Application of the System Engineering Method when Researching the Carat Pedestrian

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Abstract – Options of finding the removal distance of the vehicle from the scene of the pedestrian accident, which came at an arbitrary angle being arbitrary to the vehicle from behind passing obstacle, are considered. Changes in the estimated equations are made. Universal dependences of geometric and kinematic conditions that can be used to study pedestrian accident came from behind both passing and oncoming obstacles are systematized and obtained.

Keywords – car, pedestrian, impact, removing, obstacle

I. INTRODUCTION

Automobile-pedestrian accident is one of the types of accidents in which a pedestrian is seriously injured or dies. Accidents, involving children, who can suddenly appear on the roadway and go in any direction with any pace of movement, are the most dangerous ones [1, 2]. Such accidents require more detailed approach to expert's study. However, the techniques of expert research of accidents have common features [3–8].

II. MATERIALS AND METHODS

Expert, analyzing the accident, mentally removes vehicle and pedestrian from the scene to the position at the moment of danger, pursues the line of sight and builds additional triangles of visibility, writes geometric and kinematic conditions of movement of accident participants (road accident) and finds the distance of the vehicle from the place of accidents. When somebody moves perpendicularly from the edge of the roadway, expert has no difficulty in the calculation of removal distance. In the case of the movement of a pedestrian at an arbitrary angle to the vehicle direction, making geometry conditions has a certain complexity. Therefore the expert is appropriate to apply a single universal dependence, allowing not to spend time tracing schemes of study [9, 10].

III. RESULTS

In Fig. 1, as an example, the scheme of examinations of front accident is given, when the pedestrian came out from behind passing transportation device 1 (TD1 – is an obstacle for the driver of TD2) at an arbitrary angle in the opposite direction to TD2.

The time of occurrence of dangerous traffic situation is indicated in figure as position I. Position II shows the moment when the pedestrian leaves the lane TD2 (pedestrian is located at point K). The time of arrival is indicated in the diagram as position III. The line of sight is shown as AC. Point C – position of pedestrian at the time of occurrence of dangerous traffic situation. To simplify calculations we make a change to further build the scheme of road accident (we extend the line of sight CA to the intersection with a line drawn through the left-hand side of TD1 and denote as CA’ [9]).
Fig. 1. Scheme of pedestrian accident examinations, at coming of the pedestrian from behind passing TD1 at an arbitrary angle in the opposite direction to TD2 in front accident.

In the scheme: \(a_x\) and \(a_y\) – coordinates of driver position in the car; \(S_{dis}\) – distance of the vehicle from the place of pedestrian accident; \(S_r\) – route of pedestrian from the moment of occurrence of a dangerous traffic situation to the moment of accident; \(B_a\) – overall width of the vehicle; \(l_y\) – distance from the sides of vehicle to the place of accident in its front part; \(r_s\) – distance which TD1 has passed from the moment of occurrence of dangerous situation until pedestrian crosses its route; \(\alpha\) – angle of the direction of movement of pedestrian.

From similarity of observability triangles \(A'B'C\) and \(DEC\) geometric condition takes the form: \(\frac{A'B'}{B'C} = \frac{DE}{EC}\) or in accordance with the designations in Fig. 1.

\[
\frac{S_{dis} + a_y + a_y \cdot t g \beta + S_x \sin \alpha}{S_x \cos \alpha + B_a - l_y} = \frac{S_r + \Delta_y + [(\Delta + l_y) \cdot t g \beta - S_x \sin \alpha]}{S_x \cos \alpha - \Delta_y - l_y}. \tag{1}
\]

The solution to geometric conditions (1) relatively to \(S_{dis}\) is possible if you know the route of pedestrian \(S_r\) and movement \(S_i\) of TD1 vehicle.

These values can be determined from kinematic conditions of movement of vehicles and pedestrian:

\[
S_i = \frac{V_n}{V_2} S_{dis}, \tag{2}
\]

\[
S_i = \frac{V_f}{V_r} \left( \frac{\Delta + l_y}{\cos \alpha} - S_x \right). \tag{3}
\]

From observability triangle \(ABC\) we find \(t g \beta\)

\[
tg \beta = \frac{S_{dis} + a_y + S_x \sin \alpha}{S_x \cos \alpha + B_a - a_y - l_y}. \tag{4}
\]

Similarly, let’s consider the option of road accident with pedestrian who came from behind passing TC1 at an arbitrary angle relative to the carriageway in the passing direction to TD2 (Fig. 2) and draw a geometric condition.

Fig. 2. Scheme of automobile-pedestrian accident, with pedestrian, who came from behind passing TD1 at an arbitrary angle relative to the carriageway in the passing direction to TD2.

\[
\frac{S_{dis} + a_y + a_y \cdot t g \beta - S_x \sin \alpha}{S_x \cos \alpha + B_a - l_y} = \frac{S_i + \Delta_y + [(\Delta + l_y) \cdot t g \beta - S_x \sin \alpha]}{S_x \cos \alpha - \Delta_y - l_y}. \tag{5}
\]
The unknown values of pedestrian route $S_p$ and vehicle movement $S_v$ of transportation device 1 are defined by the formulas (2) and (3), and $\tan \beta$ from observability triangle $ABC$:

$$\tan \beta = \frac{S_{dis} + a_x - S_v \sin \alpha}{S_v \cos \alpha + B_a - a_y - l_y}. \quad (6)$$

Figures 3 and 4 present the options for lateral accident of a car with a pedestrian came from behind passing TD1, at an arbitrary angle in the opposite or same direction, respectively, to TD2.

From the equality of similar triangles both for accident scheme in Fig. 3, and scheme of the incident, shown in Fig. 4, we find the distance of the vehicle from the place of accident of pedestrian, making geometric and kinematic conditions for both options of accident.

Geometric condition for road accident scheme, shown in Fig. 3, takes the form:

$$S_{dis} + a_x + a_y \cdot \tan \beta + S_v \sin \alpha = S_v + \Delta_y - [\Delta \cdot \tan \beta - S_v \sin \alpha]. \quad (7)$$

Geometric condition for road accident scheme shown in Fig. 4 takes the form:

$$S_{dis} + a_x + a_y \cdot \tan \beta - S_v \sin \alpha = S_v + \Delta_y + [\Delta \cdot \tan \beta - S_v \sin \alpha]. \quad (8)$$

Distance $l_y$ in geometric conditions (7) and (8) for lateral crash is equal to 0, and $\tan \beta$ will be calculated by the formula:

- scheme of the accident, shown in Fig. 3:
  $$\tan \beta = \frac{S_{dis} + a_x + S_v \sin \alpha}{S_v \cos \alpha + B_a - a_y}. \quad (9)$$

- scheme of the accident, shown in Fig. 3:
  $$\tan \beta = \frac{S_{dis} + a_x - S_v \sin \alpha}{S_v \cos \alpha + B_a - a_y}. \quad (10)$$

The values of undetermined values $S_p$ and $S_v$ for both options will be defined by making kinematic conditions:

$$S_p = \frac{V_1}{V_2} (S_{dis} + l_y). \quad (11)$$

$$S_v = \frac{V_1}{V_2} \left( \frac{\Delta}{\cos \alpha} - S_p \right). \quad (12)$$

Next to all the options of auto-pedestrian accident at passing movement of TD1 and TD2 you need to calculate stopping distance of the car $S_v$, which, in uniform motion of vehicle, is equal to [1]:

$$S_v = (t_i + t_2 + 0.5t_3)w + \frac{V^2}{2j}. \quad (13)$$

where $t_i$ – driver reaction time, $c$; $t_2$ – time delay of brake drive, $c$. $t_3$ – braking time response, $c$. $j$ – steady deceleration during braking of the vehicle m/s².

Next, we compare $S_v$ of TD2 with the distance, after that court expert will provide an opinion on the possibility or lack of possibility to prevent an accident with pedestrian.

The difference in geometric conditions on schemes 1, 2, 3, 4 is in the signs before the values $S_p \sin \alpha$, $\Delta_y$, and before the expression $[(\Delta + l_y) \tan \beta - S_v \sin \alpha]$. To simplify the calculations and reduce the complexity of the work of court expert, we will introduce $K_2$ and $K_3$ coefficients before the value and expression, respectively, $K_{2\alpha}$ coefficient before the value, proposed to be introduced in [7], is denoted as $K_2$. The value of $l_y$ in a lateral accident is zero. Then geometric condition (1) for all cases of pedestrians who came from behind passing TD1 at an arbitrary angle in any direction to TD2 at the face or lateral accident will take the form:

$$S_{dis} + a_x + a_y \cdot \tan \beta \pm K_1 \cdot S_v \sin \alpha = S_v \pm K_1 \cdot \Delta_y \pm K_3 [(\Delta + l_y) \tan \beta - S_v \sin \alpha]. \quad (14)$$

and value $\tan \beta$:

$$\tan \beta = \frac{S_{dis} + a_x \pm K_1 \cdot S_v \sin \alpha}{S_v \cos \alpha + B_a - a_y - l_y}. \quad (15)$$

where in face impact $l_y = 0$ and in a lateral impact $l_y = 0$.

![Fig. 3. Scheme of automobile-pedestrian accident, with pedestrian, who came from behind passing TD1, at an arbitrary angle in the opposite direction to TD2, during lateral crash.](image-url)
The values of coefficients $K_1$, $K_2$, $K_3$ for each variant of impact at the exit of pedestrian moving in the opposite direction to $TD_2$ from behind passing $TD_1$, are shown in Table 1.

### Table 1. The options of accident, the study of which is possible using geometric condition (14)

<table>
<thead>
<tr>
<th>№</th>
<th>Type of accident (impact)</th>
<th>The road situation before the accident, the study of which is possible with applicable geometrical condition (14)</th>
<th>The values of coefficients geometric conditions (14)</th>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$K_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>At the impact with butt end of vehicle</td>
<td>The pedestrian stepped into the roadway in the opposite direction to $TD_2$ before $TD_1$ crossed and left the band of its movement</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>At the impact with lateral side of vehicle</td>
<td>The pedestrian stepped into the roadway in the same direction with $TD_1$ crossed and left the band of its movement</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>At the impact with pedestrian</td>
<td>The pedestrian stepped into the roadway in the opposite direction with $TD_2$ before $TC_1$ crossed and left the band of its movement</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>At the impact with pedestrian</td>
<td>The pedestrian stepped into the roadway in the same direction with $TD_2$ before $TC_1$ crossed and left the band of its movement</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td></td>
</tr>
</tbody>
</table>

If we consider similarly accident with pedestrian, coming over the oncoming obstacles, the geometric condition will be written as follows:

$$\frac{S_{d_1} + a_x + (B_x - a_x) \cdot \tan \beta \pm K_1 \cdot S_{y} \sin \alpha}{S_y \cos \alpha + B_y - l_y} = \frac{S_x \pm K_1 \cdot S_y \pm K_2 \cdot \sqrt{S_y^2 + S_x^2} \cdot \sin \alpha}{S_y \cos \alpha - l_y} \cdot (16)$$

Where $\tan \beta$:

$$\tan \beta = \frac{S_{d_1} + a_x \pm K_1 \cdot S_y \sin \alpha}{S_y \cos \alpha + a_y - l_y} \cdot (17)$$

Comparing geometric conditions (14) and (16), and formula (15) and (17) to find $\tan \beta$, it can be concluded that the difference in geometric conditions is the only in one value, which is before $\tan \beta$. The difference in formulas (15) and (17) is only in denominator defining. If you hit a pedestrian, coming from behind the counter $TD_1$, when denominator is defined as $S_y \cos \alpha + a_y - l_y$, and if you hit a pedestrian emerging from behind passing $TD_1$, $l_y$ is only in denominator defining. If you hit a pedestrian, coming from behind passing or moving in the same direction $TD_2$, we need to make single geometric condition by introducing $m_1$ and $m_2$ parameters:

- for the case of pedestrian coming from the oncoming $TD_1$: $m_1 = B_a - a_y$;
- for the case of pedestrian coming from passing $TD_1$: $m_1 = a_y$.

Thus, geometrical conditions (14) and (16) will be written as a single one for all options of auto-pedestrian accident:

$$\frac{S_{d_1} + a_x + m_1 \cdot \tan \beta \pm K_1 \cdot S_y \sin \alpha}{S_y \cos \alpha + B_y - l_y} = \frac{S_x \pm K_1 \cdot S_y \pm K_2 \cdot \sqrt{S_y^2 + S_x^2} \cdot \sin \alpha}{S_y \cos \alpha - l_y} \cdot (18)$$

Value $\tan \beta$:

$$\tan \beta = \frac{S_{d_1} + a_x \pm K_1 \cdot S_y \sin \alpha}{S_y \cos \alpha + m_2 - l_y} \cdot (19)$$

where in face impact $l_y = 0$, and in lateral impact $l_y = 0$.

Thus, we received uniform geometric condition (18) and the formula (19), which can be applied for finding removal distance with different options of auto-pedestrian accident, when a pedestrian comes at the roadway at any angle, both because of oncoming and passing vehicles. In case of decelerated motion of vehicle, kinematic conditions and stopping distance of the vehicle will have different view [1–3, 12, 13].

![Fig. 4. Scheme of automobile-pedestrian accident, with pedestrian, who came from behind passing TD1, at an arbitrary angle in the same direction to TD2, during lateral crash.](attachment:image.png)
Stopping distance of the vehicle during decelerated motion [1, 11, 12]:

\[ S_{st} = (t_1 + t_2 + t_3)V + S_{sk}. \]  
(20)

Here \( S_{sk} \) - automobile skidding track length, m.

Kinematic condition of vehicle and pedestrian movement:

\[ S_i = \frac{V_i}{V_p} \left( \frac{\Delta l_i}{\cos \alpha} - S_i \right). \]  
(21)

From the equality \( \frac{S_a}{V_a} = \frac{S_s}{V_s} \):

\[ S_i = \frac{V_r}{V_s} \left( S_{dis} + \frac{(V_a - V_{acc})^2}{2j} \right). \]  
(22)

Values \( V_a \) and \( V_{acc} \) are defined by the known formulas [1]:

\[ V_a = 0.5 \cdot t_{ed} \cdot j_{ed} + \sqrt{2 \cdot S_{sk} \cdot j}, \]  
(23)

\[ V_{acc} = \sqrt{2 \cdot S_{pr} \cdot j}. \]  
(24)

The solution of equations (20, 21, 22) will give the required value of automobile removal distance from the place of pedestrian accident in slowed motion.

IV. CONCLUSION

Conclusion. Received unified universal dependence (18) allows to simplify the study of pedestrian accidents, reduce the risk of errors and inaccuracies, improve the quality of calculations and therefore to improve the efficiency of experts and the whole expert community in general. According to research it is possible to make an algorithm, with subsequent development of software for calculations of impact on computer.

Analysis of a car collision with a pedestrian using the developed research methodology and computer software will make it possible to plan more rationally relevant measures to ensure pedestrian traffic safety [13–15].

References