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ORIGINAL PAPER

ESTIMATING THE POTENTIAL OF A WARNING SYSTEM PREVENTING ROAD ACCIDENTS AT PEDESTRIAN CROSSINGS

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ABSTRACT. **Background:** The safety of pedestrians is one of the main traffic safety issues today and despite measures being applied, the number of pedestrian deaths in traffic is not changing. According to the Pareto Rule, 80% of consequences come from 20% of the causes and here the question arises whether we have already used these 20% of the most efficient measures. Todaythe European Union (EU) puts big hopes are on contemporary technologies, such as Advanced Emergency Braking Systems (AEB) and cooperative intelligent transport systems (C-ITS). This decade, we can expect smarter vehicles with automatic brakes, and smarter infrastructure which can communicate with vehicles. Along this other profits technological development provides new opportunities for improving pedestrian safety. One of the most promising solutions is deployment of C-ITS systems at uncontrolled crossings. It would monitor the situation and warn the road users of potential dangers as well as make the vehicles brake automatically. However, before making large investments into this field, one has to be sure that this approach will work. The aim of this paper is to describe typical vehicle-pedestrian crash scenarios and to estimate whether a C-ITS warning system is able to prevent them. Research estimates the potential of this system and provides insights to its must-have features.

Methods: To understand the situations in which the warning system should function, researchers carried out traffic conflict studies at uncontrolled crossings with traffic filmed in both winter and summer. They determined and described serious conflicts and, based on their scenarios, classified them into three types. Then, researchers selected the most critical conflict of each type and analysed whether warning signals can be provided to the vehicle and the driver early enough to prevent collisions. For these purposes, researchers used a modelling software for traffic accident investigation. To access the efficiency of the C-ITS warning system, researchers estimated the probability of preventing collisions and used the efficiency parameters of classical traffic calming measures.

Results: The C-ITS warning system has good potential in preventing vehicle-pedestrian collisions at uncontrolled pedestrian crossings. It is remarkable and very promising that it would be able to prevent all types of conflicts analysed in the scope of this study by warning AEB-equipped vehicles. Warning the driver would be also effective, but the system work will largely depend on the quality of warning signals. An effective C-ITS warning system should be capable of predicting the trajectories and acceleration of road users as well as calculating the stopping distance of vehicles based on the coefficient of static friction. Study showed that in some cases, the system will have to give false positive alarms, but the fewer such alarms will be given, the more efficient the system will be. A disturbing or annoying C-ITS warning system cannot be considered effective.

Conclusions: Road accident statistics contain general data about vehicle-pedestrian collisions at uncontrolled crossing, but there is few information about behavioral patterns leading to accidents. Based on large-scaled traffic studies, researchers were able to determine these patterns and described how road users act when being involved in a dangerous situation. This knowledge helped to model typical vehicle-pedestrian collisions as well as their possible scenarios. Researchers used the conflict models totest the C-ITS warning system and to understand its efficiency. The study results were implementedin a prototype that has been developed in Estonia and is being tested it in real traffic conditions of a smart city in the scope of the Finnish-Estonian project “FinEst Twins”.The next steps are to analyze the test resultsand to conduct research to understand how to warn drivers (and pedestrians) most effectively.

Key words: AEB, C-ITS, traffic conflict, traffic study, uncontrolled pedestrian crossing.

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INTRODUCTION

The safety of pedestrians and other vulnerable road users is one of the main traffic safety issues today. Modern vehicles offer a high level of protection to drivers and passengers, but pedestrians and cyclists are left with significantly lower chances to survive in a road accident. In Europe, 22% of all road fatalities are pedestrians [European Commission 2018].

Analysis of 16 years' long trends in the behaviour of road users indicated that pedestrian safety is the most crucial problem in road safety in Estonia [Ess and Antov 2017]. According to the Estonian Road Administration, 24.6% of traffic accidents registered in Estonia in 2011–2019 were vehicle-pedestrian collisions and 40.4% of them occurred at uncontrolled pedestrian crossings. Half of all the vehicle-pedestrian collisions happened in Tallinn.

Pedestrian safety is an important topic not only for Estonia, but for the entire EU. Figures show that the decrease in the number of vehicle-pedestrian crashes (as well as other crashes) stagnated in 2012 [European Commission 2019a], which made the achievement of Vision Zero targets for 2020 impossible. To overcome these difficulties, the EU puts big hopes on modern technologies, such as AEB, which can decelerate and stop the vehicle automatically, and C-ITS, which allows vehicles to communicate with each other, with the road infrastructure, and with other road users [European Commission 2019b]. From 2015, all new heavy-duty vehicles are equipped with AEB [European Commission 2016] and from 2022, all vehicles, including passenger cars, will also be equipped with AEB [Regulation (EU) 2018/858]. Euro NCAP has already included AEB systems to their tests, but it must be mentioned that these tests are done in almost ideal conditions – dry road, no precipitation, visibility at least 1 km [European New Car Assessment Programme 2017].

In real-life situations on uncontrolled pedestrian crossings, the efficiency of AEB is limited by the performance of the sensors of vehicles (radar, lidar, camera) and by the fact that they cannot 'see' behind the obstacles. However, a smart pedestrian crossing (SPC) can be applied. This is a C-ITS system that monitors the surroundings of pedestrian crossings from multiple locations and detects potential danger much earlier than the sensor of a vehicle. The system could warn both the vehicles and the drivers of potential danger. The AEB could use the signal received from the SPC as a trigger for automatic braking. This article aims at estimating the potential of such an SPC for preventing vehicle-pedestrian crashes at uncontrolled pedestrian crossings. For this purpose, researchers determine typical conflict situations at uncontrolled crossings in Tallinn, using a modelling software to 'convert' them to collisions and estimate whether a smart C-ITS device could prevent them or not.

TRAFFIC CONFLICTS AND SIMULATION

Crashes in traffic result from many objective factors operating together and in safety studies, it is essential to estimate the cause-effect relationship of a crash on a time scale [Elvik et al. 2009]. Crash reports from police databases do not provide precise information for analysis, but this can be done by means of traffic conflict studies. These studies assume that there are sufficient similarities between actual accidents and 'almost accidents' of the same type [Polders and Brijs 2018]. Traffic conflicts are observational situations in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged [Svensson 1998]. Traffic conflict studies measure the number of conflicts and their severity, validate with traffic crash data, classify them, and find out precursors to crashes [Tarko 2012].

Conflicts are determined by means of special parameters or indicators which help to estimate the severity of a critical situation. The most common parameter in such studies is the time to collision (TTC) and its variations. TTC is the time until a collision between the vehicles would occur if they continued on their present course at their present rates [Laureshyn et al. 2016]. During the conflict, the TTC value varies over time, and therefore, a proper evaluation requires a continuous monitoring with the identification of the critical value. Usually, this is the lowest TTC value in the interaction – the minimal time to collision (TTCmin). As a rule, time TTCmin under 1.5 s is considered critical. However, for conflicts between vehicles and vulnerable road users, the proximity to a collision is only one dimension of its severity; the potential consequences (nearness to a serious personal injury) should be also taken into account [Polders and Brijs 2018]. These consequences can be estimated in relation to impact speed and a probability of death or injury [Astarita et al. 2019].

TTC can be used only if the trajectories of the road users are crossing and therefore do not take into account potentially dangerous 'near misses'. For this reason, some studies use a variation of TTC, placing emphasis on the second (later) road user. The respective conflict parameter is called T2. It shows the expected arrival time of the second road user to the potential collision point. T2 can be calculated also in the case of a non-collision course, which is an advantage compared to TTC [Laureshyn et al. 2016]. One more conflict parameter used in some studies is the deceleration to safety time. It shows the nearness to a collision through the minimal necessary deceleration for a driver to avoid the collision [Hupfer 1997]. Some parameters take into account not only deceleration, but also the potential impact speed, i.e. the speed at the moment of the collision supposing a braking deceleration [Johnsson et al. 2018].

Traditionally, traffic conflict studies were carried out using trained observers in the field. As this approach involves a risk of missing or misjudging conflicts without providing an option to look through them again, video recordings of the sites are often collected. However, a manual analysis of the video footage is often very time-consuming. Researchers have thus developed video analysis software for the automated tracking of road users to identify traffic conflicts automatically to reduce the time spent on analysing the video footage. The tool is a so-called watchdog system that detects events that should be investigated further while discarding the parts of the video with no activity of interest [Madsen and Lahrmann 2017]. One example of such software is Road User Behaviour Analysis (or RUBA) developed at Aalborg University. The performance of such systems depends on weather and light conditions, occlusion, shadows, and complex traffic scenes with multiple road user groups sharing the same space. Hence, a human-in-the-loop is therefore still necessary [Madsen and Lahrmann 2017]. To calculate conflict parameters (TTC and others), researchers use software which allows the extraction of road user positions frame by frame and calculating their speeds, accelerations, and a number of surrogate indicators of safety, such as TTC. An example of such software is the video analysis tool T-Analyst developed by the University of Lund [Bulla-Cruz 2020].

Classical conflict studies investigate the cause-effect relationship of a crash, but do not consider possible scenarios provoked by errors of conflicting road users and crash consequences. This can be done by means of microsimulation, which is a traffic simulation approach to reproduce all dynamic interactions among vehicles in fine detail. The state-of-the-art microsimulation converts conflicts traffic conflicts to crashes, simulates potential human errors and crash consequences [Astarita et al. 2019].

DEVELOPED METHODOLOGY

To assess the potential efficiency of SPCs in preventing vehicle-pedestrian collisions, a large-scale traffic conflict study was held. Traffic at uncontrolled crossings was filmed with high-resolution cameras and the video material was analysed to detect serious vehicle-pedestrian conflicts. Observation places have been selected according to crash statistics and these were the most dangerous crossings in Tallinn. The selection following criteria was:

- number of vehicle-pedestrian collisions in 2012–2018: not less than three;

- no significant changes in traffic management from 2012;
- different types of crossings (number of lanes, refuge island);
- suitability for camera placement (a pole or building near the crossing where it is possible to place the camera).

As a result, for the purposes of the study, ten uncontrolled crossings of the following types have been selected:

- three crossings on 1 + 1 roads without a refuge island;
- four crossings on 2 + 2 roads with a refuge island;
- three crossings with 3 lanes in one direction with a refuge island.

The traffic study consisted of two parts – the pilot study (held in winter 2017–2018) and the main study (held in summer 2018). The pilot study revealed several issues with cameras and batteries. Action cameras with power banks were used, but this approach did not justify itself, as the workload of changing power banks and memory cards did not correspond to the number of conflicts detected. During the main study, researchers used upgraded systems, which consisted of a security camera with a Wi-Fi connection and a vehicle battery stored in a box placed on the street pole. Cameras were placed at the height of approximately five metres and a Wi-Fi connection was used to tune the filming angle.

In each location, traffic was filmed for two weeks during the working days, making up 10 days for each location in total. The video material was analysed both using the semi-automatic software RUBA and by manual review performed by a team of trained staff. However, the share of semi-automatic analysis was very low due to the fact that the software produced too much 'noise' in the timestamps, because it was impossible to place cameras at a height that would provide a filming angle optimal for the software.

The research highlighted and described serious conflicts. In most cases, the severity of conflicts was determined by a team of researchers visually, taking into account nearness to serious injury for the pedestrian. In case of doubt, researchers proceeded from the possible impact speed – a conflict was classified as serious if the impact speed was 20 km/h or higher. This threshold was chosen because respective studies [Roséna et al. 2011] show that starting from this impact speed, the health risk for pedestrians starts increasing. The impact speed was calculated according to the formula below [Bosch automotive engineering 2007].

$$V_{impact} = V_{vehicle} - (TTC_{min} - t_r - t_a - 0{,}5 \cdot t_s) \cdot \varphi_x \cdot g \quad (1)$$

where:

t_r is reaction time (1 s)

t_a is response time (0,15 s for passenger cars)

t_s is pressure build-up time (0,36 s for passenger cars)

φ_x is coefficient on static friction

g is gravity constant

Parameters for the calculations were collected with the help of T-Analyst. This software allows combining orthophotos and a camera view to create a system of coordinates and calculate the speed of road users, TTC, T2, and other conflict parameters (see Figure 1). In case of 'near-misses' when there was no collision course and therefore it was impossible to calculate the TTC, researchers used T2 as the closest possible value to TTC.

Fig. 1. Determining conflict parameters with T-Analyst

All the serious conflicts determined were classified into types based on the similarity of their circumstances. For each conflict type, researchers determined the most serious conflict. This was done by means of TTC_{min} and impact speed as well as the risk of serious injuries. These conflicts were modelled using the PC-Crash software, which is used for traffic accident analyses. It allows animating pre-accident situations and 'see' it from different perspectives (see Figure 2). To create PC-Crash models, researchers used data retrieved from T-Analyst (the trajectories, speeds, and accelerations of road users). Conflicts were 'converted' to collisions using PC-Crash. Researchers investigated them and determined the timing of C-ITS warning signals. It was analysed whether the timing of warning signals is realistic and whether the driver could see the warnings and react in a proper manner (brake with maximum deceleration). After that, researchers added the reactions of typical road users to conflict models and analysed if they lead to additional hazards.

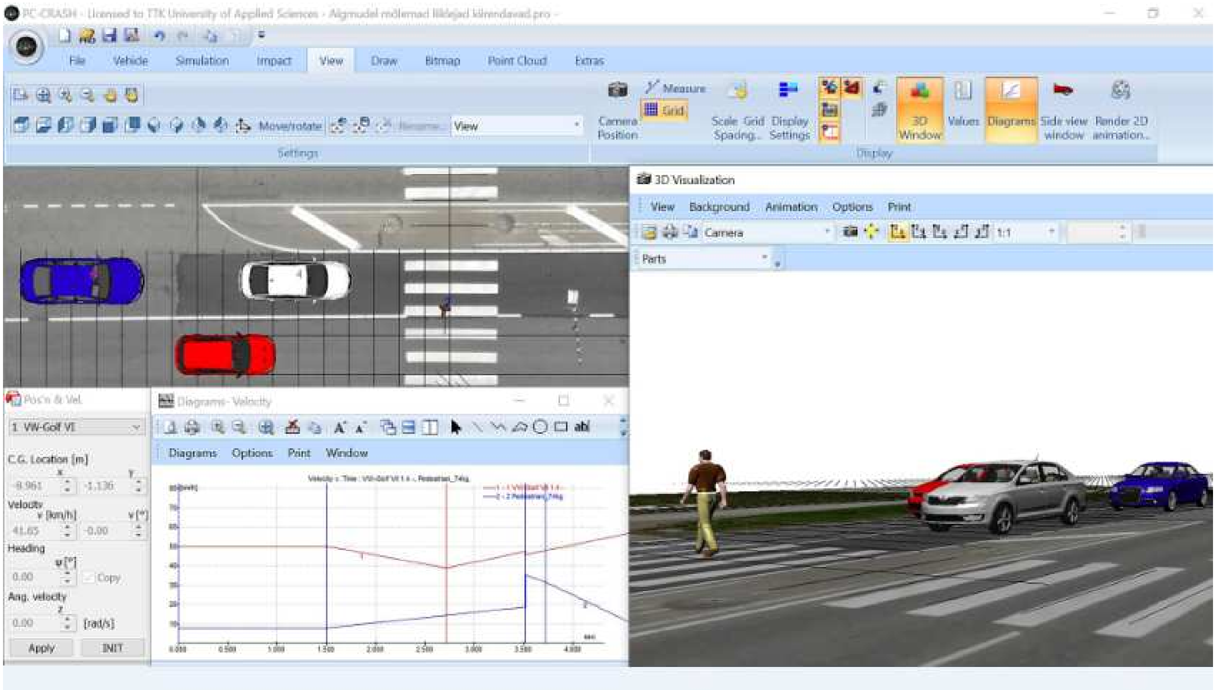

Fig. 2. Using PC-Crash to analyse traffic conflicts

THE STUDY

Conflict study

Researchers collected and analysed 1512 hours (approx. 2 months) of video material. A total of 283 hours were recorded during the pilot stage and 1229 hours during the main stage of the study. A total of 90 serious conflicts were determined. Sixteen of them were unclassified (conflicts with alarm vehicles, unusual pedestrian behaviour, vehicle-cyclist conflicts, etc). A total of 74 serious conflicts were selected for analysis. All of them took place at pedestrian crossings situated at multi-lane roads, as no serious conflicts were determined on 1 + 1 roads.

Serious conflicts were classified into three types (see also Figure 3):

- one vehicle stops before the crossing while another vehicle in the next lane conflicts with the pedestrian (Type 1)
- a vehicle conflicts with a pedestrian who is about to step to the crosswalk from the sidewalk or refuge island (Type 2)
- a vehicle conflicts with a pedestrian who is already crossing the carriageway (Type 3)

The principal difference between Types 2 and 3 lies in the fact that for Type 2, the pedestrian has not yet started crossing the carriageway and the driver may hope that the pedestrian stops before the zebra. For Type 3, the pedestrian is already on the carriageway and the situation is potentially more dangerous.

Type 1

Type 2

Type 3

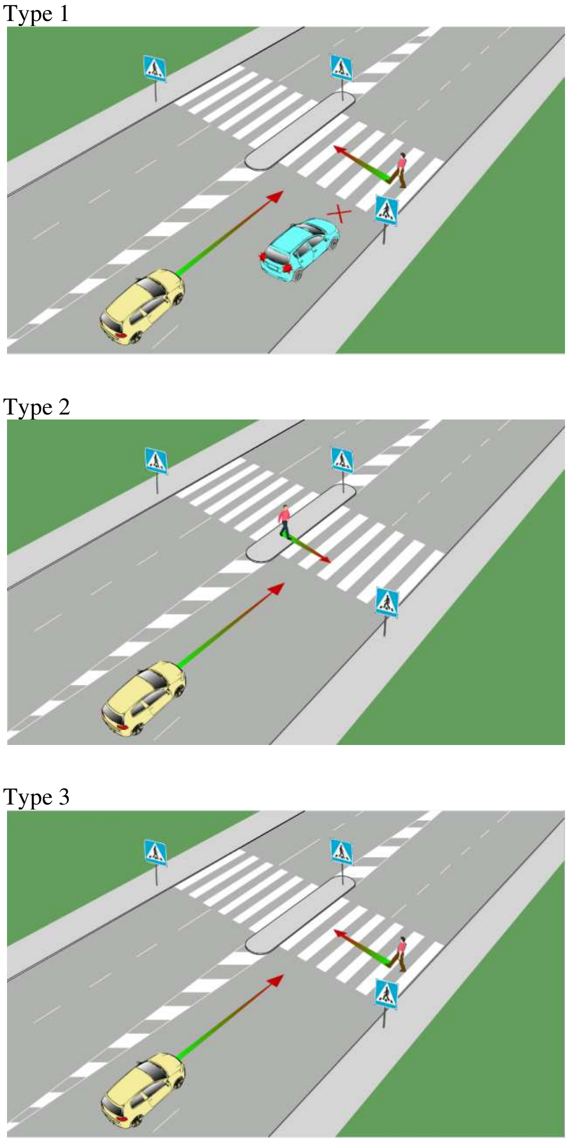

Fig. 3. Typical conflicts

It should be mentioned that between these types of conflicts there have been determined situations when a pedestrian was approaching both from the right and from the left. As it does not change the essence of the conflict, researchers ignored the direction of motion of pedestrians in their classification.

Half of serious conflicts correspond to the first type, one third to the third type, and the rest to the second type (see Figure 4). Much to our regret, due to strict personal data protection legislation, it was impossible to get detailed description of pedestrian accidents from the police, which made conflict validation with real crash data complicated. Researchers were provided only with superficial accident descriptions, which contained little to no detail. Researchers analysed the descriptions of 40 accidents which took place in 2012–2018 at the same multi-lane pedestrian crossings where the traffic conflict study has been conducted. Five vehicle-pedestrian collisions corresponded to the first type of conflicts, also five to the second, and two to the third type. Due to a lack of information, it was impossible to classify the remaining accidents, but analysis showed that conflicts of all three types ended with real traffic accidents.

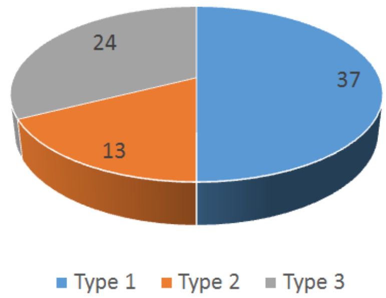

Fig. 4. Serious conflicts by types

Microsimulation and analysis

For every conflict type, researchers selected the most serious conflict and analysed it in T-Analyst and PC-Crash. Researchers used T-Analyst to determine road users' trajectories, speeds and accelerations as well as TTC_{min} and T2. Afterwards this data was imported to PC-Crash to create conflicts' models which were used to analyse capability of the SPC to prevent collision.

The type 1 conflict is presented on Figure 5. The vehicle initially moved at a speed of 36.4 km/h and the pedestrian at a speed of 7.9 km/h. This situation is interesting because of its dynamics. Analysis showed that the dense traffic flow caused visual distraction, so the driver and pedestrian saw each other at the very last moment. In a critical situation, the driver started decelerating while the pedestrian started running and jumped away from the approaching vehicle. TTC_{min} was 1.0 s.

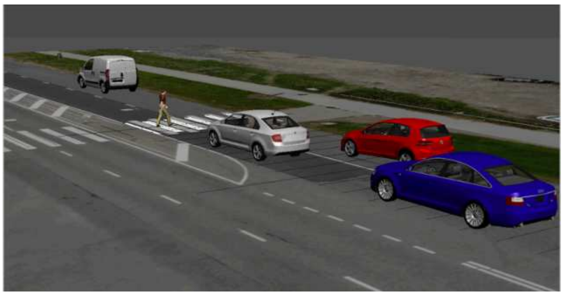

Fig. 5. Model of the type 1 conflict

In case of a collision, the vehicle would have hit the pedestrian at a speed of 34 km/h. Taking into account the speed and road conditions, the SPC should warn the driver at least 18 m before the crosswalk. This distance is relatively small, and one can admit that the driver would see the warning signal even when moving in a dense traffic flow. However, it should be taken into account that the driver does not see the pedestrian ahead and the question arises whether they react in an expected manner (brakes with maximum deceleration)?

In the case of an AEB system, the warning signal should be given at least 9 m before the crosswalk. Because of many moving objects hiding the pedestrian from the sensors of vehicles, the AEB system may not detect the pedestrian in time, especially in difficult conditions (precipitation, fog). For this type of conflicts, the vehicle would need additional input from the SPC.

The type 2 conflict is presented on Figure 6. The vehicle moved initially at a speed of 57.6 km/h (while the speed limit is 50 km/h) and the pedestrian at a speed of 5.4 km/h. It was snowing and the road was slippery. The conflict took place in the dark, but the road lighting was on and the crosswalk had additional illumination. There were no obstacles that could limit the driver's field of view. The driver assessed the situation incorrectly and when it was too late for braking, took the decision to accelerate and pass the crosswalk before the pedestrian. The pedestrian noticed the vehicle just before stepping to the carriageway from the refuge island. He stopped abruptly, slipped, and nearly fell down. $T2_{min}$ was 1.24 s.

Fig. 6. Model of the type 2 conflict

In case of a collision (for instance, if the pedestrian started accelerating), the vehicle would hit the pedestrian at a speed of 57.6 km/h. Taking into account the speed and road conditions, the SPC should warn the driver at least 41 m before the crosswalk. This raises a number of questions. Would the driver notice a warning signal located in front of the crossing? Would the speeding driver realise the danger and react to the warning signal, which is located so 40–50 m ahead? Would the driver take into account road conditions when braking? To sum up, there is certain doubt that warning the driver would have the expected effect in this situation.

In the case of the AEB system, the warning signal should be given at least 27 m before the crosswalk. In difficult weather conditions, the vehicle may not detect the pedestrian with its own sensors and may need additional input from the SPC.

The type 3 conflict is presented on Figure 7. The vehicle initially moved at a speed of 41.4 km/h and the pedestrian at a speed of 6.5 km/h. It was snowing and the road was slippery. The pedestrian moved along the road off the pavement (the trajectory is shown on Figure 7 with the blue line). He did not turn his head before crossing the road and because of his hood, he did not see the approaching vehicle in his peripheral vision. The driver started decelerating after the pedestrian had stepped to the crosswalk. Due to the late reaction, the car passed just in front of the pedestrian. $T2_{min}$ was 0.27 s.

Fig. 7. Model of the type 3 conflict

In case of a collision, the vehicle would have hit the pedestrian at a speed of 42.5 km/h. Taking into account the speed and road conditions, the SPC should warn the driver at least 26 m before the crosswalk. In the case of the AEB system, the warning signal should have been given at least 16 m before the crosswalk. In both cases, the warning should be given before the pedestrian changes direction to cross the road, i.e. before it is clear that he intends to step on the crosswalk. This case shows that in some situations, the SPC should give false positive warnings, especially in locations where the pavement is situated just next to the carriageway and the pedestrian can either cross the street or proceed walking parallel to it. Both for drivers and for AEB-equipped vehicles false positive signals would mean that sometimes they will have to brake ‘just in case’. However, this speed behaviour is typical for defensive driving style and many drivers are doing it in real traffic every day.

Coming back to the potential efficiency of SPC, in this situation, it is likely to prevent collision by warning the driver, as he or she sees the pedestrian, but postpones braking for the moment when it is too late. A warning signal would help to take a decision in time. It is important to note that in this particular case, one cannot expect the AEB to react in time without a warning signal from the SPC. As the pedestrian changes his direction suddenly and is very close to the crosswalk, the AEB will not consider him a conflicting object, before he actually turns and starts crossing. As a result, the vehicle will start decelerating later than needed. This means that the SPC should be ‘smart’ enough to predict the trajectories of pedestrians and to assess possible risks. It sets high standards to its software and processing power. Most probably the system should be based on machine learning, i.e. it should ‘learn’ the behaviour of road users from real traffic.

RESULTS

According to analysis performed withing microsimulation for all the situations studied, researchers answered the question ‘Would an SPC help to prevent a collision?’ Results are presented in Table 1.

Table 1. Ability for preventing collisions by type

Type of warning	Type 1	Type 2	Type 3
Warning the driver	likely	doubtful	likely
Warning the AEB-equipped vehicle	yes	yes	yes

Source: own work

Results show that the SPC will work most efficiently by warning AEB-equipped vehicles – they do not fail to react, and their pre-braking time is shorter. At the same time, in all the three situations studied, the AEB might need additional input, especially in case of visual distractions and difficult weather conditions. Warning the driver is assessed rather pessimistically, as with our current knowledge, we cannot be sure that the driver will react at the warning signal as expected. If we warn the driver, he or she might not notice the warning signal or react properly. At the other hand, conflict study showed that 53% of drivers involved in serious conflicts did not take any action. They might have assessed situation incorrectly or were distracted, so the warning signal might be useful. In this context, the efficiency of the SPC will highly depend on the efficiency of warning signals (first of all, on their type and location).

To sum up, from the cases studied, one can conclude that SPCs have a good potential to prevent typical vehicle-pedestrian crashes at uncontrolled crossings. Warning the vehicles has better potential than warning the drivers, because the efficiency of SPCs will largely depend on the quality of warning signals.

FEATURES TO PROVIDE EFFICIENCY OF THE SPC

In the scope of their study, researchers determined certain 'must have' features for an efficient SPC. First, an important feature for the SPC is calculating the stopping distances. If the road is dry and the vehicle's speed is 50 km/h, the SPC should warn the driver at least 30 m before the crossing, but in case of snow on the carriageway, 68 m before the crossing. The system should be smart enough to know the coefficient of static friction and to warn road users and vehicles in time.

Secondly, the SPC should predict road users' behavior. Analysis of traffic conflict showed that road users behave in different ways in pre-crash situations. The most common behavior for drivers is taking no action at all (53%); however, 1% start accelerating. The most common behavior for pedestrians is deceleration (74%), while 7% start accelerating. Researchers added the most typical behaviour patterns to traffic conflict models and checked if these patterns increase collision risks. Results are presented in Table 2. Impossible scenarios are marked with '-'.

Table 2. Potential probability for preventing collisions by type

Driver	Pedestrian	Type 1	Type 2	Type 3
Does nothing	Accelerates	No collision	Collision	Collision
Accelerates	Does nothing	Collision	No collision	High collision risk
Accelerates	Accelerates	Collision	High collision risk	Collision
Turns away	Does nothing	-	No collision	-
Turns away	Accelerates	-	No collision	-
Turns away and accelerates	Does nothing	-	No collision	-
Turns away and accelerates	Accelerates	-	No collision	-
Turns away and decelerates	Does nothing	-	No collision	-
Turns away and decelerates	Accelerates	-	High collision risk	-

Source: own work

Results show that in most cases, the acceleration of a conflicting road user leads to collision or high collision risk. Analysis of Type 3 conflict showed that the SPC should be capable to predict pedestrian's trajectory. At the same time modelling typical behaviour patterns of road users indicate that to prevent collisions effectively the SPC should also predict possible acceleration of the driver and the pedestrian.

In the third place, the SPC should be orientated not only to the vehicles, but also to the road users. The system will be most efficient for the AEB-equipped vehicles, but their share in traffic will be relatively low during the next decade. According to Estonian Transport Administration, the average age of a passenger car in Estonia is 12.9 years. The total number of passenger cars is approximately 910,000, while the number of annually sold new cars (which will be all AEB-equipped starting from 2022) is approximately 26,000. It means that the SPC should warn not only vehicles, but also drivers and its efficiency will largely depend on the warning signals. This topic needs additional research. It is important to understand which warning signals are most efficient for drivers and if it makes sense to warn pedestrians as well. One of the most important questions is where will road users look when they see (or hear) the warning? Is there a risk that they will pay attention only to the warning signal and fail to see the hazard?

How to measure efficiency of the SPC

A question arises how to estimate or measure efficiency of the SPC. This can be done by comparing number of collisions or traffic conflicts before and after implementing the SPC, but this approach will be very time-consuming. Both collisions and conflicts are rare events in traffic and getting a trustful sample size would be complicated, so alternative approach can be used.

In a broad sense, the SPC is a new generation traffic calming measure (TCM). Both the SPC and classic TCMs serve the same purpose – make drivers choose safe speeds – with the only difference being that classic TCMs do not 'understand' if there is a risk of collision or not. Therefore, when analysing the efficiency of the SPC, one can proceed from TCMs.

Ess and Antov proposed methodology to estimate the effectiveness of TCMs from the perspectives of vehicle speed and public acceptance [Ess and Antov 2016]. It assumes measuring speeds in certain locations in front and behind the TCM and calculating 85th percentile location speed and mean location speed. On the one hand, the choice of speed should guarantee traffic safety, but on the other hand, also smoothness of motion. In the context of the SPC, it means that the vehicle should reduce speed to the needed extent, but only if there is direct need for that. Warnings should not be given 'just in case' – the number of false positive signals forcing to brake should be as low as possible. The SPC is feasible to measure both speed parameters and share of false positive warnings automatically and use this data to improve its algorithms.

Public acceptance, i.e. road users' attitudes towards the TCM, is also taken into account – the better this attitude, the more efficient the TCM. Drivers and pedestrians should understand that the SPC is implemented not to disturb, but to help them. The better is their attitude towards the SPC, the more efficient it is. Public acceptance is estimated by means of survey.

Methodology described above can be used to estimate efficiency of the SPC, but also to compare different warning algorithms to improve road safety.

CONCLUSIONS

The general conclusion is that the SPC has good potential to prevent vehicle-pedestrian collisions at uncontrolled pedestrian crossings.It defenetly makes sense to invest money and time in research and development. The most effective is to warn AEB-equipped vehicles, as they react faster and brake automatically. Most importantly, in many situations, AEB will need input from the SPC and will not be able to prevent collision on its own. At the same time cooperation between AEB and C-ITS system would be able to prevent all types of conflicts analysed in the scope of this study.

Warning the drivers also has good potential, but much will depend on the quality of warning signals. Additional research is needed to understand how to warn drivers in the best way and whether it makes sense to warn the pedestrians along with the drivers. At the same time, it is important to warn not only the vehicles, but also the road users, as the share of AEB-equipped vehicles is rather small and will increase slowly.

To work efficiently, the SPC must be able to predict change in the speed and direction of road users as well as calculate the braking distance of vehicles according to the coefficient of static friction of the carriageway. False positive warnings are inevitable, but the number of such warnings should be as low as possible. The attitude of road users towards SPC should be positive, otherwise it cannot be considered effective.

The study results were used in working out the first prototype of the C-ITS warning system. At the moment of publication, it is being tested in Tallinn in the scope of Finnish-Estonian project "FinEst Twins", which aims at selecting smart city pilots with strong scientific, innovative and commercial potential for future studies [FinEst webpage]. The C-ITS prototype is equipped with cameras and sensors and uses narrow artificial intelligence algorithms to analyse the traffic situation and detect potential vehicle-pedestrian conflicts [Bercman Technologies webpage and webpage of the city of Tallinn]. The project will end last from 01.01.2020 to 31.08.2023.

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