

Experimental Calculation of Pre-crosswalk Stopbar Optimal Location

Pavels Jelinskis, *Riga Technical University*

Abstract. One of the possible solutions to improve safety on un-regulated pedestrian crosswalks is to use special stop-bars before crosswalks. The aim of these stop-bars is to determine a point, where motorist should stop the vehicle for the pedestrian on a multi-lane roads. The experiment was conducted to determine and calculate the optimal distance, at which the stop-bar should be located before a crosswalk. Experiment was carried out using five different types of motor vehicles, adhesion factor on road surface was measured and calculated. Following article contains experimental data, calculations and conclusions.

Keywords: pedestrian crosswalk, road traffic safety, pedestrian safety, crosswalk equipment, traffic safety improvement

INTRODUCTION

The main idea of the conducted experiment was to determine the optimal distance for the location of a stop-bar before the un-regulated pedestrian crosswalk. Incorrect distance will not give the proper effect from the stop-bar, because the basic parameter, which determines the safety on a multilane crosswalk with stopped vehicle before it is the road centerline blind spot angle.

The shallower this angle is, the greater distance separates overtaking vehicle and road-crossing pedestrian, as the distance at which pedestrian is able to notice an approaching motor vehicle becomes greater with the decrease of a centerline blind spot angle. Five different classes of motor vehicles were chosen for the conduction of the experiment and it was carried out in several stages, using different road conditions to be able to gain the most realistic data for the calculations.

Adhesion factor of the road surface was actually calculated from the measurements and braking distances of different vehicles were calculated, measured and the results were compared and illustrated in charts. Speed of the overtaking motor vehicle was chosen as 40 km/h, which was determined as the most probable speed in the real situation which could take place at the urban traffic near the pedestrian crosswalk on a multi-lane road [1].

SCHEME OF THE EXPERIMENT

The scheme of the experiment is based on four main divisions which can be described as follows:

- comparison of calculated braking distances with measured distances using an accepted value of road surface adhesion factor;
- calculation of vehicles' stopping distances using accepted value of motorist's reaction time

- measurement of the centerline blind spot angle influence depending on the distance from vehicle to the crosswalk (two different experimental distances were adopted)
- selection of the effective distance, maintaining safe interval between pedestrian and motor vehicle in different situations.

This experiment was carried out by using five motor vehicles of different types: one class "A" premium supermini 2001 Volkswagen Lupo 3L 1,2 TDI, two class "C" compacts – 2007 Dacia Logan 1,5 TDI and 2006 Renault Thalia 1,2 (which was not equipped with the ABS system, so this motor vehicle was used also in order to measure an adhesion factor of the road pavement surface), one class "K" 1999 Dodge Grand Caravan SE 3,3 passenger van and one 2007 Ford Transit 2,2 TDCI cargo van (due to its size and construction this cargo van was used as a vehicle, which was stopped before the un-regulated pedestrian crosswalk and obscured a view for crossing pedestrian to create a worse possible scenario of road crossing in urban conditions).

First braking distances of all vehicles which were used during an experiment braking distances were measured in different road conditions, and before every measurement in a conditions, that varied from previous, an adhesion factor of the road surface pavement was measured. Then a Ford Transit cargo van was stopped before the un-regulated pedestrian crosswalk and a pedestrian started to cross it, at the same time a Renault Thalia was approaching this crosswalk, trying to overtake the stopped van. At the moment pedestrian noticed the approaching vehicle it stops, and at the moment the overtaking motorist notices the pedestrian it begins to brake. This action was taken under two different conditions – when a cargo van was stopped directly before the crosswalk and when it was stopped some distance away. Then centerline blind-spot angles were calculated and the optimal stop-bar location distance was determined.

PROCEEDING OF THE EXPERIMENT

Experiment was divided into several stages. The first step of the experiment conduction was measurement and calculation of road surface adhesion factor.

Measurement and calculation of a real adhesion factor

On the road where vehicles' braking experiment took place the real road surface adhesion factor was measured and calculated. As adhesion factor, which is only calculated, may not always represent a true value of real road surface condition, several measurements were conducted. They gave

the result which was used as a base for the precise value of the road surface adhesion factor.

Adhesion factor was calculated using measured data of vehicle's braking distance (1. formula) [4]:

$$S_{BR} = \frac{V^2 \left(\frac{m}{s}\right)}{2j} = \frac{V^2 \left(\frac{km}{h}\right)}{2g\varphi} = \frac{V^2}{26g\varphi} = \frac{V^2}{254\varphi}, \quad (1)$$

where

S_{BR} - braking distance;

V (m/s) – speed of the vehicle measured in m/s;

V (km/h) – speed of the vehicle measured in km/h;

g – G-force;

φ – road surface adhesion factor.

From the above mentioned formula it is possible to calculate a real road surface adhesion factor, knowing a braking distance of the vehicle (2. formula) [4]:

$$\varphi = V^2 / 254S_{BR}, \quad (2)$$

where

φ – road surface adhesion factor;

V – speed of the vehicle;

S_{BR} - braking distance.

As the speed, which was chosen for the experiment was equal to 40 km/h, measurement of the adhesion factor was conducted at that exact speed, using vehicle which was not equipped with ABS system (in this experiment it was Renault Thalia 1,2, year of construction 2007). Vehicle braked three times on the same road and at each braking the distance was measured. Every measured distance varied from others by one meter. The following braking distances were measured: first measurement – 9m, second measurement – 11,3m, third measurement – 10,1m. So the average braking distance was calculated as 10m. Using this value, the real road surface adhesion factor was calculated (3. formula) [4]:

$$\varphi = V^2 / 254S_{BR} = 40^2 / 2540 = 0,63 \quad (3)$$

where

φ – road surface adhesion factor;

V – speed of the vehicle;

S_{BR} - braking distance.

Measurement and calculation of stopping distance

The stopping distance of the vehicle was calculated at different speeds and using different road surface adhesion factors to determine a mean value, which could then be compared with that value which was measured and be used in

further calculations. The overall formula of the stopping distance is the following (4. formula) [4]:

$$S_T = S_1 + S_2 + S_{BR}, \quad (4)$$

where

S_{ST} – vehicle's stopping distance;

S_1 – distance travelled during the time of motorist's latent reaction;

S_2 - distance travelled during the time of braking system engagement;

S_{BR} - braking distance.

The time of motorist's latent reaction was accepted as 1 second [2], the time of braking system engagement was accepted as 0,1 seconds [3], the time of maximal deceleration accession is 0,1 seconds (parameter not given in overall formula of stopping distance). All results are abbreviated.

Determining distance travelled during the time of motorist's latent reaction, distance travelled during the time of braking system engagement and braking distance, calculations were based on a full stopping distance formula (5. formula) [4]:

$$S_{ST} = t_1 V + t_2 V + 0,5t_3 V + V^2 / 2j, \quad (5)$$

where

S_{ST} – vehicle's stopping distance;

V – vehicle's speed;

t_1 - time of motorist's latent reaction;

t_2 - time of braking system engagement;

t_3 - time of maximal deceleration accession;

j – vehicle's deceleration.

The calculated stopping distance from three measurements at the speed of 40 km/h on the dry paved road surface is equal to (6. formula) [4]:

$$\begin{aligned} S_{ST} &= t_1 V + t_2 V + 0,5t_3 V + V^2 / 2j = (t_1 + t_2 + 0,5t_3) * V + \frac{V^2}{2j} = \\ &= (1 + 0,1 + 0,5 * 0,1) * 11 + \frac{11^2}{14} = 20(m) \end{aligned} \quad (6)$$

where

S_{ST} – vehicle's stopping distance;

V – vehicle's speed;

t_1 - time of motorist's latent reaction;

t_2 - time of braking system engagement;

t_3 - time of maximal deceleration accession;

j – vehicle's deceleration

Measured braking distances of different vehicles on different road surfaces gave the following results (Fig. 1):

As adhesion factor was measured using only one vehicle (as mentioned above it was Renault Thalia 1,2, year of construction 2007) which was not equipped with ABS system so the wheels were blocked during braking in order to determine an adhesion factor on a real road surface, the value of 0,63 was accepted as the most precise.

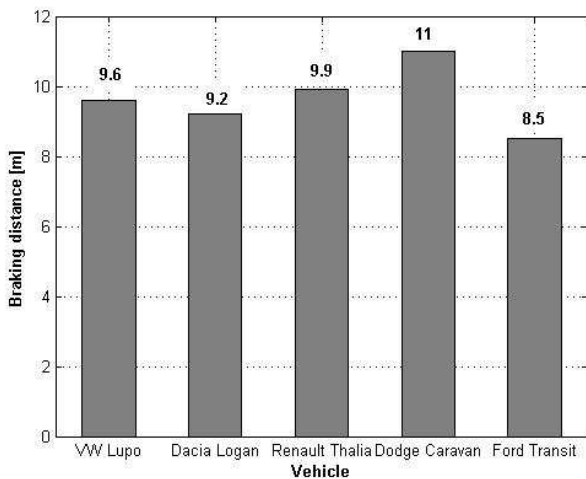


Fig. 1 Measured braking distances of different vehicles with adhesion factor of 0,63

Similar measurements were taken on a wet paved road surface, representing different results, as the surface adhesion factor decreased significantly. Results are displayed on a chart (Fig. 2):

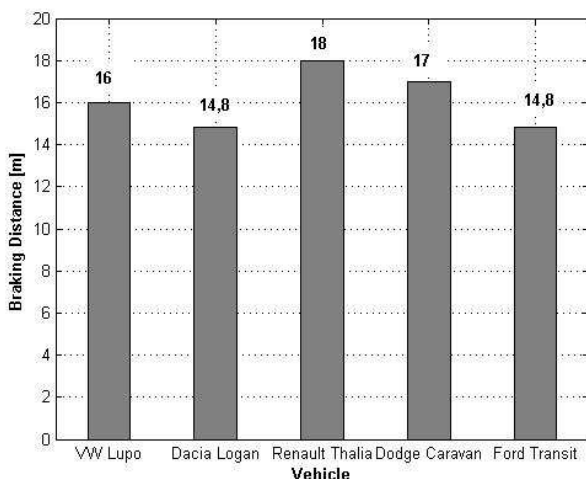


Fig. 2 Measured braking distances of different vehicles with adhesion factor of 0,4

Considering the fact, that all of the participating vehicles during an experiment were equipped with “mud + snow” type tires, to evaluate braking distances on wet paved road surface, the adhesion factor was not measured, but the calculated one was used. This was done due to a fact that measurements of the adhesion factor for different types of vehicles would not be precise (even though one of the vehicles was not equipped with ABS system) on wet paved road surface compared to dry surface. That effect could cause a significant variation of the experiment results.

Next step was to determine a stopping distance on icy pavement. As in previous case, adhesion factor was calculated (Fig. 3):

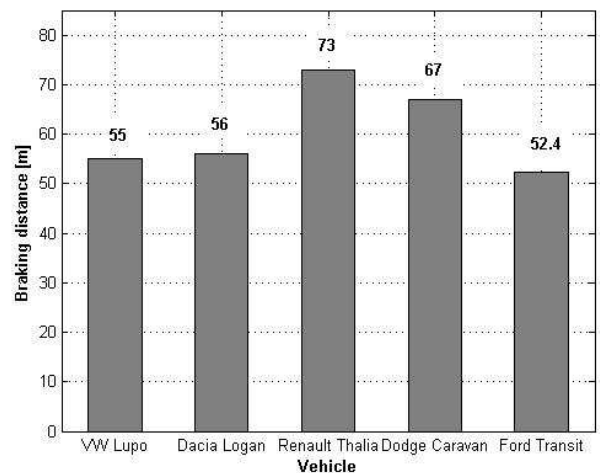


Fig. 3 Measured braking distances of different vehicles with adhesion factor of 0,1

Evaluation of the most suitable braking calculation led to a conclusion, that the most realistic data could be achieved from the experiment on a dry paved road surface, because in other cases distances from the stop-bar to a crosswalk would be practically impossible to introduce in real traffic situation.

RESULTS OF THE EXPERIMENT

As the results of the experiment, three main achievements were reached. They are the following:

- the real braking parameters of different motor vehicles were compared with theoretical calculated values;
- technical abilities of the overtaking vehicle to stop before the crosswalk after detecting a pedestrian on the crosswalk were evaluated;
- the effective distance of the pre-crosswalk stopbar was determined.

Calculation of a centerline blind spot angle and experimental determination of a stopbar location

The stopping distance of vehicles was calculated in various road conditions in order to determine a mean value between different vehicle types and braking conditions.

Using the above mentioned results, the conclusion it to be made that the most suitable scenario for the average urban traffic is the 40 km/h speed on the dry paved surface. Further measurements of a safe distance between overtaking vehicles and pedestrians were based on these values. Speed of walking pedestrian was accepted as 5 km/h (1,4 m/s) which was considered to be a normal average walking speed.

Now, when a large vehicle (in this case it was a Ford Transit cargo van) is stopped before the un-regulated pedestrian crosswalk, approximately 1m before it, a pedestrian approaches a crosswalk and starts to cross the multi-lane road till the moment when he/she notices an overtaking vehicle. In this experiment an overtaking vehicle was the same Renault Thalia, which was previous used in the determination of road surface adhesion factor. Ford Transit van is designated as

vehicle „A” and an overtaking Renault Thalia is vehicle „B” (Fig. 4). Here is to be mentioned, that this cargo van was chosen for the role of stopped vehicle because it is a cargo van and it has no side windows in a cargo compartement so pedestrian in unable to see anything through this vehicle, thus imitating the worse scenario.

Considering above mentioned calculation results (from the charts) it is obvious that after noticing a pedestrian a Renault Thalia driver has no technical possibility to stop the vehicle before the crosswalk. This leads to a conclusion that the only possibility of avoiding a collision is that pedestrian could

notice the approaching vehicle and stop before crossing its path.

In this experiment pedestrian had stopped on the road and, when passing vehicle had already stopped well away after the crosswalk, the interval between a pedestrian and the vehicle was measured. Next thing that was measured was the centerline blind spot angle, which was determined from the imaginary extension of the port side line of stopped vehicle (this line was chosen because the pedestrian could not see anything further beyond this line). The result is displayed in graphic scheme on Fig. 4:

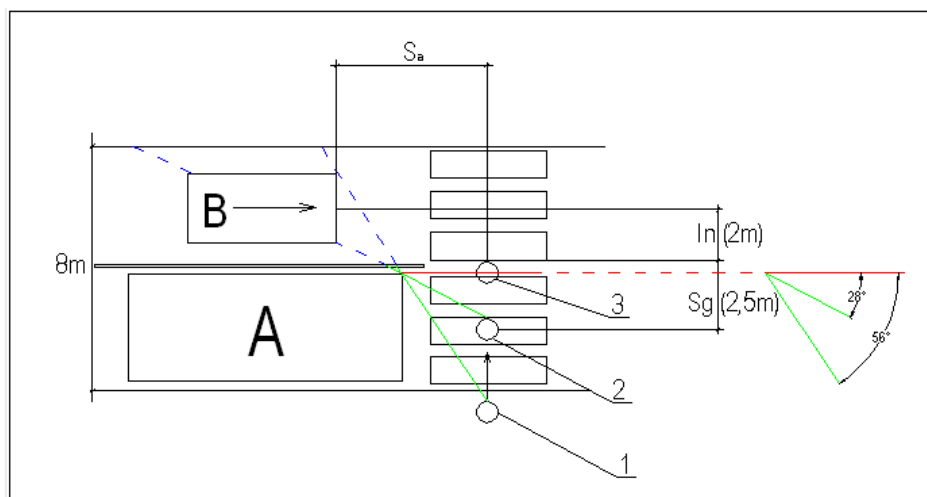


Fig. 4 Graphic display of centerline blind spot angle with a vehicle stopped directly before the crosswalk

The distance “ S_a ” that is displayed on the scheme, describes the actual distance with the given road centerline blind-spot angle between the lateral frontline of an overtaking vehicle and the walking path of the road-crossing pedestrian. Positions “1”, “2” and “3” designates actual positions of the pedestrian at the different stages of road crossing – a position before walking on a road, when pedestrian can’t physically see the approaching vehicle, a position when pedestrian is located approximately at the middle of the width of the stopped cargo van and when he/she is now able to see the overtaking vehicle and finally when a pedestrian crosses the road centerline.

The distance “ S_g ” describes the measured distance, that was actually travelled by the pedestrian from the moment he/she was able to detect an approaching vehicle till the moment he/she had actually stopped (including a reaction time of a pedestrian).

The distance “ I_n ” describes a measured interval between the stopped pedestrian and the passing vehicle. In this case the interval measurement was taken from the longitudinal axe of the overtaking vehicle to include in the calculations a

possibility of small, very shallow-angled avoiding manouvers which, when performed by overtaking motorist, could have some effect in passing a pedestrian without collision.

Experiment was carried out on a 8m wide multi lane road, the distance between an overtaking vehicle and the pedestrian trajectory was measured as 3,5m when pedestrian had notices an approaching vehicle and the interval between vehicle and pedestrian was equal to 2m.

There is important conclusion that can be made from analyzing the above mentioned data: if a pedestrian had been pushing a baby trolley (trolley length in horizontal projection is approximately 0,8m) the trolley surely would intrude a path of an overtaking vehicle „B”. Vehicle „B” would certainly collide with a baby trolley just at the moment when a trolley-pusher pedestrian would notice this vehicle.

In the next phase of experiment a cargo van was stopped some 5m before the crosswalk. And here is a significant change in results, displayed on a Fig. 5:

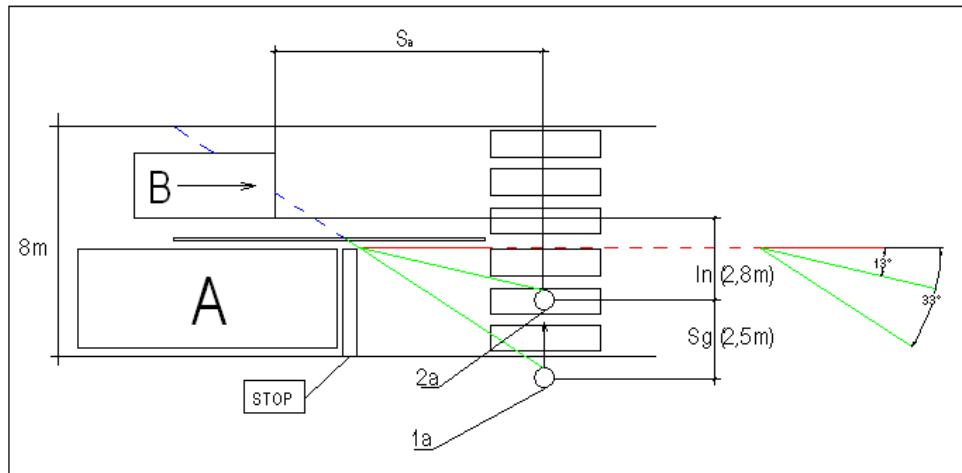


Fig. 5 Graphic display of centerline blind spot angle with a vehicle stopped 5m before the crosswalk

In this case centerline blind spot angle (determined as equal to a vehicle's "A" port side line extension angle) had decreased significantly thus increasing the distance at which road-crossing pedestrian had noticed an approaching vehicle "B" and stopped.

As previous, the distance " S_a " that is displayed on the scheme (Fig. 5), describes the actual distance with the given road centerline blind-spot angle between the lateral frontline of an overtaking vehicle and the walking path of the road-crossing pedestrian.

Also the meaning of the distance " S_g " stayed the same – it describes the measured distance, that was actually travelled by the pedestrian from the moment he/she was able to detect an approaching vehicle till the moment he/she had actually stopped (including a reaction time of a pedestrian).

The distance " I_n " describes a measured interval between the stopped pedestrian and the passing vehicle – as we see, this interval has now increased by approximately 0,8m – this is a plane length of a baby trolley (assumed for the experiment) that could be located in the front of a pedestrian, so in this case it is a large difference, because now it stayed outside of the path of passing vehicle.

Positions "1a" and "2a" at the Fig. 5 designates actual positions of the pedestrian at the different stages of road crossing – a position before walking on a road, when pedestrian now can physically see the approaching vehicle, a position when pedestrian had stopped for an approaching vehicle – this point is located approximately at the middle of the width of the stopped cargo van – similar to the situation, that was displayed on Fig. 4 earlier but now pedestrian is at the significant lateral distance from the overtaking vehicle.

The measured interval was now equal to 2,8m and the conclusion is that a baby trolley which could be pushed by a pedestrian, now didn't cross the overtaking vehicle's "B" trajectory (not considering the width of the vehicle and assuming the vehicles "B" starboard side is merging with a road centerline thus gaining an additional safety margin).

CONCLUSIONS

This experiment was conducted in aim to determine an optimal distance and location of the pre-crosswalk stopbar, which would be effective not to allow a situation when a road-crossing pedestrian or a baby trolley which he/she could be pushing ahead would ever cross the trajectory of the overtaking vehicle due to a blind spot phenomenon.

The centerline blind spot angles, which were calculated from the measured values, were accordingly equal to 28° and 56° without the pre-crosswalk stop-bar (Fig. 4), but with the stop-bar located 5 meters before the crosswalk these angles had changed to 13° and 33° (Fig. 5).

There were some theoretical calculations carried out as well as a practical experiment was done. After all experiments and calculations the conclusion can be made, that the reasonable and actually suitable distance between the stopbar and the crosswalk is equal to approximately 5 meters.

REFERENCES

1. Jerzy Wicher. Bezpieczeństwo samochodów i ruchu drogowego. – Warszawa: Wydawnictwa Komunikacji i Łączności, 2004, ISBN 83-206-1536-4, 316 lpp.
2. Stanisław Gaca, Wojciech Suchorzewski, Marian Tracz. Inżynieria ruchu drogowego. – Warszawa: Wydawnictwa Komunikacji i Łączności, 2009, ISBN 978-83-206-1707-8, 187 lpp.
3. Ryszard A. Stefański. Prawo o ruchu drogowym. – Warszawa: Wolters Kluwer Bu, 2008, ISBN 978-83-206-1707-8, 118 lpp.
4. Transportation Engineering: Online Lab Manual - http://www.webs1.uidaho.edu/niatt_labmanual/index.htm, August 2003.
5. Pedestrian Crosswalk Safety: Final Report, Peter Boyce, Ph.D. and John Van Derlofske, Ph.D. - <http://www.uth2.org/research/assets/17/crosswalksafety1.html>, March 2003

Pavels Jelinskis, Mgr. Sc. Ing. born in Riga, joined Riga Technical University in 2002, graduated as a professional bachelor in 2007 and as a master of science in 2008. Presently a doctoral student in a Road Transport Institute at the Faculty of Transport and Mechanical Engineering. Since 2002 worked as a technical interpreter of mechanical documentation, had practice at Volvo Truck maintenance base, presently works with doctoral dissertation at Road Transport Institute.

Pāvels Jeļinskis. Gājēju pārejas stoplīnijas optimālā novietojuma eksperimentālais aprēķins

Viens no iespējamajiem risinājumiem, kas varētu uzlabot satiksmes drošību uz neregulējamām gājēju pārejām, ir speciālu stoplīniju izmantošana pirms šādām pārejām. Šādu stoplīniju uzdevums ir noteikt attālumu, kādā vadītājam būtu jāapstājas, lai dotu ceļu gājējam, kas šķērso vairākjoslū brauktuvi. Ņemot vērā to, ka vairākums negadījumu, kuros iesaistīti gājēji uz neregulējamām gājēju pārejām, notiek apsteigšanas manevru laikā, stoplīniju izmantošana ievērojami palielinātu gājēju redzes leņķi, samazinot brauktuves viduslīnijas aklās zonas leņķi tā, lai gājēji spētu pamanīt tuvojošos transportlīdzekļi un nešķērsotu apsteidzošā transportlīdzekļa trajektoriju. Šādu stoplīniju izmantošana, lai ļautu apsteidzošā transportlīdzekļa vadītājam laikus pamanīt gājēju un apturēt transportlīdzekli, tika atzīta par nelietderīgu, ņemot vērā faktu, ka šāda uzdevuma veikšanai stoplīnijas attālums no gājēju pārejas būtu tik liels, ka tas nebūtu praktiski izmantojams ceļu satiksmē. Eksperiments tika veikts, lai noteiktu un aprēķinātu optimālo attālumu, kādā būtu jāizvieto stoplīnijas pirms gājēju pārejām. Eksperimentā tika izmantoti pieci dažādu tipu transportlīdzekļi, tika nomērīts un aprēķināts ceļa virsmas saķeres koeficients. Šis raksts satur eksperimentālus datus, aprēķinus un secinājumus. Līdzīgi risinājumi jau tiek izmantoti daudzviet pasaulē, tomēr šis eksperiments ļāva precizēt, kā tieši visefektīvāk izmantot šādu sistēmu, kā arī pateicoties tam, ka eksperimentā tika izmantoti dažādu klašu automobiļi, tika iegūti rezultāti, kas ir daudz tuvāki reālajai satiksmes situācijai, nekā tas būtu tad, ja tiktu izmantots tikai vienas noteiktas klases automobilis. Eksperiments tika vairākkārt atkārtots dažādos ceļa apstākļos.

Павел Елинский. Экспериментальный расчёт оптимального расположения стоп-линии перед пешеходным переходом

Одним из возможных решений, способных повысить безопасность дорожного движения на нерегулируемых пешеходных переходах, является использование специальных стоп-линий перед такими переходами. Задача этих стоп-линий это определение расстояния на котором водителю следует остановить транспортное средство для того чтобы уступить дорогу пешеходу, пересекающему многополосную проезжую часть. Учитывая факт, что большинство дорожно-транспортных происшествий с участием пешеходов на нерегулируемых пешеходных переходах происходит во время манёвров опережения, использование стоп-линий в значительной степени увеличило бы угол обзора пешеходов, уменьшая угол слепой зоны таким образом, что пешеходы могли бы заметить приближающееся транспортное средство и не пересекали бы траекторию опережающего транспортного средства. Использование таких стоп-линий с целью дать возможность водителю опережающего транспортного средства во время заметить пешехода и остановить транспортное средство не сочтено целесообразным по причине наличия того факта, что в этом случае расстояние между стоп-линией и пешеходным переходом было бы столь велико, что не было бы практически применимым в дорожном движении. Эксперимент был проведён с целью определения и расчёта оптимального расстояния, на котором следовало бы расположить стоп-линию перед пешеходным переходом. Во время эксперимента было использовано пять разных типов транспортных средств, коэффициент сцепления дорожной поверхности был измерен и рассчитан. Статья содержит экспериментальные данные, расчёты и выводы. Подобные решения уже используются широко в мире, но этот эксперимент позволил уточнить, как наиболее эффективно использовать эту систему а также благодаря тому, что в эксперименте использовались автомобили разных классов, были получены результаты, наиболее соответствующие реальной дорожной ситуации нежели это было бы при использовании одного класса.