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The driver's visual perception research to analyze pedestrian safety at twilight

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Abstract

Road traffic movement at nightfall (twilight) is characterizing by a reduction of light time of the day and the rapid nightfall onset, thus the driver's eyes have less time to adapt to rapid sudden changes in illumination. The visual perception and the reaction time of the driver in conditions when pedestrians appear in nightfall conditions on the street and road network in a city is considered in the paper. Researched was conducted in uncontrolled pedestrian crossings in nightfall conditions on Ukrainian roads. Regularities of the vehicle's driver and pedestrians' interaction in nightfall conditions are obtained. Road traffic accidents occurrence probabilities at the twilight time considering the driver's reaction time and the car's movement parameters was analyzed. As a result, a model for estimating the variation the reaction time of the driver when a pedestrian appears in the nightfall (twilight) conditions was calibrated.

Keywords: *"Road lighting, pedestrians, traffic safety, driver visual perception"*

1. Introduction

A road traffic crash results from a combination of several factors, in particular, the accident risk, in terms of

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repeatability, localization, and severity, is related to three concurrent factors: infrastructure, vehicle, and human factors (Elvik et al., 2009), in this way, approximately more than 80% of traffic accidents occur due to the driver's fault. Especially, it is necessary to specify a road traffic movement at nightfall (twilight). This time period is characterizing by a reduction of light time of the day and the rapid nightfall onset. In these conditions, the driver's eyes have less time to adapt to rapid sudden changes in illumination (Ising, 2014).

According to statistics (WHO, 2018), the greatest number of injured in road accidents are pedestrians. In fact, due to this problem, a methodology that provides a quantitative evaluation of pedestrian crossing safety level through a composite index was development in Europe (Basile et al., 2010). The pedestrian movement is a particular problem of traffic safety during the dark times of the day. The difficulty of recognizing pedestrians in the driver arises when the lighting changes dramatically from 300 to 20 lux for 10-15 minutes. During this time period the risks of road accidents and the severity of the consequences increase in several times (Li et al., 2016; Wood et al., 2014a; Ising, 2014; Weber & Plattfaut, 2001).

The reason for this is a quick change in illumination. Normally, the inclusion of lighting in the city takes some time and does not take into consideration the driver's behavior. Changing the lighting causes blinders effect on the road. Drivers in conditions of blindness poorly see pedestrians, and do not have to enough time to react, therefore, the probability of a vehicle/pedestrian collision is increasing. The driver's reaction time is crucially important in such situations. In this paper, the influence of illumination on the safety of pedestrian traffic nightfall (twilight) conditions is considered.

2. Research significance

Drivers with headlights of oncoming cars (Gavrilov, 1976), failure of outdoor lighting devices or improper use of them (Rumar, 2002), reduced the performance of drivers at night (Galkin et al., 2018). Each of these causes is the result of incorrect interaction in the complex dynamic system "Driver – Vehicle – Driving around (internal and external)" (Wang et al., 2015). General characteristics of all the considered areas of improving the organization of driving are shown in Table. 1, it is possible to assert that the main driver in the "Driver – Vehicle – Driving surrounding" system is a driver that determines the direction and speed of the vehicle at every moment of movement (Kountouriotis & Merat, 2016).

Table 1 Types of use of ergonomics means to improve the organization of driving

Elements	Characteristics
Driver	1) Professional skills (Charlton & O'Brien, 2001); 2) Driving skills and their formation (Baevsky, 1984) 3) Psychological training of the driver (Phillips & Repperger, 2003; Shinar, 1978).
Internal surrounding	1) The particular environment in the cabin (climate, lighting, noise, vibration) (Johns et al., 2007); 2) Visibility (Marek, 1977); 3) Human-machine interface (Grabarek, 2018; Funatsu, 1978)
Design of transport technological processes	1) Substantiation of drivers' schedules during urban and freight transportation taking into account the psychophysiological state of the driver (Galkin, et al., 2018); 2) Tasks of the driver (Rossi et al., 2011); 3) Diver attention to cellophane and advertising (Afanaseva & Galkin, 2018)
External surrounding	1) Weather conditions (Wood et al., 2014b). 2) Traffic management: traffic sights (Maji & Tyagi, 2018; Maji & Jha, 2017); road marking (Sil & Maji, 2017); direction indicators, traffic signal alarms (Prasolenko et al.,2019) 3) Design of highways and roads: distance visibility (Eboli et al., 2017; Sullivan, 2001); curves of the plan and profile (Kulbashnaya & Linnik, 2015); Roads with a homogeneous road environment (Stoker et al., 2015)

Low traffic at night gives the driver a sense of false security and complacency. Drowsiness and lethargy appear, the perception of the road situation slows down (Tyrrell et al., 2016), decision-making time increases (Afanaseva & Galkin, 2018), and attention decreases (Wood et al., 2010). This condition is largely determined by the violation of the daily biorhythm at night, as a result of which the level of psycho-physiological functions decreases, fatigue develops faster and efficiency decreases (Murata et al., 2011). The performance is especially reduced from 10 pm to 6 am. At this time, the ability for the driver to act quickly, which is based on the special state of his nervous processes, providing immediate and expedient actions in dangerous driving situations, is sharply disrupted. The lack of such readiness leads to the fact that the dangerous situation for the driver turns out to be unexpected and he is not able to respond to it with sufficiently quick and correct actions. Therefore, the interaction between the driver and other road users and pedestrians at nightfall (twilight) is highly relevant.

Visibility at night on unlit roads is ensured by the headlights (with high beam on - at a distance of 100-150 m, with low beam turned on 30-60 m). The greater the speed, the farther from the car the driver focuses his attention, shifting his gaze to sections of roads that are worse lit. As a result, more time is needed for the perception of objects, which increases the duration of reactions (Li et al., 2016). When illuminating the road with headlights, the limited width of the visibility zone creates a danger of hitting a pedestrian, who, approaching the border of the light cone of the headlights, may not get into the illuminated area for a long time, because as the car approaches the lane, the illuminated area retreats as it decreases its width (Wood et al., 2014b).

In the modern vehicle is integrated intelligent pedestrian detection systems and car assistants can improve the safety of pedestrian traffic (Ahire, 2014), but today such systems have a high cost and their use is limited. Therefore, the authorities of many cities today are actively conducting agitation companies on the drivers and pedestrians' recommendations of movement in the dark time.

Driver external surrounding becomes more predictable due to applying new materials for highlighted risky zones. In conditions of poor visibility, objects that are painted in bright colors are perceived better. That is why the road marking is done in white, and in some countries the surface of certain sections of the road is sometimes painted in light colors; on such a road, even with limited visibility, all objects of a darker color are clearly visible (Ising, 2014). The dynamics of driver fatigue and change the emotional stress, reflecting the fact that the main danger lies in the long straight decline overloading the driver. Depending on road conditions and the level of emotional stress initial falling of this level can be observed for 0.5-1.5 min, the main source of information in this case is the traffic flow (Lobanov, 1980; Eboli, et. al., 2016).

The light-reflecting elements on pedestrian clothing have been widely used, which help drivers better detect the presence of pedestrians on the roadway (Beckwith & Hunter-Zaworski, 1998). A pedestrian in dark clothes reflects only 2% of the light, and details of clothing painted white or light colors reflect up to 90% of light and are perceived better and at a greater distance. However, pedestrians even in the summer at night often dress in dark clothes. As a result, drivers often see them when it is no longer possible to prevent an impact. Often, the causes of raids on pedestrians in the dark are often their lack of discipline and their violation of the Rules of the Road (Wood, et. al., 2014). Therefore, the road safety at night requires an additional reduction in speed. Decreasing of speed gives time for perception, analyzing, tacking decision and reacting to traffic objects. In case of limited visibility, the time of reaction should be greater than the stopping distance of the vehicle (Owens, et. al., 2010).

3. Objective and Hypotheses

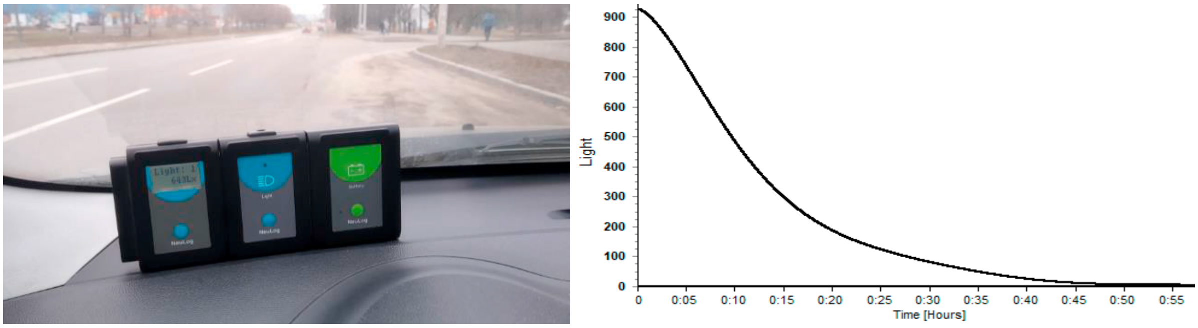
The objective of this study is to analyse the influence of lighting on the safety of pedestrian traffic nightfall (twilight) conditions. To research the influence of a drastic nightfall (twilight) appearance on the patterns of driver and pedestrian's behavior, the following considerations were taken into account:

- the change in lighting when darkness occurs;
- the reaction time of the driver when a pedestrian appears in the nightfall (twilight) conditions;
- the driver's mistakes when pedestrians appear on the road in the conditions of darkness.

The research is based on the hypothesis that the lighting, and the driver's functional condition change the driver's reaction time increasing the probability of a vehicle/pedestrian collision.

4. Methodology

This research was based on the Neulog light recorder, the Racelogic recorder is used to study the reaction time of the driver and the vehicle traffic parameters. The lighting data were collected by O. M. Beketov National University of Urban Economy research staff in the autumn-winter months of 2018 on Ukrainian roads with the Neulog light sensor (Fig. 1a). As shown in Fig. 1b after 30 minutes of sunset, the lighting in the cabin is about 100 Lx. Drivers subjectively estimated the significant complications of road objects recognition.



(a) (b)

Fig. 1. (a) Neulog light sensor; (b)Samples lighting measurements

The stopping distance of the vehicle is calculated by the formula:

$$S_{ocm}=S_1+S_2+S_3+S_4 \quad (1)$$

where S_1 = the distance covered the vehicle, taking into consideration the reaction time of the driver (m); S_2 = the distance covered the vehicle taking into consideration the time of operation of the braking systems of the car (0.1 s); S_3 = the distance covered the vehicle taking into consideration the time of the increase of effort in the braking systems of the car (m); and S_4 = the distance covered the vehicle taking into consideration the time of braking with maximum effort (m).

The Racelogic device to record the motion parameters and estimating the reaction time was installed and used. Thus, it was therefore assumed that if the driver expects to find a pedestrian, then the deceleration of the vehicle will not be more than 0.15-0.25 G. From the results of deceleration and braking action, the driver's reaction time was calculated by the following formula:

$$TR_{drv} = (T_{act} - TDV_{react}) - TV_{react} \quad (2)$$

where TR_{drv} = driver's reaction time (sec); T_{act} = time of occurrence of the event behind the device "racelogic" (sec). (fixing the time of the device every 0.05 seconds); TDV_{react} = reaction time of the driver-vehicle system (sec); and $TV_{react =}$ time of operation of hydraulic brakes of cars makes (0.1 sec) (Gavrilov, 1976).

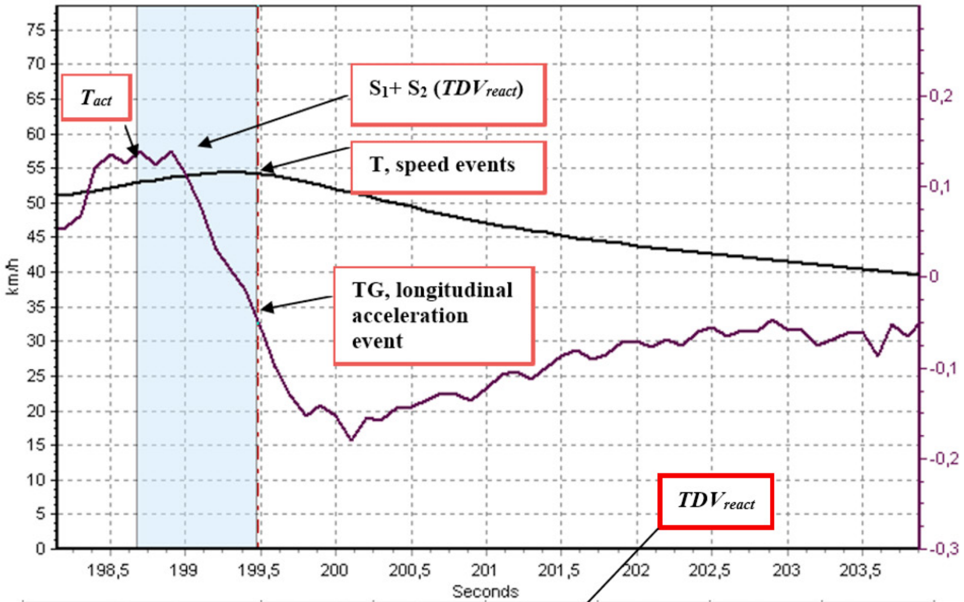
The method of evaluating the response time for the Racelogic device is as follows (Fig. 2): (i) Fixing the event on the road in real time (T_{act}); (ii) Waiting for the reaction of the system: Driver-Car; (iii) Fixing the speed change according to the "racelogic" schedule (*T*, speed events); (iv) Fixing a slowing change according to the schedule "racelogic" (*TG*, longitudinal acceleration event); (v) Reaction of the system in real time: Driver-Car by the device "racelogic" (TDV_{react}) and; (vi) Determination of the reaction time of the driver.

To determine the oscillations of the functional state of the driver in the process of moving on the route, taking into account the lighting, the method of ECG was used (Gavrilov, 1976; Lobanov, 1980; Prasolenko et al. 2015). During the driving period, an electrocardiogram of the driver was recorded.

As an indicator of the heart rate variability, the tension index of the regulatory system of the driver (*IN*) was used. It is the heart rate that is a stable and accurate indicator of the functional state (Gyulyev, et al., 2018). In the same way, cardiosens equipment was used to analyze the heart rate parameters of the driver. In this study, the index of the displacement of the stress index (the ratio of the actual index of the driver's voltage index to its value before the trip) was also used according to the following equation:

$$\Delta IN = \frac{IN_R}{IN_f} \quad (3)$$

where ΔIN = the ratio of the actual index of driver's tension to its background value (before the trip); IN_R = traffic tension index during traffic; and IN_f = Index of tension in the background when the driver is leaning back in a seat with his eyes closed before driving for 10 minutes.



Channel	Start Value	End Value	Difference	Maximum	Minimum	Average
Time (secs)	198,670	199,480	0,810	------	------	------
Speed (km/h)	52,870	54,150	1,280	54,403	52,548	53,779
Distance (metres)	1213,627	1225,685	12,059	------	------	------
Longitudinal Acceleration (g)	0,136	-0,050	-0,186	0,139	-0,050	0,083

Fig.2. Parameters of braking and reaction time behind the "RACELOGIC" device

The voltage index is determined by the following equation:

$$IN = AM_O / 2\Delta X M_O, \tag{4}$$

where AM_O = amplitude of distribution mode RR - intervals (%); ΔX = variation range of RR intervals; and M_O = the range of RR values - the most frequent intervals (distribution mode) (sec).

A group of six drivers with driving experience between 3 to 7 years, took part in the data collection. The choice of drivers with an experience of 3 to 7 years is based on the fact that, according to the statistics, these drivers are more likely to be involved in an accident. Drivers with an experience of 3 to 7 years are also characterized by "impulsive" behaviour on the road and these drivers are more risk-averse. For this group of drivers is usual to excess speed limits and other violations of traffic regulations (Gavrilov, 1976). On the contrary, drivers with a long experience seek not to fall into such situations.

5. Experimental research

In order to establish the regularities of changing the driver’s reaction time in the twilight the following aspects were considered:

- the probability of giving priority to pedestrians in conditions of variable lighting;
- the lighting change patterns while the driver drives along the route;
- the patterns of changing the driver reaction time depending on the parameters characterizing the driving surrounding, the driver’s state and the route.

At the first stage of the research, was analysed the probability of giving priority to pedestrians in conditions of variable lighting (Fig. 3). It was established that with the decrease of lighting and the onset of the dark period of the day until the turning on of street lighting, drivers make mistakes do not giving priority to pedestrians at the crosswalk.

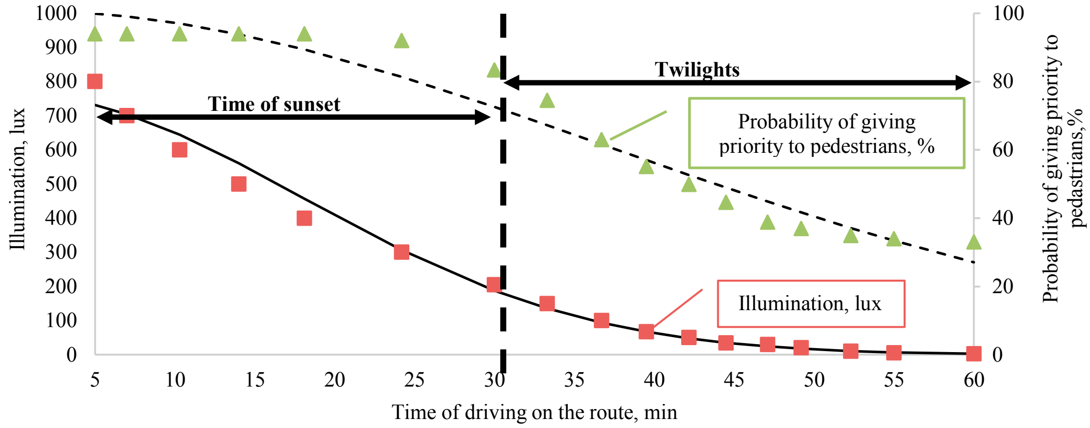


Fig. 3. Patterns of lighting changes and the probability of passage of pedestrians by drivers

From the experimental data, the lighting change patterns and the probability of giving priority to pedestrians at unregulated crosswalks were determined based on the time of movement along the route. For this purpose, Statgraphics Centurion statistical package was used and the following regression equations were obtained:

$$Lx = EXP(6.33 - 0.00155 \cdot T_{drv}^2) \tag{5}$$

Where Lx = Lighting changing; T_{drv} = time of driving on the route (min).

Changing of the probability of giving priority to pedestrians:

$$P_p = EXP(4.61 - 0.000365 \cdot T_{drv}^2) \tag{6}$$

Where P_p = priority to pedestrians.

For the calculated regression equations, the following statistical estimates were obtained: for equation 5, F–criterion = 3024.1, correlation coefficient R = 0.99 and, average error of approximation ε=9.4%. And for equation 6, F–criterion = 280.2, correlation coefficient R = 0.97 and, average approximation error ε=7.6%.

To determine the drivers' stress, a preliminary measurement of the background states was performed. The background state of each driver before the trip when the drivers tend to be less tense and calm, in a position lying in a seat with closed eyes was measured. Thus, a tension index was recorded for the drivers before the trip (Table 2).

Table 2. Parameters tested before going on the basis of indicators of cardiac rhythm

Driver Nº	Pulse	Tension Index (IN_f)
1	74	115
2	72	111
3	64	96
4	68	88
5	65	112
6	76	99

The drivers were assigned the task of moving with the desired speeds on the route 30 min before the sunset. On the chosen road there are unregulated crosswalks with an average of 3.1 units/km. During the pedestrian's appearance, the driver began to brake and had to reduce the speed of the vehicle. As a result, data on indicators of lighting, tension index, number of interactions with pedestrians and, driving time on the route were obtained. After processing such data using the statistical package Statgraphics Centurion, the following equation was obtained:

$$TRdrv = -1.09 \cdot Lx^{0.119} + 2.26 \cdot e^{0.0068 \cdot Np} + 0.025 \cdot e^{0.89 \cdot \Delta IN} + 1.99 \cdot e^{0.068 \cdot T_{drv}} \tag{7}$$

Where TR_{drv} = driver's reaction time (sec); Lx = Lighting changing; Np = Number of interactions with pedestrians (units); ΔIN= variation range of tension index; and T_{drv} = time of driving on the route (min).

For the resulting model, an approximation error of 3.77% and, a correlation coefficient of 99% were obtained.

6. Discussion and Conclusions

The paper presents the study and analysis of the influence of the sudden onset of darkness (twilight) on the behavior patterns of drivers and how this influence on pedestrian road safety. Data collection were conducted under twilight conditions during the autumn-winter months of 2018 on Ukrainian roads. A Racelogic recorder for the reaction time of the driver, and Neulog light sensor for the lighting data were used.

As a result, a model for estimating the variation the reaction time of the driver when a pedestrian appears in the nightfall (twilight) conditions was calibrated. The model considers the following factors: lighting of the environment, tension index, number of interactions with pedestrians and, driving time on the route. For the proposing model a correlation coefficient of 99% were obtained.

The study showed that the reaction time depends on driver's emotional stress and, lighting. Road traffic movement at nightfall (twilight) is characterizing by a reduction of light time of the day and the rapid nightfall onset, thus the driver's eyes have less time to adapt to rapid sudden changes in illumination. In poor lighting conditions the emotional stress increase in drivers, increasing the driver reaction time. The presented model of change of the reaction time of the driver is made for the conditions of evening twilight. A rapid decrease in lighting occurs 10-15 minutes after sunset, which increases the risk for pedestrians. In order to reduce this risk, it is necessary to use speed regulation in the pedestrian zone or switch on street lighting 10 minutes after sunset in the autumn-winter periods.

According to the analysis, similar results to previous studies were obtained; the nightfall (twilight) causes blinders effect on the road. Drivers in conditions of blindness poorly see pedestrians, and do not have to enough time to react. An increase in the time of movement along a given route also leads to increase in reaction time. Alike an increase in the voltage and tension index negatively affects the drivers' reaction time.

The proposed model of estimating the reaction time of drivers in the evening conditions has a practical use and can be applied by researchers and practitioner working in the field of road safety.

A road traffic crash results from a combination of several factors, in particular, the accident is related to three concurrent factors: infrastructure, vehicle, and human factors. Among the limitations and restrictions of the study the variables related to the infrastructure and the vehicle were not analyzed, likewise the drivers who took part in the investigation had a driving experience between 3 to 7 years and it would be interesting to know the behavior of drivers with different characteristics (i.e. sex, age, years of experience, etc.), so in future investigations these issues could be addressed.

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