Ergonomic Criterion in the Design of Roadside Information: Letters Size Methodology

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Abstract:

Purpose: The purpose of the paper was to develop original letters size methodology for roadside information.

Method: During moving on the roads, addressed to drivers and passengers is, among others, text information on information boards and signs including in the form of advertisements. Based on ergonomic principles and population data, optimisation can be made in the design of communicative messages. The author reviewed the issues concerning the visual process, optimal visual field, visual field defects, visual acuity characteristics and reading speed. This made it possible to select input data for the design of text information in terms of location in the visual field and the number of words on the sign board.

Findings: Based on these analyses, computational algorithms were built to evaluate a proposed or already implemented information message. The developed formulae enabled the preparation of a prototype computer application to support the analysis of information systems.

Practical Implications: The developed methodology makes it possible to integrate ergonomic criteria into the design process of text information. It can increase the effectiveness of information transfer and road safety. The most important areas of application are the design or evaluation of information systems: signs and road signs with text information, advertising for drivers.

Originality/Value: The author has developed a method to evaluate the design and placement of text information systems dedicated to drivers (e.g., text-information signs, advertisements including text), which is based on quantitative data such as the size of the letters, the distance from the word board, the location of the text in the field of vision, the speed of the vehicle.

Keywords: Design tools, eye movements, perceptual-motor performance, vision, driver behaviour.

JEL Classification: R40, R41, R42.

Paper Type: Research article.

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1. Introduction

Road traffic information systems, which include, among others, road signs and signals as well as road safety devices, are used in accordance with legal requirements and standards resulting from research (Jamson and Mrozek, 2017; Journal of Laws of 2019, item 2311; Liu, Wen, Zhu *et al.,* 2019). The legal regulations are based on the Convention on Road Signs and Signals, and more than 80 countries in the world have ratified it (Chapter XI, 1968).

The guidelines in legal acts refer to many ergonomic criteria (Ben-Bassat and Shinar, 2006; Chan and Chan, 2011; Dahlke, 2015; Ishartomo, Suhardi, and Rohani, 2020), such as:

- sign visibility (luminance of sign surface; location in the driver's field of vision; sign colour),
- sign size depending on the distance from which it is to be noticed,
- shape and size of letters, numbers, and pictograms.

Noticing a sign, reading, and understanding its content is a process that should be considered with keeping in mind the conditions in which the human being is at that time (Harasimczuk, Maliszewski, and Olejniczak-Serowiec *et al.,* 2021; Awh, Belopolsky, and Theeuwes, 2012; Hsiao, Chang, and Simeonov, 2018; Kaplan, Bortei-Doku, and Prato, 2018). One of the important parameters is the visual field (VF), characterized as the entire area (including that seen through the peripheral vision) that can be seen when the eye is facing forward (Sokolová, Beneš, and Holoubková, 2013). This is a functional definition that can be complemented by various measures and indexes characterizing the defect/drawback of the visual field e.g., index of the visual field characterizes the loss of the retinal ganglion cells (100% corresponds to normal spots and 0% to blind spots) (Wong and Plant, 2015). The values of the unlimited of binocular visual field for humans are approximately 200° horizontally and approximately 135° vertically (Jansen, Toet, and Delleman, 2010).

However, in various sources, angular differences can be noticed, e.g., 60° towards the nose from the midline, up to 100° towards the temples (Sokolová, Beneš, and Holoubková, 2013; Wolfe, Sawyer, and Rosenholtz, 2020). The authors also report that the scope of the binocular visual field ranges from 160° to 170° (Sokolová, Beneš, and Holoubková, 2013).

The area of human vision in which a certain amount of information can be collected through a brief look without moving the head is called the useful field of view (UFOV) (Choi, Byun, Kim, *et al.,* 2020; Ringer, Throneburg, Walton, *et al.,* 2015; Roenker, Cissell, Ball, *et al.,* 2003; Sekuler, Bennett, and Mamelak, 2000). The term "field of view" is most often used in a situation in which the field of view of a human being is shaped/limited by technical devices (Jansen, Toet, and Delleman, 2010; Torrejon, Callaghan, and Hagras, 2013). UFOV decreases with age and is also characterized by a decrease in the angle of view with increasing speed (Choi, Byun, Kim, *et al.,* 2020; Ho,

Scialfa, Caird, *et al.,* 2001; Schall, Rusch, Lee, *et al.,* 2013; Zhang, Dai, Pei, *et al.,* 2016; Ward, Gaspar, Neider, *et al.,* 2018).

However, optimal zones for visual tasks can be distinguished in this field (Figure 1). The field of vision including head movements is much larger. The relationship between the target of vision and head and trunk movements depends on many individual factors (Kim, Reed, and Martin, 2010; Kim, Gillespie, and Martin, 2014). In the case of the driver, relocation of the visual field to objects away from the road or situated in the cabin makes it more difficult to see the stimuli associated with risks in the lane of the road and increases the risk of accident (Dukic, Hanson, and Falkmer, 2006). Moreover, an important personal barrier to the perception of visual stimuli is a visual field defect.
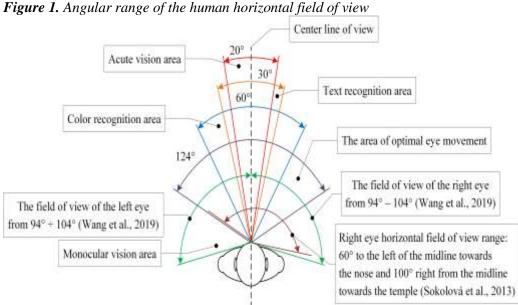
Visual field defect includes (Sokolová, Beneš, and Holoubková, 2013) loss of the central and loss of the peripheral field. In driver's case, these dysfunctions may be the reason of accidents and the restriction or withdrawal of driving licenses (Andersson and Peters, 2020; Pas-Wyroślak, Siedlecka, Wyroślak, *et al.,* 2013; Dow, 2011). Polish law stipulates those persons applying for or holding a driving license category (Journal of Laws of 2019, item 1659):

- AM, A1, A2, A, B1, B, B + E or T should have a horizontal field of view of at least 120˚, and its range should be of at least 50° to the left and right, and 20° up and down; no defects in the field of vision should be present within an angle of 20° from the fixation point;
- C1, C1 + E, C, C + E, D1, D1 + E, D, D + E or a license to drive a tram, emergency or monetary vehicle should have a horizontal field of view of at least 160°, and its range should be of at least 70° to the left and right, and 30° up and down; no defects in the field of vision should be present within an angle of 30° from the fixation point.

Milder requirements for field of view defects occur e.g., in Canada, where for lay drivers, the horizontal field of view should be of at least 120°, and the vertical field of view of 15° up and down from the fixation point (Dow, 2011).

The ranges of recommended, acceptable, and non- recommended zones of use in the horizontal and vertical fields of view are presented in the EN 894-2 standard (Figure 2). They have been defined for two types of visual tsks (EN 894-2:1997+A1:2008):

- detection tasks (tasks where the system alerts the operator),
- supervision tasks (tasks in which the operator is actively seeking information).

Figure 1. *Angular range of the human horizontal field of view*

The visual tasks performed by the driver may take different forms. Assuming that road signs are meant to alert and inform the driver, those will be detection tasks. The EN 894-2 standard also contains information on the case of letters on indicators, which are specified in angular minutes of the angle of view of the sign (letters). Analysing the field of view and collecting information during short glances (as defined in the definition of UFOV), should also be classified as eye movements. Eye movements can be divided into many types depending on the adopted division criteria. The most important movements are (Buczkowska, 2016; Noorden and Campos, 2002):
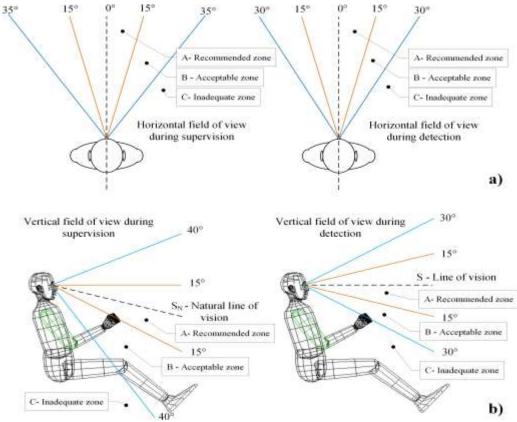
- monocular and
- binocular:
    - vergence - the axes of vision go in opposite directions to each other (e.g., during observation of an approaching or departing object in front of the observer): convergent eye movement and divergent movement;
    - conjugated - the axes of view follow the same direction (horizontal, vertical).

The vergence system includes subsystems (Buczkowska, 2016; Noorden and Campos, 2002):

- accommodative - correlated with the accommodation process;
- proximal - related to the psychological awareness of the distance of the observed object;
- tonic - related to the tonic tension of the muscles;
- fusion - compensates for the imperfections of the above subsystems.

Depending on whether the observation object, the surroundings, the observer's body are moving, or whether the stimulus to be looked at is located in a different place than the original one, relevant mechanisms are regulated by varied subsystems (Buczkowska, 2016; Stapel, Hassnaoui, and Happee, 2020; Leigh and Zee, 2015), eyes following, saccade, fixative, optokinetic, vestibular.

Figure 2. *Horizontal and vertical ranges of the "field of view" with suitability zones according to the EN 894-2: a) horizontal field of view, b) vertical field of view*

Source: *Own study based on the standard EN 894-2, using the mannequin from the APOLINEX software.*

In the case of the process of reading information on road signs, binocular movements will be more important. The factor influencing the effectiveness of reading signs is the functioning of the visual system in terms of binocular vision, accommodation or vergence. Three visual components are the most important during reading (Buczkowska, 2016; Stapel, Hassnaoui, and Happee, 2020; Leigh and Zee, 2015):

- saccades of the eyes (saccades) - defined as fast reaching the speed of up to 500 arched degrees per second;
- fixation and
- regression movements - performed in the opposite direction to the reading direction.

According to the literature, the time of reading the text consists of (Buczkowska, 2016; Carpenter, 2004; Sereno and Rayner, 2003):

- saccades – on average 10% of reading time; the average size of their movements is from 2° to 5°; the average time varies from 25 to 40 ms depending on their amplitude,
- fixation – characterized by high individual variability; it is generally in the range from 200 to 250 ms; For example, the size of a single saccade may range from 8 to 18 characters in space, and the duration of fixation may range from 100 to 500 ms;
- regression movements – take an average of 10-20% of reading time.

The research shows that the fixation of drivers' eyes depends on their seniority. Novice drivers focus their eyesight on the road (looking ahead and not to the sides) more than experienced drivers (eye fixation much more beyond the road) (Underwood, Chapman, Brocklehurst, *et al.,* 2003).

Taking into consideration the size of the letters on signs and their location in space (horizontal and vertical distance from the road), the following part of the article analyses the rules for the location of selected types of road signs according to the standardization guidelines for:

- recommended letter size depending on the distance from which the information is to be perceived (according to EN 894-2);
- vertical and horizontal field of view with the content of the sign at the recommended or acceptable distance from the driver's eye (according to EN 894-2).

2. Methodology

According to the EN 894-2 standard, recommendations regarding the size of letters in markings have been defined (Table 1). Analyzing the values in Table 1, they can be compared with the visual acuity parameters. Angle above 15 seconds of arc corresponds to excellent stereoscopic acuity ranges for humans (15 to 30 seconds of arc) (Noorden and Campos, 2002). The publication specifies that the size of the retinal areas over which spatial summation takes place is 4 to 10 minutes of arc for the retinal center and 15 to 30 minutes of arc for the retinal periphery. The graphical presentation of dimensional dependencies from Table 1 is presented in Figure 3. The distance from the letters on the road sign to the driver can be determined using trigonometric functions. According to the standard, an isosceles triangle of height *d* and base width *h* has the recommended values of the angle *α*. This allows the recommended or acceptable distance *d*, to be calculated for existing road signs.

The geometrical relationships in Figure 3a can be presented using formulas 1 and 2 (Dahlke, Wróbel, Żamojtuk, 2014; Dahlke, Miedziński, 2008).

$$tan\frac{\alpha}{2} = \frac{\frac{1}{2}h}{d} \qquad (1)$$

$$d = \frac{\frac{1}{2}h}{tan\frac{\alpha}{2}} \qquad (2)$$

Table 1. *Characteristics of recommendations for the height of signs according to EN 894-2.*

Number	Evaluation of the sign high	Value of the viewing angle α in minutes of arc
1	Recommended character heights	from 18 to 22
2	Acceptable character heights	from 15 to 18
3	Inadequate character heights	below 15

Source: *Own study.*

According to the EN 894-2 standard, the visual plane is perpendicular to the line of sight. When the letters are located above or below the horizontal line of sight on a road sign, there is a slight difference between the actual height of the letters h and the projection of h' onto an imaginary plane perpendicular to the line of sight (height d of the isosceles triangle) ($h' < h$ for $h_{cz} \neq h_z + h/2$) (Figure 3b and 4).

Because the recommendations for the height of the letters cover the ranges of viewing angles (Table 1), the distance d reaches the minimum (d_{min}) and maximum (d_{max}) values. The line of sight is inclined at an angle β to the horizontal line (Figure 3b). An isosceles triangle with an angle of apex α (varying from α_{min} to α_{max}), arms b (varying from b_{min} to b_{max}) and height d (varying from d_{min} to d_{max}) will have the base h', which will also be characterised by the variability from h'_{min} to h'_{max} ($h' = h$ for $\beta = 0$) for a given viewing angle α. The height h' becomes the recommended height according to the EN 894-2 standard and on its basis the distance d should be determined, but a useful parameter will also be the horizontal distance L_1 from the position of the sign board from the driver's eyes (this value also ranges from L_{1min} to L_{1max}).

The letters on the sign board will be at the height h_z, and knowing the eye height h_{cz}, measured from the eye to the road surface (assuming that the lower datum for h_z and h_{cz} are at the same height), the difference h_o ($h_o = h_z - h_{cz}$) (Figs. 3b and 4) and the line of sight tilt angle β can be specified. To determine the real, visible height of the letters h', equation 3 could be used (Figure 4 – Detail A).

$$h' = \frac{\frac{h}{1 + tan(\beta + \frac{\alpha}{2}) \times tan(\beta)}}{cos(\beta)} \qquad (3)$$
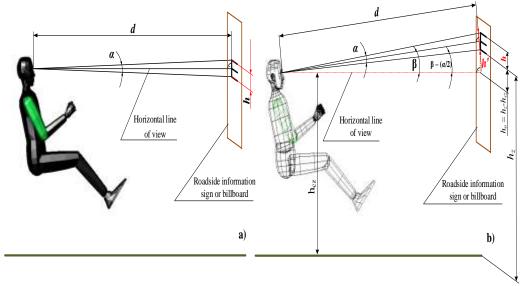
By knowing h', it is possible to correct the maximum recommended distance d for the angle β (depending on the driver's eye height h_{cz} and height h_z of the location of the letters on the sign board), the recommended viewing angle $\alpha_z = \alpha$ (formula 4):

$$d = \frac{\frac{1}{2} \times \frac{h'}{1000}}{tan(\frac{\alpha_z}{2})} \qquad (4)$$

Based on this, it is also possible to determine the lengths of the sides of an isosceles triangle b, for a given β and the real visibility of the height h' (formula 5):

$$b = \sqrt{d^2 + (\frac{1}{2} \times \frac{h'}{1000})^2} \qquad (5)$$

Figure 3. *Presentation of the difference in height of the observed text on the sign in the case of its location: a) orthogonally to the horizontal line of view; b) above the horizontal line of sight. Legend: d - distance from the eye to the sign [m], α -angle of view of the sign in degrees of arc, h - height of letters on a road sign [mm], h' – visible height of letters on a road sign [mm], β– angle of the line of sight during observing letters on a road sign [°], hcz – driver's eyes height level [m], hz – height of the letters on the sign [m] (Source: own elaboration based on EN 894-2, using a mannequin from the APOLINEX software).*

Source: Own study.

A useful parameter is also the horizontal distance L_1 from the eye to the surface of the sign board (oriented perpendicular to the board) (formula 6):

$$L_1 = cos(\beta - \frac{\alpha}{2}) \times b \qquad (6)$$

After determining the basic recommended distances from the driver to the sign, one could proceed to assess the location of the letters on the sign in the areas of the field of vision recommended or acceptable according to EN 894-2 (vertical and horizontal) (Figure 2). For the detection task, these zones include both vertically and horizontally an area defined by an angle of 15° from the line of view. The position of the letters on the sign board in the vertical field of view can be judged by identifying the angle β (Figure 4).

The angle β can be found using the arcsine function. The horizontal distance L_1 (Figure 4) from the eye to the sign for the angle $\beta = 15°$ (the border of the vertical zones A and B) will be marked as $L_{2\,\beta=15°}$ and can be determined from formula 7, and for the angle $\beta = 30°$ (border of vertical zone B and C), marked as $L_{2\,\beta=30°}$ and determined from formula 8.

$$L_{2\,\beta=15°} = \frac{\dfrac{h_z - h_{cz}}{1000}}{tan(15° - \dfrac{\alpha}{2})} \tag{7}$$

$$L_{2\,\beta=30°} = \frac{\dfrac{h_z - h_{cz}}{1000}}{tan(30° - \dfrac{\alpha}{2})} \tag{8}$$

The mentioned above cases characterise the position of the observed signs in a situation when they are in front of the horizontal line of view and the sagittal plane of the body, inclined to the plane of the sign at an angle of 0° (Figure 2a), so the sign and letters are e.g. above the road.

If the letters read are at an angle greater than 0° in the horizontal field of view (the board is positioned out of line of the roadway) (angle γ and horizontal distance A in Figure 5), it is necessary to determine the distance L_1' from the eye to the sign board, measured to the plane perpendicular to the direction of travel and passing through the sign board (and observed letter), for a given β, the real visibility of height h' and the real maximum distance d (formula 9).
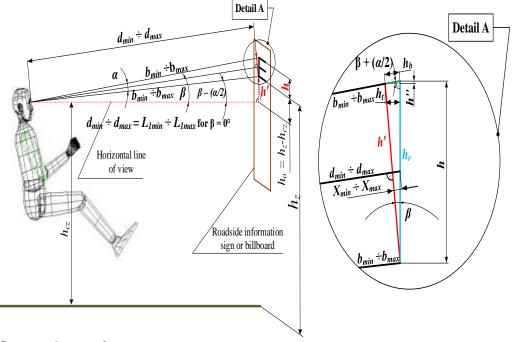
$$L_1' = \sqrt{L_1^2 - A^2} \tag{9}$$

It is also necessary to set the limit values of the distance:
- $L_{2\,\beta=15°}'$ (from the eye to the sign board (letter base) for $\beta = 15°$ (border of vertical zones A and B), measured to a plane perpendicular to the direction of travel and passing through the sign board (and the observed letter) (formula 10);
- $L_{2\,\beta=30°}'$ (from the eye to the sign board (letter base) for $\beta = 30°$ (border of vertical zones B and C), measured to a plane perpendicular to the direction of travel and passing through the sign board (and the observed letter) (formula 11);
- $L_{2\,\gamma=15°}'$ (from the eye to the sign board (letter base) for $\gamma = 15°$ (the border of the horizontal zones A and B), measured to the plane perpendicular to the direction of travel and passing through the sign board (and the observed letter) (formula 12) (Figs. 2a and 5);

Figure 4. *Detailed presentation of the difference in height of the observed word on the sign in the case of its location above the horizontal line of sight (Source: own study based on EN 894-2, using the mannequin from the APOLINEX software).*

Source: *Own study.*

$L_{2\ \gamma=30°}'$ (from the eye to the sign board (letter base) for $\gamma = 30°$ (the border of the horizontal zones B and C), measured to a plane perpendicular to the direction of travel and passing through the sign board (and the observed letter) (formula 13) (Figures 2a and 5):

$$L_{2\ \beta=15°}' = \sqrt{L_{2\ \beta=15°}^2 - A^2} \tag{10}$$

$$L_{2\ \beta=30°}' = \sqrt{L_{2\ \beta=30°}^2 - A^2} \tag{11}$$

$$L_{2\ \gamma=15°}' = \frac{A}{\tan 15°} \tag{12}$$

$$L_{2\ \gamma=30°}' = \frac{A}{\tan 30°} \tag{13}$$

In the simulation mode, several conditions were adopted:
- If $L_{2\ \beta=15°}' < A \leq L_{2\ \gamma=15°}' =>$ when calculating the length of the road along which the fixed area is within the recommended zone (zone A), the difference was assumed to be $L_1' - L_{2\ \gamma=15°}'$;

- If $L_{2\,\beta=15°}' \geq A > L_{2\,Y=15°}' \Rightarrow$ when calculating the length of the road along which the fixed area is within the recommended zone (zone A), the difference was assumed to be $L_1' - L_{2\,\beta=15°}'$;
- If $L_{2\,\beta=15°}' > L_1' < L_{2\,Y=15°}' \Rightarrow$ the fixed area in zone A is at a distance greater than d (good vision distance for angles $\alpha_z \in \langle 22'; 18'\rangle$);
- If $L_{2\,\beta=30°}' < A \leq L_{2\,Y=30°}' \Rightarrow$ when calculating the length of the road along which the fixed area is within the acceptable zone (zone B), the difference was assumed to be:
  - $L_{2\,Y=15°}' - L_{2\,Y=30°}'$ for $L_{2\,\beta=15°}' < A \leq L_{2\,Y=15°}'$;
  - $L_{2\,\beta=15°}' - L_{2\,Y=30°}'$ for $L_{2\,\beta=15°}' \geq A > L_{2\,Y=15°}'$;
  - $L_1' - L_{2\,Y=30°}'$ if $L_{2\,\beta=15°}' > L_1' < L_{2\,Y=15°}'$;
- If $L_{2\,\beta=30°}' \geq A > L_{2\,Y=30°}' \Rightarrow$ when calculating the length of the road along which the fixed area is within the acceptable zone (zone B), the difference was assumed to be:
  - $L_{2\,Y=15°}' - L_{2\,\beta=30°}'$ for $L_{2\,\beta=15°}' < A \leq L_{2\,Y=15°}'$;
  - $L_{2\,\beta=15°}' - L_{2\,\beta=30°}'$ for $L_{2\,\beta=15°}' \geq A > L_{2\,Y=15°}'$;
  - $L_1' - L_{2\,\beta=30°}'$ if $L_{2\,\beta=15°}' > L_1' < L_{2\,Y=15°}'$.

By knowing the difference in distances L_1' and $L_{2\,\beta=15°}'$, $L_{2\,\beta=30°}'$, $L_{2\,Y=15°}'$, $L_{2\,Y=30°}'$ 'and the vehicle movement speed V, it is possible to determine the times of the observed letter remaining on the sign board (and in word) in the vertical and horizontal zones of vision:
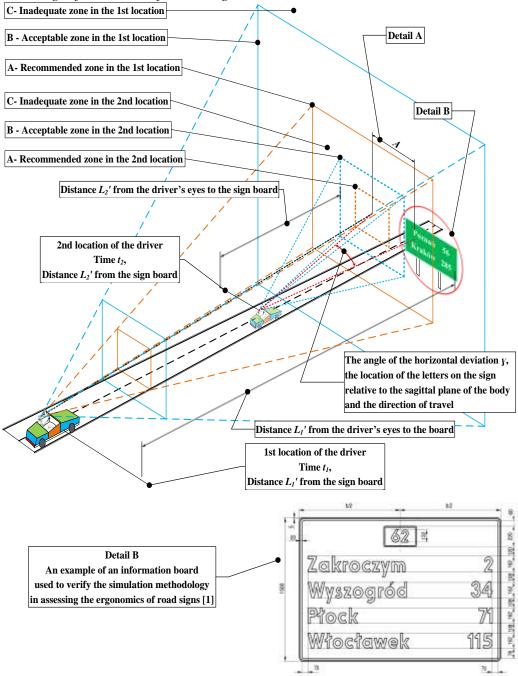
- $t_{A\,v}$ – time of the observed point remaining in the vertical zone A [s],
- $t_{B\,v}$ – time of the observed point remaining in the vertical zone B [s],
- $t_{A\,h}$ – time of the observed point remaining in the horizontal zone A [s],
- $t_{B\,h}$ – time of the observed point remaining in the horizontal zone B [s].

Due to the complexity of dimensional dependence, the analysis required the preparation of a computer tool for simulation (Figure 6).
Presented research criteria allowed:

- determination of the recommended maximum distances of letters on the sign enabling good vision according to EN 894-2;
- analysis of the location of signs in the recommended and acceptable zones of the vertical and horizontal field of vision;
- determination of the time, at a given vehicle speed, for reading the sign in the recommended and acceptable zones of the field of view (vertical and horizontal);
- defining the range of the number of characters that can be read within the prescribed time to direct the line of sight to the mark within the prescribed and acceptable field of view zone.

Figure 5. *Change in the position of the zones of the driver's field of vision along with the change of the distance from the sign.*

C- Inadequate zone in the 1st location

B - Acceptable zone in the 1st location

A- Recommended zone in the 1st location

C- Inadequate zone in the 2nd location

B - Acceptable zone in the 2nd location

A- Recommended zone in the 2nd location

Distance L_2' from the driver's eyes to the sign board

2nd location of the driver
Time t_2,
Distance L_2' from the sign board

Detail A

Detail B

The angle of the horizontal deviation γ,
the location of the letters on the sign
relative to the sagittal plane of the body
and the direction of travel

Distance L_1' from the driver's eyes to the board

1st location of the driver
Time t_1,
Distance L_1' from the sign board

Detail B
An example of an information board
used to verify the simulation methodology
in assessing the ergonomics of road signs [1]

Zakroczym 2
Wyszogród 34
Płock 71
Włocławek 115

Source: Own elaboration.

Figure 6. *Conceptual model for supporting the design or evaluation of information boards and advertising billboards*

Source: Own study.

An example of the application of the conceptual model the author will present in future scientific publications.

3. Discussion and Conclusions

The methodology for assessing the ergonomics of the design and positioning of information signs, presented in the second chapter, enables the verification of the design of the placement of road signs and boards as well as advertising boards with text information. The developed methodology did not include cultural factors which have an impact on sign reading (an example of this aspect may be differences in the direction of reading of signs (left to right, right to left and others), drivers' comprehension of traffic signs and language of letters and text) (Liu, Wen, Zhu, *et al.,* 2019), the number of information boards located near each other (redundancy information problem) (Kaplan, Bortei-Doku, and Prato, 2018), driver behaviour (Chen, Fang, and Tien, 2013; Eisma, Hancock, and Winter, 2020; He and Donmez, 2020; Munigety, 2018; Robbins and Chapman, 2018; Steinbakk, Ulleberg, Sagberg, *et al.,* 2019; Uc, Rizzo, Anderson, *et al.,* 2005; Sadłowska-Wrzesińska and Mościcka-Teske, 2016; Sadłowska-Wrzesińska, Rejmer, and Drożyner, 2014; Seya, Nakayasu, and Yagi, 2013).

To support the analysis, an application has been built to support the evaluation and drawing conclusions. It enables the use of the methodology in the process of:

1. Auditing the existing signs and information boards, advertising boards, to determine:
   - if the content has a font of the appropriate height *h* at the assumed observation distance *d*, viewing angle *β*, vehicle speed and vehicle type (parameter influencing the height of the eyes of the person observing the content on the sign board);
   - if the information is distributed at an appropriate distance from the road (distribution in recommended, acceptable or inappropriate zones of the field of view);
   - if the quantitative scope of the content will not exceed the recipient's perceptive capabilities;

2. Designing signs and information boards, advertising boards, to designate:
   - character size *h*, with the expected distance *d* and the viewing angle *β* and the vehicle speed, and vehicle type (parameter affecting the height of the eyes of the person observing the content on the sign board);
   - observation distance *d* for a given height of characters *h*;
   - the recommended distance of the information board from the road and its location in recommended, acceptable or inappropriate zones of the field of vision;
   - the quantitative scope of the content that will not exceed the perceptive capabilities of the recipient.

The numbers of read characters included in the methodology require further research. It is necessary to develop instrumental psychometric tests dedicated to the proposed methodology to identify drivers' perceptual abilities. Individual indicators of perceptual abilities characterizing the number of read signs per time unit will enable the indication of, for example, individual limiting ranges of movement speed in a vehicle (if the permissible values in road traffic exceed the perceptual abilities).

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