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Pedestrians influence on the traffic flow parameters and road safety indicators at the pedestrian crossing

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Abstract

The interaction between drivers and pedestrians at a pedestrian crossing is studied using the method of ergonomic design. The galvanic skin response (GSR) and changes of the heart rate of drivers have been measured to monitor any emotional state change when encountering a pedestrian at a pedestrian crossing. If the driver moves away from the pedestrian standing at the roadside edge, the driver experiences a minimal emotional change. However, if there is no vehicle speed and path variation, the driver experiences significant shift in the GSR and heart rate, thus highlighting a possible increase of the stress level. It was based on the research where the distance and current speed have a significant impact on the drivers and pedestrians with the following consequences for their health. To assess the influence of a pedestrian presence on the road on drivers, it was proposed to use the angular velocity of the vehicle with respect to pedestrians. The probability of the pedestrians presence in a dangerous condition for drivers at different distances and speeds of pedestrian crossing made it possible to find an optimal pedestrian position on the road. Thus, the paper proposed a safe distance for pedestrians on the road at a pedestrian crossing in order to reduce the driver stress level in the traffic flow.

Keywords: pedestrian, traffic, speed, human factor, driver

Introduction

The ergonomic design of the road carriageways is based on the theory of interaction between the driver and his/her surrounding environment. The driver percepts 90% of the information out of internal (vehicle) and external (road,

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weather, pedestrians, etc.) surrounding environment. One of the main information source used by the driver for orientation on the road are the angular velocities of objects in the surrounding. A variation in the speed and possible path of the vehicle results in changes of the angular velocity, thereby it creates the conflict of the informational action in the surrounding.

While driving, the driver is affected different stimuli (light, sound, mechanical, etc). Information concerning the traffic comes from the external surrounding to the driver through sensory inputs – perceptions. From all the types of driver perception the vision is the most important. While driving 90—95% of all incoming information is perceived by the visual perception. The normal functioning of the system «Surrounding – Driver –Vehicle» mostly depends on how accurately and reliably the visual perception works (Wang, Wu, Li, 2015). Recognition of the external images by the human visual perception is carried out sequentially, that is, the driver's attention can be switched among different objects, one by one. In this case, the driver's vision perception concerns to one-line systems (Shutenko & Gavrilov, 2003; Antomonov, 1977; Galkin, et. al, 2018). In the driver task system, a large proportion is identification a location of the vehicle. This component is referred to as the «orientation activity» because the specificity and the essence of the realization of the driver's relationship with the driving surrounding environment are reflected. Beyond the density flow of information, only a small part of it is used to organize purposeful activities. The necessary information is selected on two ways: biological significance for the organism and semantic significance for the driving process (Charlton, O'Brien, 2001). These include angular surrounding object velocities, the position of these objects to the movement direction, the angular objects dimensions, devices indications, engine noise, body vibration, etc. (Eboli, et. al., 2017).

2. References review

The relationship between deceleration rate and vehicle speed decision has been analyzed via time-related measures (Vehicle Time to Conflict Point and Pedestrian Time to Conflict Point) and the distance-related measures (Vehicle longitudinal distance to Conflict Point and Pedestrian Lateral distance to Conflict Point) by Jiang et al. (2019). The special drivers decelerating zone with sight angle has been proposed with the consideration of longitudinal and lateral conflict behavior (Jiang et al. 2019). The drivers' behavior was analyzed through the distance to the pedestrian crossing and the reaction on the pedestrian. It was done in order to assess the effectiveness of Advanced Driving Assistance Systems (ADASs) for pedestrian detection among several road environments (Bella et al., 2017). Reports the results of a multi-factorial experiment that was aimed at the following: (a) analyzing driver's speed behavior while approaching pedestrian crossing under different conditions of vehicle-pedestrian interaction and with respect to several safety measures and (b) comparing safety measures and identifying the most effective treatment for pedestrian crossings. A methodology allows assessing the safety level of a pedestrian crossing with traffic lights or without in an urban area according to the features of the crossing presented in Basile, et. al., 2010). The modeling of pedestrian's behaviour in urban areas has been reviewed by Papadimitriou et al (2009), which highlighted two aspects: route choice and crossing behaviour. The results of these research pointed on a lack of an overall and detailed consideration of pedestrian behaviour along an entire trip in urban areas. Moreover, the need for an integrated approach based on flexibility, disaggregation and more determinism are identified (Fridman et. al, 2017). The purpose of the experimental study was given to check the interaction between the driver and surrounding and simultaneously the control the speed to pedestrians.

3. Conceptual framework

Driver takes decisions based on information available from the surrounding while operating the vehicle. The information represents by the road elements. Elements become signals – stimuli, causing a certain reaction from the driver. The driver actions are tightly interconnected with the technical characteristic of the vehicle on the functional level. Their aim is to achieve driver's motives of movement, e.g. driving along a curve, overtaking, stabilization of a vehicle, crossing an intersection, etc. (Marti, et. al., 2015). Controlling the speed and the path, the driver is willing to change the capacity and speed of information flow, i.e. changes the surrounding environment influence. Therefore, changes in the driving decisions can be considered as a driver's opposition to the action of information which was provided by the surrounding (or aggregators coming from environment) (Liu, Ch., Wu, 2009). Research by Gavrilov

(1976) showed that the changes in spatial relations are carried by the angular velocities of the surrounding environment objects and the location of these objects to the travel direction. When surrounding is considered as movement environment, their angular velocities transform into visible ones. Through the perception of the speed, the driver identifies the absolute remoteness of objects (Lobanov, 1980). Operational information is evaluated by the driver for all physical and temporal parameters. An information model of the situation is formed in the driver's mind. The perception of information is carried out in several stages. At the first stage, information is received and useful signals are extracted from the noise. As a result, the driver receives the first perception of the external surrounding. In parallel with the side of the road surrounding (objects of the external surrounding), driver's perception is affected by signals (stimuli), among which there are relevant or operational (i.e., relevant to the given moment of the control process) and irrelevant ones (i.e., «noise», which have no direct meaning). The final period of human reaction to the external surrounding is an active period, while a person takes the decisions (Brookhuis, De Waard, 1993; Grabarek, 2018).

The magnitude of the angular velocity in the indicative behaviour of the driver informs the latter about the distance of moving objects. This situation is happened due to the fact that the absolute distance is perceived through current speed. In addition to the specific modality, the angular velocity also provides information about the danger situation for the object.

According to Gavrilov, (1976), the minimum value of the angular velocity, which driver hardly understands is 15-30 min/s. A clear difference in the movement is achieved at an angular velocity of 0,0524 rad/s. With an angular speed of 3,6 rad/s, feelings of visual perceptions do not arise due to the short duration of exposure time of an image of an object on the retina. The driver can notice the differences of two points in the angular speeds only if these angular velocities differ in size by no less than 15-20%.

The connection of the angular velocity with the remoteness of the objects in the surrounding predetermines its threshold signal value, which means the ability of the angular velocity to signal the approach of a dangerous object and cause a conditional reaction, expressed in the involuntary deviation of a person from this object.

Under the signal value is provide the ability of the angular speed to signal the driver about the approach to the dangerous object. Its cause a conditioned reaction, manifested in an involuntary change in speed and path or in the appearance of changes in the state of physiological and psychological functions in the driver's body.

The conditioned reflex to angular velocity is formed during life (Shutenko & Gavrilov, 2003; Antomonov, 1977). Often, encounters with an object of the surrounding may results in collisions of the person with it. As a result, the angular velocity becomes a conditioned signals informing the appearance of an unconditioned reflex dangerous to humans.

The value of the angular velocity estimated through the probability of the appearance of a conditional reaction. Experimental evaluation of this probability is difficult due to the complexity of counting all the encounters between a driver and a specific object of the surrounding. Therefore, further, to estimate the value of the angular velocity, it was proposed to use the frequency of occurrence of the conditioned reaction. Value indicator can serve as the probability of occurrence of a conditional reaction.

$$P_a = \frac{m}{m+n}, \tag{1}$$

Where: m is the number of encounters of the driver with a pedestrian which received reinforcement in the form of exceeding the limiting characteristics of the functional state of the driver; n is number of encounters that were not confirmed.

The main source of information is the angular velocities of objects relative to the driver, and their position relative to the direction of motion, the probability of a dangerous state is a function of several variables:

$$P_{ai} = f(\omega_i, x_i) \tag{2}$$

Where: P_{ai} is the number of conflict areas where a pedestrian is been in dangerous situation for the driver; ω_i – the angular velocity; x_i is pedestrian position relative to the direction of movement in a plane perpendicular to this direction.

To assess the signal value, it is suggested to use the probability of finding pedestrians in a dangerous for the movement state. These probabilities can be obtained by statistical processing of experimental data on the influence of pedestrians on the activity of the functional systems of the body of the driver. The signal value of a pedestrian will be estimated by the frequency of the fact that the actual value of the RR-interval of the driver's ECG when encounter with this pedestrian will be more than the limit. The limit value of the RR-interval was assigned on the boundary of the confidence interval for the mathematical expectation of this RR-interval (Prasolenko O., et. al, 2019).

Thus, we believe that the angular speeds to pedestrians, which are located at the roadside edge, may have an impact on the movement parameters of vehicles. The nature of this connection is easy to establish experimentally. A diagram for determining the relationship of the angular velocity to a pedestrian is shown in Fig. 1. The angle of peripheral vision which depends on the speed (Fig. 2)

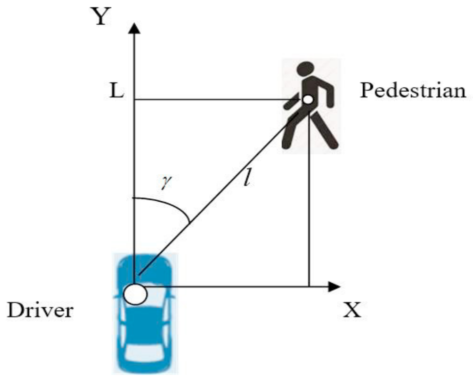

Fig.1. Estimated location of the object in the surrounding in terms of road: Y- driving direction of the vehicle

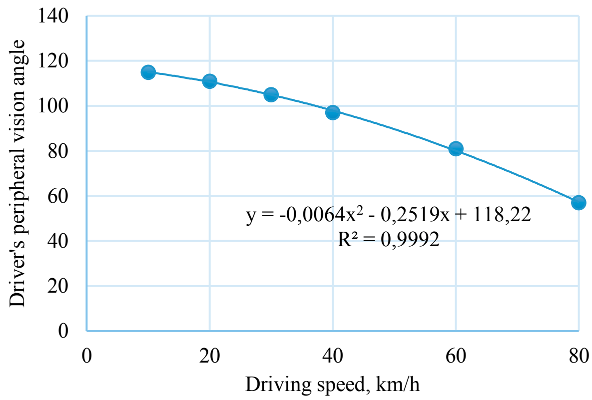

Fig. 2. The dependence of the driver's peripheral vision angle, depending on the speed (Gavrilov, 1976)

The magnitude of the angular velocity of the pedestrian in the designed situation is determined by the formula:

$$\omega_i = \frac{V_i \cdot \sin\gamma}{l_i} \cdot \frac{\pi}{180}, \tag{3}$$

where V_i – linear speed relative to pedestrian, m/s; l_i – distance from the driver to the pedestrian, m.; γ – the angle of peripheral vision which depends on the speed of the driver (Fig. 2).

The distance from the driver to the pedestrian is determined by the formula:

$$l_i = \sqrt{L^2 + x^2}, \tag{4}$$

where L – distance from the driver to the pedestrian, m; x – lateral distance perpendicular from driver to pedestrian, m.

4. Experimental research

Experimental studies were conducted on the pedestrian crossing in intersection with traffic lights in an urban area. Two classes of vehicles, «B» - small vehicles for personal needs and «C» - Light Motor Vehicle—Transport» were used in the experiments. During experimental races, continuous registration of environmental factors, indicators of the functional state of the driver's body and output characteristics of the «driver-vehicle» system was carried out.

Environmental factors of movement, plan and profile of the road were recorded using a Racelogic device. VideoVbox was used to record the actual path of the vehicle, the actual speed, etc.

The functional state of the driver's body was assessed by the results of continuous recording of the electrocardiogram (ECG). A standard «CardioSens» holter was used to register the driver's ECG. The withdrawal of

ECG data was carried out in a special placement on the middle axillary line to the right and to the left at the level of the fifth intercostal space and the upper chest.

During processing electrophysiological characteristics of the state of the tested drivers, the following characteristics were calculated:

$$\Delta F = \frac{F_O - F}{F_O}, \tag{5}$$

Where: ΔF is a change in the heart rate; F, F_O are respectively the times of the RR-interval of the ECG when driving on the road and in a state of operative rest before the trip, ms;

To participate in the experiments, a group of 6 drivers was formed with professional experience from 3 to 7 years and age from 20 to 25 years. The group included drivers with a high functional mobility of the nervous processes, high excitability and reactivity. Drivers with such properties of the nervous system are the «worst» in the composition of the traffic flow. They often get into the accidents and prefer situations with low levels of stimulation. If the «worst» drivers successfully cope with the tasks of driving a vehicle on the road, then the rest of the drivers will successfully fulfill their functions. The adequacy of the model of forming a conditioned reflex to the angular velocity relative to a pedestrian according to formula (1) was established experimentally on a straight horizontal section of the street. The street was 12 m wide and had a curbstone (Fig. 3).

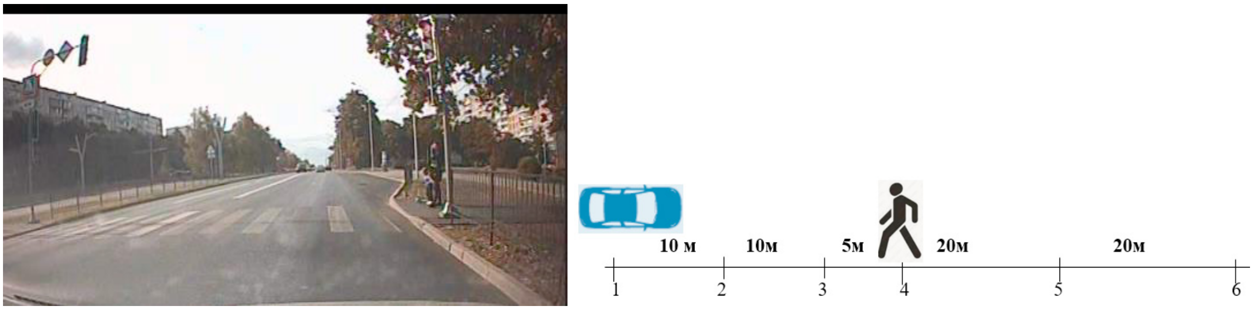

Fig. 3. Section of the street for the study of the angular velocity relative to pedestrian and the layout of counting points in the experimental part of the street: 1–6 – numbers of counting points; 10m; 20m – distances.

Checking points were arranged at the distance of 10 m from each other all along the experimental site. The first, second and third points were located before the pedestrian crossing. The fourth checking point was situated directly on the pedestrian crossing. The fifth and sixth points were located after the pedestrian crossing (Fig. 3). The position, motion parameters and the speed of the vehicle in the cross section of the road were recorded at each checking points by RACELOGIC device. To determine and control the position of the vehicle in the intersection, the carriageway was marked with chalk into sectors of 25 cm wide. Each sector had a number. The position of the vehicle was identified as a number of the sector in which the right rear wheel was situated at that moment. Experiments ran from races on the site with an unregulated mode i.e. the driver could pass the distance with the desired speed and path. Each driver performed 10 trips on the same route. A trip began at the distance of 400 m from the check point to ensure consistency of the results. Each race was arranged at time with a minimum traffic level. The results of the experiments are shown that while vehicle becomes closer to the pedestrian the distance between them is increased (Fig.4).

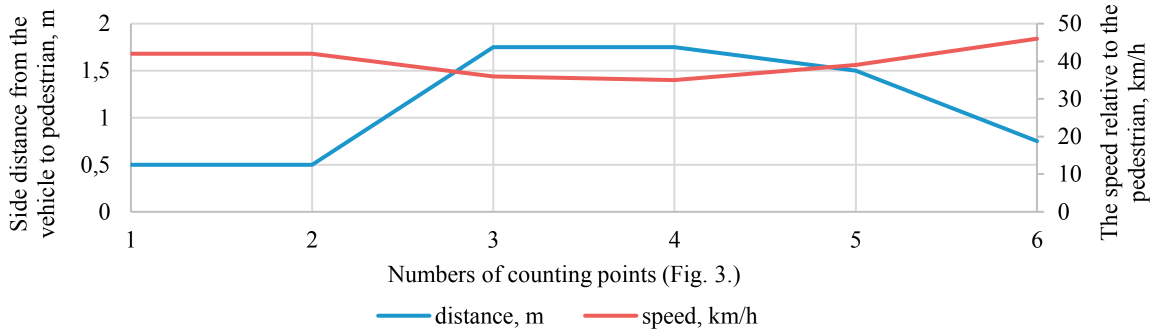

Fig. 4. Path and speed of driver's movement when encountering with a pedestrian

The results are given under unregulated mode can define the average level of indicators of the driver body condition and their intervals. The output of the indicators was used to identify the driver reaction on stimuli such as pedestrian in further experiments with a different mode. Traffic mode regulation was performed with a certain speed (20, 30, 40, 50 km/h) at a given distance to the pedestrian (0,5m (x=2m), 1,5 m (x=3m) on fig. 1). The further data processing included only the data of tenfold repetition. The driver reaction frequency to the pedestrian was calculated by the formula:

$$P_r = \frac{m}{N}, \tag{6}$$

where m is the number of the driver reaction frequency while passing the obstacles; N is total number of passage.

The number of conflict areas with the pedestrian which has been proved by support in the form of exceeding the limiting characteristics of the functional state of the driver (the time of the RR-interval of the electrocardiogram > 780 millisecond) at an angular pedestrian velocity is presented Fig. 5.

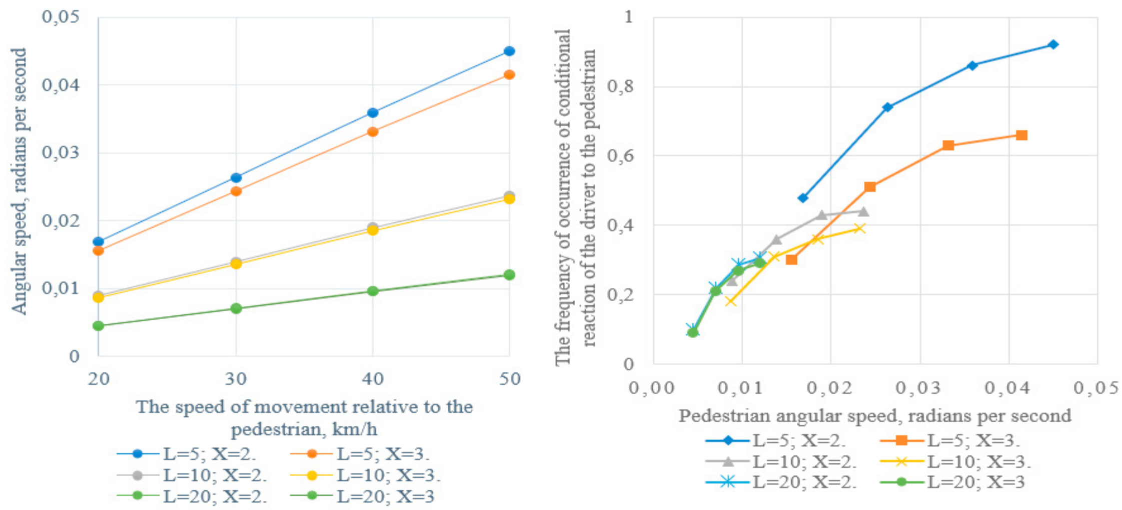

Fig. 5. Angular speed and the probability of a reflex at an angular pedestrian velocity (where L is the distance to pedestrian in the direction of drive, m; X is the side distance relative to the pedestrian in the direction of drive, m.)

The maximum driver hears rate changes had been detected at the speed of more than 0,045 rad/sec to a pedestrian. In case of the distance more than 1.5 meters from the road the angular speed decreased to 0,042 rad/sec and the driver can pass the pedestrian crossing with a minimum changes in the heart rate. Pedestrians who are been at the edge of the road interact with the traffic flow. Changing the position of the external objects to the driver's direction line enhances the effect of the angular velocity. Therefore, the angular velocity and its position to the direction of the driver can be considered as conditioned signals informing the driver about the distance to the object. Conditional-reflex relationship between apparent speed and absolute distances is formed throughout life as a result of orientation training in space.

Conclusions

Pedestrians create a sense of subjective danger in the driver behaviour. The driver instinctively reduces the speed thereby reducing the possible impact of a pedestrian on his body (Panero, 2018). If the driver does not slow down, his pulse is likely to increase, and stress may occur. The angular speed of the pedestrian to the driver can be considered as aggressor, which may inform about the danger and cause a reaction occurred in the speed and path changes or relative reaction aim at minimizing Vehicle Time to Conflict Point. These caused physical and mental energy consuming of the driver. The average speed on the road is decreased due to the driver felt stress of angular velocity and decelerated the speed. This reduction of the road capacity, increasing traffic delays and emissions of harmful substances from exhaust gases of vehicles in the traffic flow, in parallel, it increases the life risk for the pedestrians. Due to fact, the objective of ergonomic design is aim at reducing consumed energy in the operation process, the optimization of driving process can be achieved via optimization elements of surrounding parameters. This will to provide to stay driver in an optimal state. Thus, we propose to introduce a line of safe distance for pedestrians from the pedestrian crossing to the road at the traffic light intersection. Based on average width of the vehicle (1,7 m) and distance to the end of line (x = 3m, on Fig. 1), pedestrians must be at the distance of at least minimum 1.3 m from the road especially if there is a possibility and conditions for high-speed traffic flow.

The characteristics of the driver described as the concept "driver-vehicle" in the paper. The complexity of the driver reaction can be dived into two periods – hidden (latent) and active, during which the driver makes decisions (Gyulyev et al, 2018; Afanasieva & Galkin, 2018). Ergonomic design is proposed to identify the characteristics of the driver while interconnection with the road. These patterns are manifested by the subordinate principles of the natural (unmanageable from the outside) behaviour of the driver. Therefore, the driver's characteristics considered through the driver's reaction on the road and pedestrians. The driving tasks in work represented as a multi-level system, which includes three main groups of psycho-physiological processes (Afanasieva & Galkin, 2018): perception of information; work of the central nervous system (processing and storage of information); effective activity (response to the implementation of the decision). The psychological specificity of the driver's orientation is that the drivers interact with the natural images of the objects in their surroundings. Simultaneously, the main standards of perception (for e.g., spatial and temporal representations, signs of the form and colours of environmental objects) are stable and do not need transcoding (Gavrilov, 1976).

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