The investigation of pedestrians’ accident according the place where they are thrown

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Abstract. The place where a pedestrian was thrown after being hit on the side of a vehicle is relatively easy to set up due to the traces of organic substances left on the runway or the information given by the people who saw the accident or were the first to have arrived at the crime scene. The work proposes to consider whether a driver involved in such an accident has been guilty or not, if he has taken the best decisions in time according to the concrete situation, compared to the behaviour of another in a similar situation but who has reacted in normal time, and took measures to avoid or minimize the consequences in such situations. In the comparative assessment of the driver's behaviour it is necessary to know: the distance between the place where the victim was left on the road and the frontal part of the vehicle stopped; the place where the pedestrian is located when the driver has the ability to identify the danger of an accident; the area in which the pedestrian speeds are located; the distance travelled by the pedestrian from the moment the hazard is triggered and until it is hit by the vehicle, etc.

Introduction

The place where a pedestrian was hit after being struck on the side of a vehicle is relatively easy to determine due to the traces of organic substances remaining on the road or due to the details of those who provided first aid.

The aim of study is to analyse the culpability of a driver involved in such an accident compared to the compassion of another who was in a similar situation but who reacted in a normal time and showed the proper attention in noticing the danger of accident, adapted the speed according to the particularities of the traffic and took the measures to avoid or ameliorate the consequences in such situations. [1,4].

Judgments proposed to be developed in the paper refers to frontal collisions between the car and pedestrians in the crossing of the road, in cases where, in order to avoid the accident, the driver leads to an emergency braking. It is possible to define the measurements involved in the proposed analysis, such as: the throwing distance of the pedestrian from the moment of impact to the stopping on the road; The effective braking distance of the vehicle; The braking adherent friction coefficient; The speed of the car before braking; The speed of the car when the pedestrian is hit; Gravitational acceleration; The time elapsed since the driver was required to identify the danger of an accident and until the pedestrian was hit; Time of perception - reaction of an ordinary driver. The mathematical model proposed in the paper allows the determination of the main comparative sizes, according to which the driver's guilt can be assessed, such as: the speeds of the car from the times before and the pedestrian hit; the distance between the pedestrian and the vehicle from the moment of the accident hazard; if the driver has correctly assessed the timing of the accident hazard; if the driver has taken the avoidance measures required in such situations; the fastest possible speed at which the car could move to avoid an accident through the emergency braking manoeuvre.
Material and method
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In the comparative assessment of driving behaviour it is necessary for the criminal investigation to know not only the distance $S_k$ (figure 1) between the place where the victim remained and the front of the stopped vehicle, but also some other aspects such as [2,5]:

- The place where the pedestrian is at the moment when the driver has the ability to detect the danger of accident;
- The area in which the pedestrian speeds were located;
- The distance travelled by the pedestrian from the moment of the triggering of the danger until the moment of the hit;
- Age and fatigue of the driver.

The following reasoning it refers to the frontal collisions between cars and pedestrians crossing the road, in cases when an emergency braking is used to avoid the accident [3].

![Diagram](image1.png)

**Figure 1.** Hitting the pedestrian before and during the braking process

Where:
1. the speed of the vehicle in the moment when the driver had the ability to detect the danger of an accident;
2. the position of the vehicle in the moment when striking the pedestrian;
3. the position of the pedestrian at the time of the hit;
4. position of the vehicle at the beginning of braking;
5. the position of the fallen victim behind the car;
6. the position of the vehicle stopped after braking;
7. the position of the fallen victim in front of the stopped vehicle;

Next, the relationships and sizes involved in the proposed analysis are defined:

- $S_p$ (m) - the design distance of the pedestrian from the moment of the hit and until he stop on the road;
- $S_f$ (m) - braking distance of the vehicle;
• $\varphi$ - braking adherent friction coefficient;
• $W_o$ (m/s) - the speed of the vehicle before braking;
• $W_i$ (m/s) - the vehicle speed when pedestrian is hit;
• $g$ - gravitational acceleration $= 9.81 \text{m/s}^2$;
• $t_v$ (s) - the time elapsed from the moment when the driver had the obligation to notify the danger of accidents until the moment the pedestrian was hit;
• $t_r$ - perception time - reaction of an ordinary driver.

As shown in Fig. 1, the distance $S_k$ can be expressed by the relation:

$$S_k = S_p - [S_f - S_0] = S_p - [S_f - (t_r - t_v) W_i]$$ (1)

For $t_r > t_v$ and

$$S_k = S_p - S_f$$ if $t_r < t_v$ (2)

As noted, a positive value of $S_k$ characterizes the throw of the pedestrian in front of the stopped car, and a negative one, behind the car.

The relations (1) and (2) describe two possibilities of accident production, respectively on the ordinary behavior of a driver:

• the pedestrian is struck before the driver can take any avoidance maneuver (relation 1), when $W_o = W_i$;
• the pedestrian being struck during the braking of the vehicle when:

$$W_0 = W_i - (t_v - t_r) \cdot g \cdot \varphi$$ (3)

The best results are obtained by applying the Ran-Otte relation (1), (2) which establishes the relationship between $S_p$ and $W_i$:

$$S_p = 0.06739 \cdot W_i^2 + 0.2018 \cdot W_i$$ (4)

$S_f$ - braking distance is based on $W_i$:

$$S_f = \frac{W_i^2}{2g\varphi}$$ (5)

After replacing in (1) and (2) the relations (3) and (4) are obtained:

$$S_k = \frac{0.06739 \cdot g \cdot 0.5096}{\varphi} \cdot W_i^2 + \left[0.2818 + (t_v - t_r)\right] \cdot W_i$$ for $t_r > t_v$ and

$$S_k = \frac{0.06739 \cdot g \cdot 0.5096}{\varphi} \cdot W_i^2 + 0.2818 \cdot W_i$$ for $t_r < t_v$.

The previous relationships allow appreciation of the victim’s position regarding how she was hit, that is, before or after braking, from which conclusions can be drawn regarding the attention shown by the driver. On the other hand, depending on $S_k$, the speed of $W_i$ can be determined by solving equations (6) and (7):

For $t_r > t_v$,

$$W_i = W_0 = \frac{1}{2} \left\{-0.2818 + (t_v - t_r)\right\} \cdot A + \sqrt{[0.2818 + (t_v - t_r)]^2 \cdot A^2 + 4 \cdot S_k \cdot A}$$ (8)

and for $t_r < t_v$,

$$W_i = \frac{1}{2} \left[-0.2818 \cdot A + \sqrt{(0.2818 \cdot A)^2 + 4 \cdot S_k \cdot A}\right]$$ (9)
The distance $S_e$ between cars and pedestrian when the driver had the obligation to detect the danger of accident, is determined by the relation:

- for condition $t_r > t_v$ ($W_0 = W_i$)
  \[
  S_e = (t_v - t_r) \cdot W_i 
  \]
  (11)

- for the condition $t_r > t_v$ ($W_0 > W_i$)
  \[
  S_e = W_i \cdot t_v + \frac{g \cdot \phi}{2} (t_r^2 - t_v^2) 
  \]
  (12)

It can be found the biggest $W_e$ which the accident could be avoided by energy braking, that is, for which the stopping of the vehicle was possible even in the place where the pedestrian was when he was struck:

\[
\frac{w_e^2}{2 \cdot g \cdot \phi} + t_r \cdot W_e = S_e 
\]
  (13)

\[
W_e = \left[ -\frac{t_r}{2 \cdot g \cdot \phi} + \sqrt{\left(\frac{t_r}{2 \cdot g \cdot \phi}\right)^2 + 8 \cdot S_e \cdot g \cdot \phi} \right] 
\]
  (14)

Through possible values of the sizes on which $S_e$ depends some conclusions and assessments can be made regarding the driver's behaviour useful for analysing the accident. Were considered:

- impact speed $W_i = 5; 10; 15; 20; 25, and 30$ m/s;
- a reactive time $t_r = 0.8$ seconds and $t_r - t_v$ differences of: - 0.6; 0.3; 0; 0.2; 0.6 and 1.2 sec;
- braking adherent friction coefficient $\phi = 0.4; 0.6; 0.8$.

**Results**

The results of the calculations made with the mentioned values of the considered sizes are presented synthetically by the graphical representations in figures 2, 3 and 4. Some conclusions can be drawn from the analysis of these relations, the most important ones being specified below [6,7].

Knowing the distance $S_k$ allows to determine the main comparative sizes after which the driver's guilt can be assessed, namely:

- The speed of the car from the previous moments and the effective moment of hit the pedestrian
- The distance between the pedestrian and the vehicle from the moment the occurrence of the danger of accident
- If the driver correctly appraised the moment of the danger of accident
- If the driver has taken avoidance measures that could be done in such situations;
- What was the highest speed wherewith the car could move in the event of accident avoidance by energy braking

When the pedestrian is hit before the braking ($t_r > t_i$) and is designed behind the vehicle, when $t \leq 0.5$ seconds even though the braking is very energetic. However, at such brakes, (usually with ABS, which can provide a $\phi = 0.8$), if the hit occurs during braking, the place of the victim's thrown is in front of the car, if $t_r > 0.5$ sec.
Figure 2. The dependence between $W_o$ and $S_k$, for $\phi = 0.4$

Figure 3. The dependence between $W_o$ and $S_k$, for $\phi = 0.6$
For the forward thrown at the same distance $S_k$ the speed of the car must increase as the $t_v$ increases over 0.5 sec. In the case of forward thrown, the distance $S_k$ increases with the initial speed $W_o$ but decreases with the increase of the $t_v$.

If the braking is moderate with $\phi = 0.6$ the place of thrown is located behind the stopped car, at distances that increase as the $t_v$ decreases. Rarely, at speeds up to 22m/s victim is thrown at a small distance, up to 1m, only if $t_v \geq t_r$.

When braking is less efficient, for example with $\phi = 0.4$ regardless of the speed or value of the $t_v$, the pedestrian is thrown behind the car at a distance that increases as the $t_v$ decreases.

**Conclusions**

Most of the time, at high speeds, when the pedestrian is hit before the effective braking, that is thrown behind the car, even though the braking maneuver that occurs after the impact itself is very energetic.

If the time from the moment when the driver had the obligation to detect the danger of accident and until hitting the pedestrian is greater than 0.5 seconds, the impact occurs during the braking of vehicles and the pedestrian is thrown in front of the car.

If the braking of the vehicle is moderate, or less efficient, the place where pedestrian are thrown is located behind the stopped vehicle.

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