural aspects at zebra crossings with a clear give way obligation. The field survey was conducted in the capital city Tallinn and some other bigger cities, at 16 crossings with a rather different shape. The main goal of surveillance was to find which factors could affect drivers' attitude to give way. The survey was conducted at the daytime, at off peak hours with a different traffic and pedestrian volume during one hour surveillance periods, twice in each crossing. The situation when there was a pe-

destrian or a group of pedestrians clearly representing their wish to cross the road. The determined parameters in the mentioned situations were: the sequence number of the motorist stopped at zebra crossing, thus giving way to pedestrian(s) counting started when the pedestrians walked to the crossing, and first motor vehicle approaching the crossing. Such situations were defined as contacts. Also some other background data like the number of pedestrians waiting to cross at the same time (pedestrian group size), hourly pedestrian and motor vehicle traffic were determined.

We were also interested which of surveyed factors could possibly have influence on drivers attitude to give way. Thus some regression analysis was performed. When comparing the average sequence number of the first stopped car (SN) and other obtained in survey data, we could assume that pedestrian group size (Fig 1), as well as pedestrian traffic volume (Fig 2) had only minor influence on driver's behaviour, when motor vehicle traffic volume was found to be the main factor here (Fig 3). This result is also illustrated with figures below. Thus we can consider that in more – strain traffic situations drivers are much less favourable to give way than in a low-volume traffic.

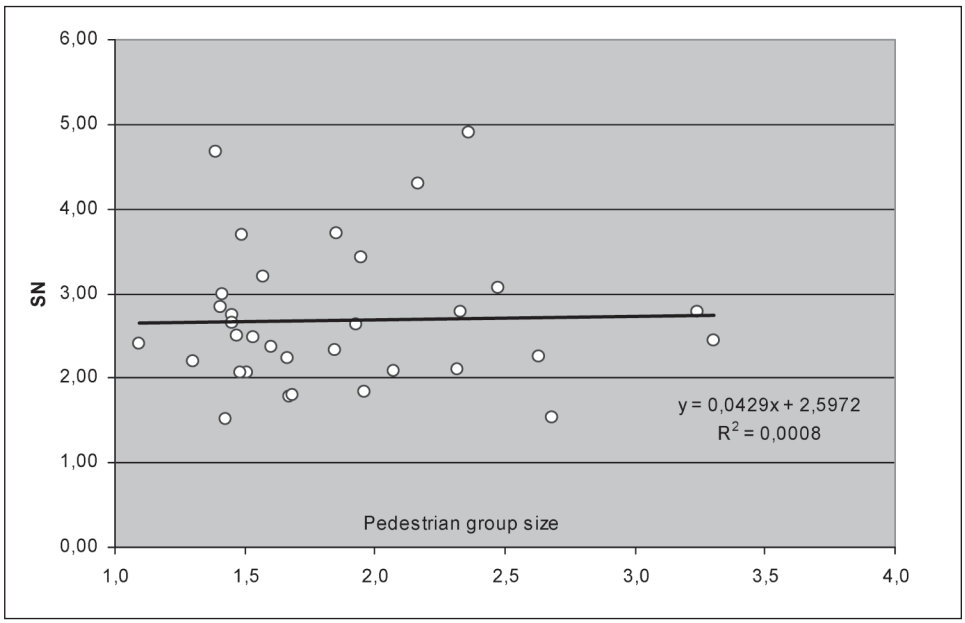

Fig 1. Dependence on the average sequence number of the first stopped car (SN) and pedestrian group size

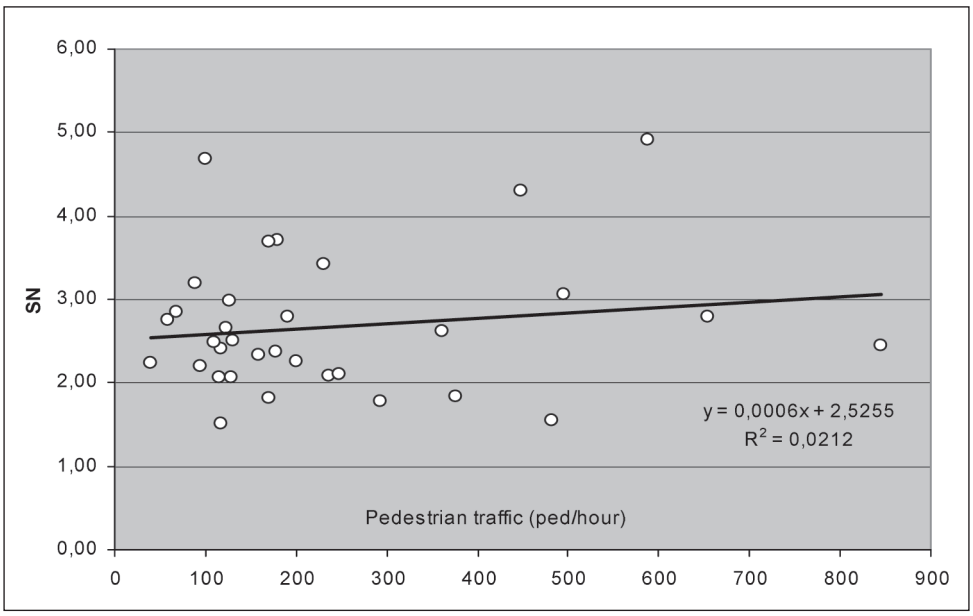

Fig 2. Dependence on the average sequence number of the first stopped car (SN) and pedestrian traffic volume

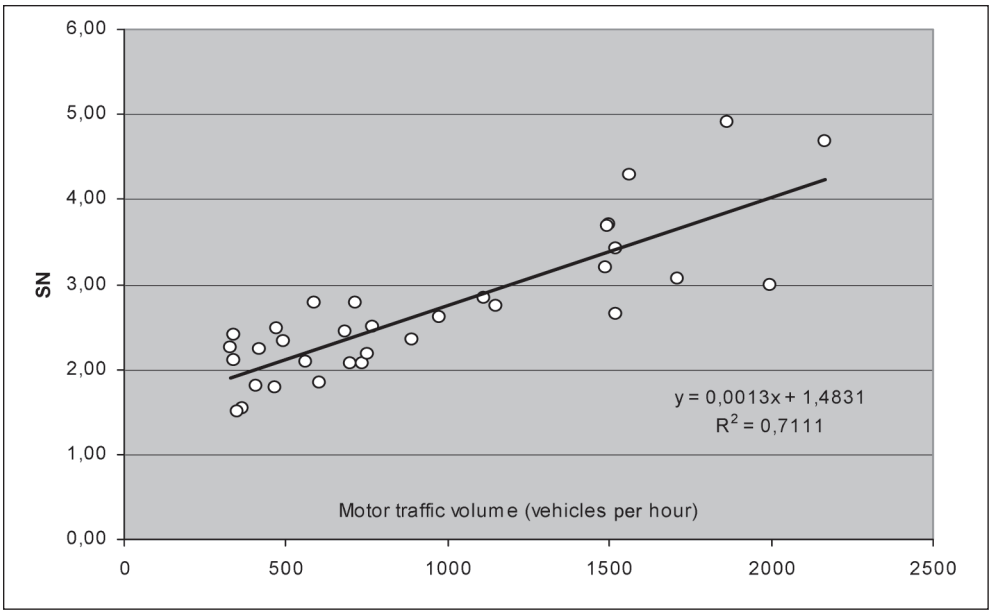

Fig 3. Dependence on the average sequence number of the first stopped car (SN) and motor vehicle traffic volume

5.2. Motorists' choice of speed in the vicinity of zebra crossings

The former surveys contain indications that, when installing zebra crossings and road lighting, the safety effects obtained for pedestrians depend on the speed level of vehicular traffic and the quantity of traffic. It is thus important to determine the speed values at crossings, but especially does the crossing itself has any influence on drivers speed choice when approaching the crossing.

It should be highlighted that the technical data was obtained from another survey, which aim was to analyse data about real speeds and delays when moving in urban street network. The equipped with GPS receiver, video recorder and data storage devices car used the in-flow driving method at previously chosen routes in Tallinn. The car speed and location were fixed in every second during the movement. Later the location of non-signalised crossings located at the chosen routes was assigned and thus it was possible to survey the actual driving speeds at the vicinity of zebra crossings. It is important to understand that situations with waiting for crossing pedestrians (contacts) were eliminated from the survey this time, as we were interested only in empty crossing influence on speed choice.

Each route was driven at least 6 times, mainly at off-peak hours, where speed choice was relatively free. When eliminating the contact situations with pedestrians, the total number of measured situations was 120, at 29 crossings, of which on 24 was introduced the speed limit of 50 km/h and at 5 crossings – 70 km/h. The speed was measured at 4 locations at the crossing vicinity – at 100 m (coded here as –100) and 50 m (coded as –50) before the crossing, at crossing (coded as 0) and at 50 m after the crossing (coded as +50).

The main results of data analysis are presented as follows:

1. The average speeds at crossings are rather high. At almost 60 % of runs the speed was higher than a speed limit. Only at 12 % of runs the speed was less than 40 km/h. The situation was especially dangerous at crossings where the speed limit of 70 km/h is allowed. The smallest measured speeds were between 55 and 60 km/h.

The running speed distribution measured at crossings is presented in Fig 4.

2. The change in speed in the vicinity of zebra crossing is minor. When comparing average speeds of different runs in the vicinity of zebra crossings, we got a picture in Table 4.

It is important to note that when comparing speeds at –100 and 0 only in 59 % of cases the speed at crossing was less than at –100. Respective data at –50 and 0 show the 57 % of cases. Thus nearly in a half of measured cases the speed was not lowered at crossings when comparing with speed in 100 and 50 m to the crossing.

The data obtained from the survey shows also that the braking, if any, starts near the crossing. After passing the speed comes regularly up again in a very short distance after zebra crossings. The typical speed change in the vicinity of crossings is illustrated in Fig 5.

The situation is especially critical at the crossings with speed limit of 70 km/h. On these sites an average speed is dangerously high in the whole vicinity of zebra crossing and does not allow breaking safely when driver occurs a pedestrian waiting at the roadside. Thus these sites do not follow the traffic rules of giving way and should be discarded.

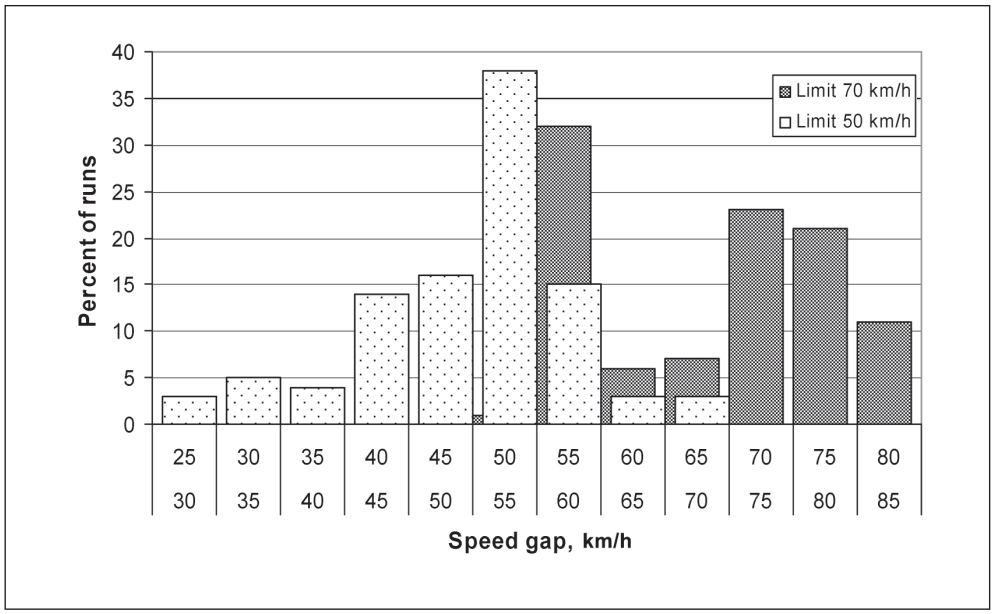

Fig 4. Running speed distribution measured at crossings

Table 4. Average speed in the vicinity of all pedestrian crossings, km/h

Speed limit, km/h	Distance (m):	–100	–50	0	+50
50	Average	47,2	45,7	44,6	44,7
	max	63	56,1	55,1	56,5
	min	32,4	27,7	27,1	15,6
70	Average	70,1	70,4	69,9	70
	max	77,4	78,1	78,1	78,5
	min	60,8	60,2	57,6	57,6

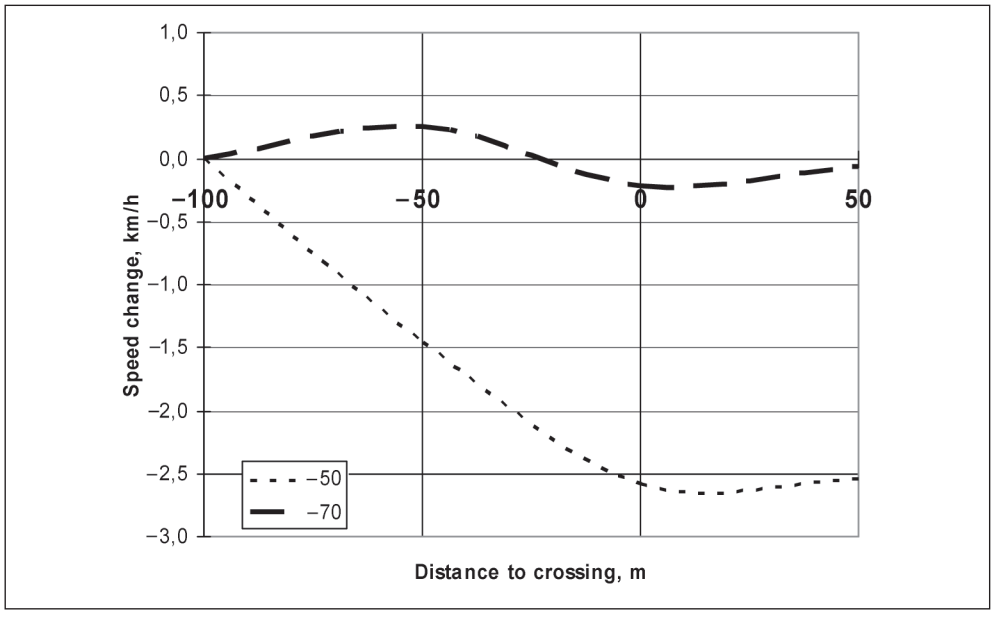

Fig 5. Typical speed change in the vicinity of crossings

6. Summary and conclusions

This report is based on field surveys and data analyses concerning the pedestrian safety. The key topics are: accident and risk development for pedestrians, motorists' behaviour aspects at zebra crossings, particularly their obligation to give way and also speed choice in the vicinity of zebra crossing, as well as safety effect for pedestrians of zebra crossing design. The key results are summarised below:

1. The pedestrian casualty risk in Estonia is on average approx 2–6 times higher than in other old EU countries.
2. 44 % of pedestrian casualties occurred in urban areas during 1998–2002. Pedestrian accidents are predominant in urban areas.
3. One of risky sites for pedestrians remains to be pedestrian crossings.
4. The driver's attitude to give way at pedestrian crossings is low in Estonia. This attitude is poorly depending on pedestrians, but strictly on motor traffic volume. In the situation of give way obligations drivers are first worried about the time lost at crossing and potential risk of rear-end collisions, after then comes the risk of pedestrian collision.
5. Even if there are clear regulations for motorists to give way, a number of drivers simply ignore this regulation. Thus in average only every third driver stops at crossing when there is a pedestrian indicating his/her wish to cross the road.
6. The average speed and speed distribution of motorised vehicles has a major influence on pedestrian safety. There is a clear relationship between the permitted speed and the severity of pedestrian injuries in accidents. The proportion of fatalities among pedestrian casualties increases in step with increasing permitted speed. In other words, speed kills.
7. Existing shape of pedestrian crossings does not have a big influence on drivers' speed choice. An average driving speed on a pedestrian crossings is high and this speed is not significantly lowered when approaching the pedestrian crossing.
8. Especially bad situation is recognised at pedestrian crossings where the speed limit for motorists is 70 km/h. The normal regulation of giving way to pedestrians does not apply here usually. The drivers are regularly ignoring the give-way obligations, do not lower speed and pedestrians are in case of crossing the road just having a big enough gap between motor vehicles.
9. There is an urgent need to reconstruct pedestrian crossing in a modern safe way. Some crossings should be liquidated or replaced by signalised ones, especially where safety standards are impossible to apply or higher than regular speed limit wanted to keep.

Altogether, the main task considering pedestrian safety is to lower the casualty rate for pedestrian crossing. Most of the pedestrian accidents occur in urban areas. Elderly pedestrians, drunken pedestrians and pedestrians in darkness are important target groups in treatments against fatal accidents. Thus it is highly needed to introduce new modern standards in pedestrian crossing design in order to lower speeds and improve driver's visibility in the vicinity of pedestrian crossings.

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