ASSESSING THE EFFECT OF TURNING VEHICLES AND PEDESTRIANS ON THE SAFETY OF AN URBAN ROAD SECTION (USING EXAMPLES FROM THE COMMONWEALTH OF INDEPENDENT STATES)

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Abstract

The article is devoted to an analysis of accidents involving pedestrians in traffic. An analysis of the statistical data of accidents involving pedestrians in the Republic of Belarus has been made. The main patterns and trends of accidents involving pedestrians are identified. A detailed analysis of the accident rate at pedestrian crossings and intersections was carried out, which made it possible to establish the most dangerous types of collisions during the interaction of transport and pedestrian flows. Experimental studies of collision situations were also carried out, which made it possible to establish the dependence of the violation rate on the composition of the right-handed traffic flow, on the type of traffic signal that regulates traffic on the right, as well as on the size of groups of pedestrians in front of cars.

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Key words

- Road traffic,
- Pedestrian,
- Traffic conflicts,
- Crosswalk, Traffic light intersection,
- Road accidents,
- Risk.

1 INTRODUCTION

Pedestrians are the most numerous, unprepared, and unprotected category of road users. They are characterized by a huge dispersion of psychophysiological properties related to age, size, health, intelligence, education, level of knowledge of traffic, etc. (Földes, Csiszár, 2016). Therefore, much attention is being paid to studying the problems of road safety and pedestrians (Zegeer, Bushell, 2012). The behavior of pedestrians is often distinguished by seeming inconsistencies and unpredictability, although in fact everything is quite logical and predictable (WHO, 2013). It is logical from the point of view of a particular pedestrian, but predictably in the sense that illogical actions can always be expected from a pedestrian. In order for the driver to understand the logic of the pedestrian, he must know some of its features (Gorodokin, Almetova, Shepelev, 2017). For example, a pedestrian has more freedom in choosing directions that are not legally regulated and are not physically limited. In this case, not only the traffic situation, but also any other event, i.e., the appearance of a familiar, interesting sight, an unexpected sound, etc., can be a motive. Much depends on his age, well-being, etc. (Kapski, 2008). The person determines the distance to

an object by the size of the silhouette of this object i.e., the smaller the silhouette, the greater the distance, and vice versa (Avineri, Shinar, Susilo, 2012). Having estimated the size of the silhouette of the object under study, for example, a car, a person compares these sizes with some standards stored in his memory and, in this way, “estimates” the distance. Obviously, such an estimate of the distance is approximate, and error is very likely. Moreover, the color of the vehicle affects this assessment, i.e., dark ones appear farther away, while bright ones, on the contrary, appear closer; the transparency of the air, the direction of the sun, the time of day, and the state of the pedestrian’s health, experience, fatigue, etc., are also significant. It is easier for the driver here; he is constantly engaged in this work, he is healthy (getting a medical screening), sober, experienced, and has “working” standards. For a pedestrian, for obvious reasons, everything is much worse. Children are the most unpredictable in their behavior because they do not have enough experience of “everyday” road standards since they do not even immediately see the car as a whole, but in separate, most clearly distinguished fragments, for example, moldings, headlights, wheel caps, flicking windscreen wipers (Breen, 2002; Galkin et al., 2019). Older people, who devote a lot of their attention to not slipping or falling, also

Tab. 1 Distribution of accidents with injured in the Republic of Belarus for 2003–2013 (Bulbenkov, Lyvanskyi, Poludnia, 2011)

1 vehicle and pedestrian / Total											
Years	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Accident	3371 / 7194	3361 / 7218	3370 / 7717	3513 / 8283	3103 / 7501	2872 / 7238	2684 / 6739	2517 / 6363	2361 / 5897	2010 / 5187	1834 / 4730
Died, people	760 / 1764	739 / 1688	729 / 1673	749 / 1726	606 / 1518	596 / 1564	520 / 1322	485 / 1190	478 / 1200	396 / 1039	371 / 894
Injured, people	2809 / 7361	2831 / 7522	2855 / 8047	2945 / 8832	2671 / 7990	2431 / 7576	2300 / 7198	2178 / 6832	2021 / 6334	1710 / 5569	1537 / 5033

have problems in traffic because the road standards have already begun to be erased from memory (Vrubel, Kapskyi, 2013; Schlosser, et. al., 2017). However, these are not all the significant factors; it is necessary to determine the speed of a moving car, which is estimated by the speed of change of its silhouette. If the silhouette increases rapidly, the speed is high; if slow, it means the speed is low (Galkin, et. al., 2018). Other standards should already be extracted from the memory, i.e., changes in the size of the silhouettes in order to compare them with the subject; then the speed can be estimated (Zeedyk, Kelly, 2003). In this case, the influence of the color of the vehicle, the transparency of the air, the status of memory, etc., has an even greater importance than when determining the distance. In addition, it must be borne in mind that at the same speed, the change in the size of the silhouettes at a small distance occurs much faster than in a long one. As a result, an error in determin-

ing the speed, as well as in determining the distance, is very likely. And an error while determining the distance to an approaching car and its speed is more likely than its absence (Ekman, 1997). In other words, if an untrained person determines this distance and speed 10 times, he is guaranteed to make a significant mistake in more than five cases. The main issue is: can a driver in such situations rely only on the pedestrian or not? The answers are unequivocal. In terms of road preparation, the pedestrian is significantly inferior to the driver; this should be taken for granted and taken into account in the process of driving. In this regard, an accident analysis with pedestrians should be carried out in order to know the patterns and causes of accidents and to take adequate measures to eliminate them (Traffic Safety Facts, 2004).

An analysis of the statistical information contained in the official statistical bulletins of the Ministry of Internal Affairs of the Republic

Tab. 2 Distribution in the Republic of Belarus of road accident participants with victims and the victims themselves by category for 2003–2013 (Bulbenkov, Lyvanskyi, Melchenko, 2012)

Participant categories	Participated in accident, people										
	Died people										
	Injured, people										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Drivers	8826	8932	9648	10474	9477	9270	8796	8421	7696	6881	6400
	440	397	413	437	398	430	369	329	315	304	247
	1796	1879	2105	2400	2181	2171	2052	1999	1828	1605	1496
Pedestrians	3524	3508	3529	3647	3236	3011	2806	2638	2455	2095	1901
	756	725	720	745	601	596	518	483	474	396	371
	2757	2773	2803	2897	2631	2411	2280	2147	1978	1695	1527
Passengers	2712	2742	2995	3376	3052	2984	2785	2577	2471	2239	1898
	367	393	374	358	365	391	302	256	287	241	194
	2302	2308	2591	2975	2649	2560	2448	2286	2162	1989	1691
Cyclists	638	624	644	671	612	512	484	468	440	336	355
	184	149	152	173	138	127	119	112	115	85	71
	450	468	488	493	466	382	358	350	323	249	281
Carters	87	114	74	74	74	60	55	51	45	44	32
	17	19	12	12	11	12	7	5	8	10	4
	48	73	44	47	45	33	39	33	25	22	19
Others	8	27	25	26	23	27	30	25	20	12	26
	0	5	2	1	5	8	7	5	1	3	7
	8	21	16	20	18	19	21	17	18	9	19
Total	15795	15947	16915	18268	16474	15864	14956	14180	13127	11607	10612
	1764	1688	1673	1726	1518	1564	1322	1190	1200	1039	894
	7361	7522	8047	8832	7990	7576	7198	6832	6334	5569	5033

Fig. 1 Distribution of road accidents with victims and the victims themselves at regulated pedestrian crossings of the Republic of Belarus for 2003–2013 (Azemsha, et al., 2015)

of Belarus (Bulbenkov, Lyvanskyi, Poludnia, 2011; Bulbenkov, Lyvanskyi, Melchenko, 2012; Azemsha, et al., 2015), established that the accident rate involving pedestrians is 38–45% of all accidents with injuries (Tab. 1). Moreover, as can be seen from Table 2, about 40% of those killed in accidents are pedestrians.

It should be noted that more than 30% of the injured in traffic accidents are pedestrians out of the total number of road users involved in an accident (see Tab. 2).

Figure 1 shows the distribution of accidents with injured people and the number of the injured themselves at regulated pedestrian crossings in the Republic of Belarus in the time period studied (10 years). It can be seen that a small burst was observed in 2011. This increase in accidents is quite possibly related to the then economic crisis, which may have significantly affected the welfare of pedestrians and caused their distraction from the traffic process to more pressing problems.

Tab. 3 Distribution of road accidents with injured people due to violations of traffic regulations by pedestrians in the Republic of Belarus for 2003–2013 (Bulbenkov, Lyvanskyi, Melchenko, 2012)

Indicator	Accident										
	Died Injured										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Crossing over a carriageway in an unsuitable place	1228 -	1102 -	1055 216 872	1154 230 958	907 198 728	710 153 573	682 132 559	605 119 505	507 123 403	442 102 347	369 94 283
The drunken state of the pedestrian	575 -	650 -	533 101 453	547 105 459	498 87 436	400 74 343	411 83 335	369 66 314	314 76 247	298 64 245	289 71 226
Unexpected exit from the vehicle, constructions, trees, etc.	298 -	296 -	217 37 183	217 39 181	213 45 176	202 43 166	156 22 135	167 34 134	146 31 124	104 14 92	77 14 63
Disobeying traffic control signals	71 -	88 -	135 11 126	79 5 77	77 4 79	86 11 80	73 7 70	75 6 70	83 10 75	81 12 70	63 8 58
Games on the roadway	120 -	262 -	239 106 150	235 117 132	163 64 106	156 70 95	156 71 93	165 72 97	178 100 84	70 33 38	57 27 33
A pedestrian under 7 years old unaccompanied by an adult	26 -	36 -	37 6 35	26 1 26	19 1 18	17 1 16	10 0 10	14 3 11	16 1 15	9 1 8	8 0 8
Other traffic violations by pedestrians	226 -	222 -	330 90 146	236 105 135	386 172 228	350 164 195	336 143 203	342 155 192	306 151 165	243 117 131	177 84 97

The problem of the human factor in ensuring road safety, especially in times of limited visibility, is related to the mechanisms of perception and the processing of information by the driver in accordance with the traffic situation. The speed of information processing by the driver is influenced by many factors: his functional and emotional state, the extent of any illumination, the road conditions, the presence of obstacles on a certain section of the road, the presence and condition of road markings, road signs, road equipment, traffic lights, etc. (Prasolenko, et. al., 2019). Thus, the time of the reaction and the number of conflict situations will directly depend on the traffic infrastructure and the organization of the traffic, intersections, and roads. Investigating conflict situations and violations in different sections will allow for the assessment of the influence of traffic factors on the number of traffic accidents in order to reduce their number. The results of this research points to a lack of overall and detailed considerations of vehicle-vehicle, vehicle-pedestrian, and vehicle-infrastructure behaviour along an entire journey in urban areas (Vakulenko, et. al., 2019). The purpose of the research is to assess the safety of an urban road section when considering accidents involving turning vehicles and pedestrians.

2 APPROACHES AND PRINCIPLES OF THE RESEARCH IN DETAIL

Accidents involving pedestrians have also been investigated by many authors (Draskóczy, Hydén, 1995). The results of an analysis of accidents involving transport-pedestrian conflicts at regulated intersections are presented in (Kot, 1991). Up to 90% of accidents with pedestrians occur with the participation of the vehicle in the direct (transit) direction, which is explained by the high speed of the traffic flow. Accidents involving turning vehicles and pedestrians account for about 10%, which is explained by the relatively low speed of the turning flows. In (Lenard, Badea-Romero, Danton, 2014), traffic flows interacting with pedestrians crossing the carriageway from left to right and from right to left as a car was moving were also analyzed (Schlosser, et. al., 2016). Conflict interactions between pedestrians and left-handed transverse flows were studied in (Lord, Smiley, Haroun, 1998), in which the degree of danger of a collision between pedestrians and wheeled vehicles was investigated.

In (Ewing, 1996), the results of the forecasting of accidents in a transport – pedestrian conflict are presented using the method of conflict situations. The method is based on the existence of a relationship between the number of conflict situations and accidents and is one of the most modern and rapidly developing methods for predicting accidents (Archer, 2001). By counting the number of conflict situations at a given object in a relatively short time, it is possible to determine with sufficient accuracy not only the number of expected accidents, but also the main causes of the accident. It is established that for 10,000 conflict situations at low speeds ($V \leq 30$ km/h) there are from 3 to 25 accidents, and at high speeds ($V \geq 30$ km/h) - from 25 to 55 accidents. Traffic light intersections and junctions are characterized by higher values for the conversion factor of conflict situations in an accident than for unregulated sections. In (Kapski, Pegin, Korchagin, 2015), a method was proposed for classifying intersections by hazard for pedestrians, based on 5 factors: the number of accidents with pedestrians, relative pedestrian accidents, the ratio of individual age groups of pedestrians, the level of disobedience of signals, and the number of traffic-pedestrian conflicts. Pedestrian hazard indicator F is determined by the formula:

$$\Phi = \frac{\sum_i^n W F_i H v_i}{\sum_i^n W F_i} \quad (1)$$

where

$W F_i$ – the weight factor of the private indicator i ;

$H v_i$ – the hazard (risk) level for the private indicator i ;

$\sum_i^n W F_i$ – the sum of weights for all the indicators of the intersection studied;

n – the number of risk factors (indicators), $n = 5$.

The relative pedestrian accident rate for each intersection studied was normalized for its correlation with other intersections and was determined as the ratio of the average annual number of accidents involving pedestrians at the studied intersection to the total volume of traffic and pedestrian traffic. When determining the volume of traffic, the total mileage of the vehicle at the intersection and the total paths that pedestrians walk along all the pedestrian crossings of the intersection were taken into account. As an additional factor, the share of vehicles performing corner maneuvers was taken into account.

As a result, the relative pedestrian accident rate was proposed to be determined by the formula:

$$AR = \frac{n_{a3} \cdot 10^7}{P \cdot P_n} \Delta_{nos} \quad (2)$$

where

n_{a3} – the number of accidents involving pedestrians over 3 years old (7 a.m.-6 p.m.);

P – vehicle run for the period 7 a.m. - 6 p.m., auto-km;

P_n – the pedestrian walking route for the time of 7 a.m. – 6 p.m., people-km;

Δ_{nos} – rate of the turning vehicles at the intersection.

The relative pedestrian-transport conflict was defined as the proportion of pedestrians participating in the conflict with a vehicle (mainly a turning one).

To determine some of the accident parameters, a focal analysis was carried out. It contains a variety of topographies and consists of applying and studying all the available information about accidents on a large-scale diagram of the site (the outbreak). In the outbreak itself, in this case, at a regulated intersection, accidents are grouped into conflict zones located in certain parts of the intersection. This is because the accident rate depends, among other things, on the speed of the traffic flow and the mutual visibility of the participants. Since the parameters in the “transport – pedestrian” conflict in different parts of a pedestrian crossing differ significantly, their accident rate is not the same. According to the research, the designation scheme, index numbers, and names are shown in Fig. 2.

One of the approaches to the intersection is assigned number 1, while the remaining approaches are assigned numbers 2, 3, and 4 clockwise. Each of the traffic flows is assigned an index, the first digit

Fig. 2 Designation scheme of traffic and pedestrian flows and conflict points at an intersection

of which indicates the number of the approach by which the vehicles of this stream arrived at the intersection (entrance); the second is the number of the approach by which they departed from the intersection (exit). For example, a left-turning flow arriving from input 1 has an index of 12; a forward direction flow (hereinafter referred to as a transit flow) has an index of 13; and a right-direction flow has an index of 14. In accordance with these approaches, the studies below were performed.

3 EXPERIMENTAL RESEARCH AND RESULTS

The statistical information on the accident rate in the conflict was collected for the pedestrian transport in four cities of the Republic of Belarus, i.e., Minsk, Vitebsk, Hrodna, Lida, and two other cities - St. Petersburg, Russia, and Almaty, Kazakhstan. These cities were selected in such a way as to detect possible differences depending on the size of the city, i.e., from St. Petersburg, where more than 6 million people live, to Lida, where about 100,000 people live. It should be noted right away that there were no fundamental differences in the accident characteristics depending on the size of the city for the samples studied.

Tab.3 shows some accident indicators in “transport-pedestrian” conflicts. About 7-17% of all accidents involving pedestrians occur at traffic light intersections. Moreover, the accident rate in “the turn transport - pedestrian” conflict makes up from 5% to 20% of the accident rate with pedestrians at traffic light intersections or from 0.6 to 2% of the total accident rate with the participation of pedestrians.

The severity of the consequences of accidents in “the turning

vehicle – pedestrian” conflict is significantly lower than the average severity of accidents involving pedestrians, i.e., 3 deaths per 100 injured (in general, this ratio is 100: 27). It should be noted that in the current accounting system, accidents involving pedestrians that did not affect their health are equated to accidents without injuries and are not included in the state statistical reporting, i.e., they have the status of “non-reporting”. It is possible to obtain information about such accidents, as a rule, if there are systems for their automated metering and analysis, which are not used in all the cities. It is necessary to keep records of “non-reporting” accidents, which do not contradict and even correspond to the current government approaches in the Republic of Belarus for the accounting and analysis of indicators and accident indicators.

Most of the accidents investigated (81%) were caused by drivers who, in violation of the traffic rules, did not let pedestrians walk across the pedestrian crossing. However, about 19% of the accidents were caused by pedestrians; basically, they occurred in the passage of the carriageway outside the pedestrian crossing (next to it) and the unexpected exit to the carriageway when the driver does not have the technical ability to stop and avoid a collision. The percentage of children under 14 years old is about 20% from the total number of injured, which is close to the average value for accidents involving pedestrians. The accident losses in the conflicts investigated that were calculated by the method (Vrubel, Kapski, Kot, 2006), are approximately 0.1-0.3% from the total accidents involving pedestrians. Therefore, the accident rate in a conflict involving pedestrians at traffic light intersections occupies a modest place in the general accident rate with the participation of pedestrians. Nevertheless, it does exist; it leads to socio-economic losses and must be taken into account

Tab. 3 Average annual accident rates involving pedestrians

Index			Dimension	Cities					
				St. Petersburg	Almaty	Minsk	Vitebsk	Hrodna	Lida
Population			thousands of people	6000	1300	1700	350	300	100
Analysis period			years	1	3	20	4,5	14	14
Total number of accidents			accidents	3007	771	524	250	196	34
			accidents/ 100,000 inhabitants	59.0	59.3	30.8	71.5	65.4	33.6
The number of accidents at traffic light intersections			accidents	341	108	82	22	13	3
			accidents/ 100,000 inhabitants	6.7	8.3	4.8	6.2	4.4	2.5
			% from total accidents with pedestrians	11.3	14.0	15.7	8.6	6.8	7.4
Traffic light intersection accident involving turning vehicles	General indicators		Number of accidents	17.0	13.7	9.5	2.4	1.6	0.5
			% from total number of accidents	0.6	1.8	1.8	1.0	0.8	1.5
			% from total accidents a traffic light intersections	5.0	12.7	11.6	11.3	11.8	20.0
	Severity of consequences	death	Thousands of people	1.0	0.7	0.3	0.0	0.0	0.0
		injury	Thousands of people	13.0	7.3	6.9	1.8	0.9	0.4
		non-reporting	Thousands of accidents	4.0	6.7	1.2	0.4	0.6	0.1
	Accidents losses*		Thousands of dollars	78.4	50.6	24.7	2.5	1.3	0.5
			% from total losses	-	-	0.28	0.16	0.10	0.10

Notes: * - data of the cost of 1 accident - according to work [4].

Fig. 3 Scheme of interaction of traffic and pedestrian flows at the crossing of a regulated intersection (figures in % indicate the share of accidents)

when making decisions. It should be borne in mind that the desire to increase safety in a “turning vehicle-pedestrian” conflict by dividing flows over time with an increase in the number of traffic light phases often leads to an increase in the accident rate in general for a “transport-pedestrian” conflict for several reasons:

firstly, pedestrians wait longer for the green signal, which to a greater extent provokes them to violate the rules;

secondly, in some schemes of multiphase regulation, one half of the pedestrian crossing remains free from transport, but pedestrians are prohibited from crossing it, which also provokes them to violate the rules;

finally, thirdly, in a multiphase control, turning traffic flows usually occur due to the green signal of an additional traffic light section, which for many drivers, especially those in left-hand traffic, is associated with conflict-free traffic, so they perceive any pedestrians as violators with all the ensuing consequences.

Fig. 3 shows data on the distribution of accidents during the interaction of traffic and pedestrian flows at a pedestrian crossing located in the zone of a regulated intersection. Pedestrian crossings are assigned indices 1, 2, 3 and 4 in accordance with the number of entrances. The pedestrian flow index consists of a crossing number and a letter indicating the direction of movement of the pedestrians (4II and 4I in Fig. 3). At each of the crossings, two parts are distin-

Fig. 4 Distribution of accidents involving pedestrians at traffic light intersections, depending on the direction of the pedestrian's movement

guished: the entrance zone, located on the lanes of the carriageway, along which vehicles approach the intersection and the exit zone located on the lanes of the carriageway along which vehicles leave the intersection.

Fig. 4 and Tab. 4 show the distribution of accidents at the pedestrian crossings of a traffic light intersection, depending on the direction of the traffic and pedestrian flows, which was obtained from an analysis of 1842 accidents in cities of the Republic of Belarus, including 194 accidents in “turning vehicle – pedestrian” conflicts.

The most dangerous collisions at crossroads are conflicts with direct-flow traffic flows (24 and 4), which are explained by the high speed of these flows. Such conflicts account for 89% of all accidents with pedestrians at traffic light intersections. Conflicts with left-turning drivers - pedestrians and right-turning drivers - pedestrian are approximately equivalent - they account for 5% and 6%, respectively. The total accident rate in the exit zone from an intersection is slightly higher, which, among other things, is explained by the worse conditions of orientation for a pedestrian interacting with three multidirectional traffic flows.

In conflicts with direct transport, approximately two-thirds of accidents occur with the participation of pedestrians who have not yet reached the middle of the carriageway (conflicts 4-4I and 24-4p in Fig. 3). The main reason for this distribution (Tab. 4, Fig. 4) is the lack of time for the driver to respond, because the pedestrian is in the danger zone immediately after entering the roadway.

As a concomitant reason, approximately 20-25% of pedestrian conflicts with direct transport vehicles due to the insufficient length of the transition interval of traffic lights should be noted; the interval does not provide an opportunity for all pedestrians to clear the carriageway before the start of the movement of the conflicting traffic flow.

Tab. 4 Distribution of pedestrian arrivals at regulated intersections in cities of Belarus

Transition zone	Traffic flow designation (Fig.3)	Total pedestrian runs	including:		Part of accident from all accidents at the transition	Accident rate	
			when pedestrian is moving from left to right	when pedestrian is moving from right to left		with pedestrians walking from left to right	with pedestrians walking from right to left
at the entrance	4 (total)	889	326	563	48.3%	36.7%	63.3%
at the exit	24 (transit)	759	281	478	41.2%	37.0%	63.0%
at the exit	34 (left-turning)	90	49	41	4.9%	54.4%	45.6%
at the exit	14 (right-turning)	104	28	76	5.6%	26.9%	73.1%
Total:		1842	684	1158	100%	37.1%	62.9%

In a right-hand traffic - pedestrian conflict, an additional reason complicating the conditions of interactions is the deterioration of lateral visibility for a pedestrian to whom the vehicle approaches from the rear to the left (conflict 14-4p in Fig. 3). As a result, the share of accidents involving pedestrians of the 4p flow ("associated path") for the right-hand flow reaches almost 75%. In a conflict with left-hand traffic, a pedestrian moving in the 4-l direction (conflict 34-4 l in Fig. 3) cannot see the vehicle as well as pedestrians in the opposite direction. However, before entering the danger zone, a pedestrian in the 4L direction moves for several seconds along the transition and, at this time, he is already in the driver's field of vision. As a result, the share of accidents for the left-hand flow involving pedestrians in both directions is almost the same. In general, with "passing" trajectories (conflicts 14-4p and 34-4l), 64% of all accidents in a conflict were recorded as turning vehicles - pedestrians, which was taken into account when developing accident forecasting methods. If the driver, in a conflict with a pedestrian, gave way ahead of him in advance, or if the pedestrian intentionally refused to go first, then such a traffic situation qualified as potentially dangerous. If the driver or the pedestrian is forced to take urgent evasive actions, such a traffic situation qualifies as a conflict.

According to the degree of danger, there are light, medium and heavy traffic situations. In relation to the conflicts under study, the following classifications have been adopted:

light - the driver did not give way to the pedestrian, thereby forcing him to stop or accelerate sharply at the last moment (1-0.5 s), or the car stopped abruptly in front of the pedestrian (very dangerous);

medium - the driver did not give way to the pedestrian, forcing him to jump sharply from the conflict point at the very last moment (less than 0.5 s), or the car stopped abruptly at the very last moment before the pedestrian was already at the conflict point (miraculously passed);

heavy - the driver did not give way to the pedestrian, as a result of which the car came into contact with the pedestrian, but did not cause any bodily harm (miraculously survived).

Collisions are also divided into light, medium and heavy:

As a result of a light collision, there is no significant damage to vehicles, goods or the arrangement of roads or bodily injuries to pedestrians. Many researchers combine light collisions and heavy traffic situations in one transition group.

Medium collisions lead to significant damage to vehicles, goods and roads, or to minor bodily injuries in people, but which do not lead to impaired health.

Heavy collisions are accompanied by injuries, injuries or death. Such collisions qualify as accidents with victims and are divided into 2 groups: accidents with injuries and fatal accidents.

Since the accident rate of "the turning vehicle - pedestrian" conflict at traffic light intersections is low, it is hard to obtain a repre-

sentative sample of accidents. Therefore, studies were conducted by visual observations of traffic situations, including video recordings.

The studies were conducted for a total of 183 hours at 131 pedestrian crossings in Minsk and 26 pedestrian crossings in Grodno. The conditions of the traffic conflicts were recorded for 16,047 right-turning vehicles and 1651 left-turning vehicles. Of the 17,698 traffic situations, 2314 were classified as potentially dangerous, and 1160 were classified as traffic situations of which 1142 were classified as light, 16 as medium and 2 as severe.

To assess the conditions of conflict interactions between pedestrians and turning traffic flows, two indicators were introduced, i.e., the conflict ratio and the violations rate.

The conflict ratio is defined as the proportion of turning vehicles that come into conflicts with pedestrians:

$$\eta_{\kappa} = \frac{n_{\kappa}}{n} \leq 1 \quad (3)$$

where

n_{κ} - the number of vehicles conflicting with pedestrians,
 n - the total number of turning vehicles.

The conflict ratio evaluates the quality of the traffic light control circuit (from the viewpoint of traffic safety). The smaller η_{κ} , the control scheme is safer. If the surface level pedestrian crossing κ is absent, $n_{\kappa} = 0$, the duration of the transitional intervals provides the opportunity to be released from the danger zone by pedestrians and vehicles.

The violation rate is defined as the proportion of vehicles whose drivers created the conflict situation (CS) in relation to the number of conflicting vehicles:

$$\eta_{\eta} = \frac{n_{\eta}}{n_{\kappa}} \leq 1 \quad (4)$$

where

n_{η} - the number of vehicles creating a CS.

The violation rate characterizes the probability of CS in a "turning vehicle - pedestrian" conflict (the probability of a potentially dangerous situation developing into a conflict). The smaller η_{η} , the fewer violations and the conflict is safer. In the ideal case, $\eta_{\eta} \rightarrow 0$. However, $\eta_{\eta} > 0$ is found most commonly in practice, because each driver has his own psychological factors. The main results of the experimental studies are shown in Tab. 5.

The results of the experimental studies make it possible to establish the dependencies of the conflict ratio and the violations rate on some parameters of the road that were used in the calculation model for predicting accidents and in assessing "turning vehicles - pedestrians" conflict control.

Fig. 5 The influence of the traffic control scheme of right-turn traffic flows on the Conflict Ratio η_{κ} .

Fig. 6 Dependence of the Violation Ratio η_{η} on the direction of movement of the turning vehicle

Table 5 The results of the study of “pedestrian- turning transport” conflict situations

Traffic direction		Driving conditions	Number of vehicles			Factor of	
			Total	interacting with pedestrians	created a conflict	conflict	violations
Right-turning	Minsk	Total:	13,372	3280	832	0.25	0.25
		Including when driving on a signal:					
		of the main traffic light	5912	1901	533	0.32	0.28
		the additional section “to the right”	440	94	34	0.21	0.36
		the additional section “to the right”+ information section	3879	713	157	0.18	0.22
		the additional section “to the right”+ information plate	3141	572	108	0.18	0.19
	Hrodna	total:	2675	432	121	0.16	0.28
		Including when driving on a signal:					
		of the main traffic light	228	98	21	0.43	0.21
		the additional section “to the right”	543	83	34	0.15	0.41
		the additional section “to the right”+ information section	1904	251	66	0.13	0.26
	Total for 2 cities:		16,047	3712	953	0.23	0.26
Left-turning	Minsk	total:	1546	538	192	0.35	0.36
		Including when driving on a signal:					
		of the main traffic light	1546	538	192	0.35	0.36
	Hrodna	total:	105	43	15	0.41	0.35
		Including when driving on a signal:					
		of the main traffic light	82	31	6	0.38	0.19
		the additional section “to the left”	23	12	9	0.52	0.75
	Total for 2 cities:		1651	581	207	0.35	0.36

The effect of the traffic light control scheme on the conflict ratio is shown in Fig. 5. It can be seen that the movement of the turning flow is allowed in two phases of the traffic light, but the movement of the pedestrian in only one of them. It significantly reduces the conflict ratio because part of the turning vehicles pass the crossing during the traffic light cycle when pedestrians are not allowed to cross.

Another factor that has an effect on the conflict ratio η_k is the rate of the crosswalk flow; if the rate of the crosswalk flow decreases, the conflict ratio η_k also decreases. When the crossing or pedestrian is absent, $\eta_k = 0$.

Fig. 6 shows the dependence of the violation rate on the direction of the turning movement.

In the left-hand flow, the share of drivers creating conflict situations is 30–40% higher than in the right-hand flow. This is due to the higher speed of the left-turn flow and the more difficult conditions for its implementation.

Fig. 7 shows the dependence η_h of the traffic flow's composition. The amount of drivers creating conflict situations increases with an increase in the reduction coefficient. That is explained by the difference in the characteristics of the vehicle and pedestrian, complications of the braking maneuver for a large-sized vehicle, and also deterioration of the lateral visibility conditions (especially to the right) from the cab of a truck, bus or trolleybus.

The dependence of the η_h on the size of a group of pedestrians in front of a vehicle is shown in Fig. 8. The most dangerous is the

crossing of the roadway alone. With an increase in the number of pedestrians in the group, the proportion of drivers violating the rules decreases, which is explained by the more confident behavior of pedestrians in the group, a decrease in the possibility of getting around the group by a vehicle, and an increase in the risk for the driver to hit a pedestrian.

The dependence of the η_h on the regulation method is shown in Fig. 9.

Fig. 7 The dependence of Violation Ratio η_h on the composition of the turning vehicle flow (data for Minsk)

Fig. 8 The dependence of the Violations Ratio η_h on the size of the group of pedestrians in front of a vehicle

Fig. 9 The dependence of the Violation Ratio η_h on the type of traffic signal that regulates the movement to the right

When moving to the right according to the signal of the additional traffic light, the value η_h increases by more than 35% compared with the movement of the signal of the main traffic light, which is explained by the peculiarities of the perception by drivers of the signals of the additional sections.

4 CONCLUSIONS

As a result of the analysis, the main indicators and features of the accident rate during the joint movement of pedestrians and turning traffic flows at traffic light intersections have been determined. It was found that in general, accidents in the conflict under study are small and account for 5–20% of the accidents at traffic light intersections with pedestrians. Nevertheless, accidents during the joint movement of pedestrians and turning traffic flows exist and must be taken into account when making decisions on the organization of traffic.

The experimental studies of conflict situations in the interactions of pedestrians and turning traffic flows at traffic light intersections allowed for the development of an improved methodology for predicting accidents. At the same time, the reduction of conflict situations by the degree of danger and the dynamics (by conflict situations), and the reduction of accidents by the severity of the consequences were used firstly in the calculation forecasting model. This allowed for an increase in the accuracy of the forecast by several times in comparison with known methods.

The most dangerous situations at crossroads is a conflict with traffic flows in straight directions. Such conflicts account for 89% of all accidents with pedestrians at traffic light intersections. “Pedestrian – left-turning transport” and “pedestrian – right-turning transport” conflicts are approximately equivalent; they account for 5% and 6% of accidents, respectively. The total accident rate in the exit zone from an intersection is slightly higher, which, among other things, is explained by the worse orientation conditions for a pedestrian interacting with three multidirectional traffic streams.

The share of drivers creating conflict situations in a left-turning flow is 30–40% more than in a right-turning flow. This fact is explained by the higher speed of the left-turning flow and the more difficult conditions for its performance.

The studies presented cover a wide range of issues related to changing the functional state of the driver from the factors of the road environment. The presented approach for determining the parameters of conflict situations can be further used to evaluate traffic conditions on routes. The presented dependencies of the changes of the functional state of the driver on changes in illumination showed that at low levels of illumination, there is an increase in the number of accidents and their severity. Under stress, drivers can increase the level of accidents. Drivers’ behavior in different driving conditions requires further investigation and assessments of their impact on conflicts and traffic violations.

REFERENCES

- Archer, J. (2001) *Traffic conflict technique: Historical to current state-of-the-art*. Stockholm, Sweden: Kungl Tekniska Högskolan. Institutionen för Infrastruktur KTH, Stockholm, 2001. Access at: http://www.ctr.kth.se/publications/ctr2001_05.pdf.
- Avineri, E. - Shinar, D. - Susilo, Y. O. (2012) *Pedestrians' behaviour in cross walks: the effects of fear of falling and age*. Accident Analysis & Prevention, 44(1), 30-34.
- Azemsha S.A. - Galushko V.N. - Skirkovski S.V. - Vruble Y.A. (2015) *Data analysis of traffic accidents and their causes in Gomel for 2013 and 2014*, Science & Technique, 3, 65-73 (in Russian).
- Breen, J. (2002) *European priorities for pedestrian safety*. In: Pedestrian Safety Seminar, Sydney, 19 pp. Access at: <http://www.maa.nsw.gov.au/getfile.aspx?Type=document&ID=44320&ObjectType=3&ObjectID=3905/>
- Bulbenkov V.V. - Lyvanskyi O.H. - Poludnia E.E. (2011) *Svedenyia o sostoianny dorozhno-transportnoi avaryinosty v Respublyke Belarus v 2010 hodu* : analytycheskyi sb. / sost.: – Mynsk : MVD Resp. Belarus,. – 89 pp.
- Bulbenkov V.V. - Lyvanskyi O.H. - Melchenko N.A. (2012) *Svedenyia o sostoianny dorozhno-transportnoi avaryinosty v Respublyke Belarus v 2011 hodu* : analytycheskyi sb. Mynsk : Polyhrafycheskyi Tsentr MVD Resp. Belarus, 89 pp.
- Draskóczy, M. - Hydén, C. (1995) *Pedestrian safety measures-Past and future*. Risser et al. (eds.), 86-96.
- Földes, D. - Csiszár, C. (2016) *Conception of future integrated smart mobility*. In 2016 Smart Cities Symposium Prague (SCSP), Prague, (pp. 1-6). IEEE. DOI: 10.1109/SCSP.2016.7501022
- Galkin A. - Drill N. - Bibik N. (2016) *Applying City Marketing as a Tool to Support Sustainable Development in Small Cities: Case Study in Ukraine*. Transportation Research Procedia, 16, 46-53
- Galkin, A. - Davidich, N. - Melenchuk, T. - Kush, Y. - Davidich, Y., - Lobashov, O. (2018) *Modelling Truck's Transportation Speed on the Route Considering Driver's State*. Transportation research procedia, 30, 207-215.
- Gorodokin, V. - Almetova, Z. - Shepelev, V. (2017) *Algorithm of signalized crossroads passage within the range of permissive-to-restrictive signals exchange*. Transportation Research Procedia, 20, 225-230.
- Ekman, L. (1997) *Fotgängares situation vid övergångsställe*. Institutionen för trafikteknik, LTH. tekniska högskolan i lund, lunds universitet, 17 pp.
- Ewing, R. (1996). *Pedestrian and transit friendly design*. Joint Center for Environment and Urban Problems. Florida Atlantic University/Florida International University, USA, 103 pp.
- Kapski, D. (2008) *Prognozovanie avarijnosti v dorozhnom dvizhenii*. Minsk: BNTU, 243 pp.
- Kapski, D. V. - Pegin, P. A. - Korchagin, V. A. (2015) *The Features of Evaluation of Vehicle and Pedestrian Conflict at Intersections*. Bulletin of PNU, 37(2).
- Lenard, J. - Badea-Romero, A. - Danton, R. (2014) *Typical pedestrian accident scenarios for the development of autonomous emergency braking test protocols*. Accident Analysis & Prevention, 73, 73-80.
- Lord, D. - Smiley, A., - Haroun, A. (1998) *Pedestrian accidents with left-turning traffic at signalized intersections: Characteristics, human factors, and unconsidered issues*. In 77th Annual Transportation Research Board Meeting, Washington, DC, USA. Access at: http://safety.fhwa.dot.gov/ped_bike/docs/00674.pdf.
- National Highway Traffic Safety Administration (2004) *Traffic Safety Facts, 2004 Data: Motorcycles*. Washington, DC: National Highway Traffic Safety Administration, US Dept. of Transport, DOT HS, 810, 620.
- Prasolenco, O. - Burko, D. - Tolmachov, I. - Gyulyev, N. - Galkin, A. - Lobashov, O. (2019) *Creating safer routing for urban freight transportation*. Transportation research procedia, 39, 417-427.
- Schlosser, T. - Schlosser, P. - Cápayová, S. - Hodáková, D. (2017) *Terminals for Suburb Bus Transport in Bratislava*. In IOP Conference Series: Materials Science and Engineering (Vol. 245, No. 4, p. 042059). IOP Publishing. Available at: doi:10.1088/1757-899X/245/4/042059
- Schlosser, T. - Zuzulová, A. - Cápayová S. - Schlosser, P. (2016) *New public transport tramway line in Bratislava – Way of improving the environmental conditions*, In SGEM 2016. 16th International Multidisciplinary Scientific GeoConference. Book 4. Energy and Clean Technologies: conference proceedings. Albena, Bulgaria, 30 June - 6 July 2016. 1. ed. Sofia: STEF 92 Technology, 2016, pp. 475-482. ISSN 1314-2704. ISBN 978-619-7105-64-3, WOS:000391348700061.
- Vakulenko, K.- Kuhtin, K.- Afanasieva, I. - Galkin, A. (2019) *Designing Optimal Public Bus Route Networks in a Suburban Area*. Transportation Research Procedia, 39, 554-564.
- Vruble, Yu. A. - Kapskyi, D. V. (2013) *Opasnosty v dorozhnom dvizhenii*. M.: Novoe znanye, 244 pp.
- Vruble, Yu. A. - Kapski, D. V. - Kot, E. N. (2006) *Opredelenye poter v dorozhnom dvizhenii*. Mynsk: BNTU, 240 pp.
- World Health Organization. Violence, Injury Prevention, & World Health Organization. (2013) *Global status report on road safety 2013: Supporting a decade of action*. World Health Organization.
- Zegeer, C. V. - Bushell, M. (2012) *Pedestrian crash trends and potential countermeasures from around the world*. Accident Analysis & Prevention, 44(1), 3-11.
- Zeedyk, M. S. - Kelly, L. (2003) *Behavioural observations of adult-child pairs at pedestrian crossings*. Accident Analysis and Prevention 35, 771-776.