ISSN 1822-427X print
ISSN 1822-4288 online

THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

http://www.bjrbe.vgtu.lt

2006, Vol I, No 2, 109–114

THE DYNAMIC APPROACH TO EVALUATION OF VISUAL ROAD IMAGE

Atis Zariņš

Dept of Roads and Bridges, Riga Technical University, Kaļķu str. 1, LV-1658 Riga, Latvia
E-mail: atisz@bf.rtu.lv

Abstract. The motor road visual quality, which includes such basic categories, as visual clearness and fluency, in conformity with earlier investigations, has an essential significance in the driver's information perception. The managerial decision taken by the driver depends on its result and, hence, on the traffic safety, too. To secure the road visual depiction, adequate to the situation, it is necessary to perform a visual analysis the designed motor road alignment. Up to now, the described road visual analysis methods have been based on evaluating the static perspective image elements, which do not correspond to the real perception process in case of a car driving. This work describes the opportunity of the dynamic, corresponding to real perception circumstances, visual quality evaluation. The method anticipates the image line evaluation according to the visual fluency criterion, when the image changes corresponding to the observation point location, in the real car movement case. The method is checked by the optimization solution example following the visual quality criterion corresponding to the given road parameters.

Keywords: road alignment, road visual quality, car-driving process, image analysis, dynamic image perception.

1. Introduction

The motor road visual quality impact on the traffic safety and car driver's working capacity becomes more topical with the increasing velocity of car movement and reduced time devoted to receive and process the information. As proceeds from the earlier research, when choosing the motor road alignment solution, the quality of visible road image is of primary importance [1–5]. It results in the fact that from the visible information the car driver obtains the most essential part of information required to take a managerial decision in the situation, when there is little influence of the traffic flow. Some papers present studies that measured drivers' assessment of the degree of danger or crash risk, based on information from a presented visual image or other sources [6, 7]. In its turn, adequacy of the taken managerial decision influences the result of its implementation and, hence, the traffic safety.

The dynamic character of road image perception initially was implemented by creating animations from separate perspective images or physical models, and later by using computer techniques. These methods support an animated road image for the subjective visual quality analysis.

Now some visualisation and animation techniques are developed useful for evaluation of designed road image using quantitative criteria and visually. The road alignment analysis by driving simulator is based on driving speed assessment [8]. Multipurpose designing system described in, includes possibilities of visual estimation with real time interaction [9].

The criterion for estimating the visual quality of road image is established in [10]. The correlation between apparent (R_S) and actual plan radius (R_G) was described as *image distortion* (Q_S). The marginal values for application of this parameter is fixed.

The criterion based on sight distance for detecting safety relevant problems in spatial alignment, and the depth of partial road disappearance along the driver's view have been developed [11].

However, criteria and evaluation methods mentioned above do not consider several essential parameters and conditions associated with the image perception, for instance, the scale factor, that is important when the 2D perspective scene or image is beeing used for estimation. This can lead to obtaining incomplete results.

2. Previous and related works

Parameters and characteristics of 2D central projection image of the road, obtained from the position of the car driver's eyes, has been used until now to investigate and evaluate the road visual quality. This quality is determined by the evaluation of features and interconnection of the road construction and its ambient background. The following groups of such features are pointed out and examined in previous works [2, 3]:

- features and indications, described by now as visual clearness,
- features and indications, described as visual fluency.

These features, characterising mutual relations of the road alignment elements and also separating background elements and their interchange parameters, are united into such categories as harmony, rhythm and style. According to J. Naudzuns the road visual clearness criteria are [3]:

$$KR \geq 0, \text{ provided } \; /K/ \leq /K_S = 0{,}147ae^{0{,}00349u}/, \quad (1)$$

where: K – the curvature of road element image line, R – the corresponding plan curve radius, K_S – the experimentally defined threshold of the curvature visual perception, a – the distance to the image plane, u – the distance to the evaluated element.

The criterion for assessing the visible road image or necessary indication of visual fluency developed by P. Dzenis and revised by J. Naudzuns [12, 13]:

$$K = \frac{x_E^3}{ah^2R}, \quad K_{acceptable} \leq 750m^{-1}, \quad (2)$$

where: K – the extreme value of curvature of image element estimated, x_E – the abscissa of extreme point in image plane, a – the distance to image plane, h – the elevation of observation point above the carriageway, and R – the actual plan radius.

As other required criteria for evaluating fluency of the road visual image in the research, the perception threshold of the visual break of the road visual image line is determined [3]. It was derived using consequence (2), and therefore it involves the scale factor. It is considered to be one of the main criteria of the motor road visual quality. Due to this, the road image line is considered to be a visual fluency, if curvature of the evaluated line corresponds to the criteria (3a–3c). Corresponding evaluation stages of the threshold value for static image (7,5 m wide carriageway, at the projection plane distance of 1 m) are defined with correlations for:

$$\text{the break} - \; KE = 810 + 5{,}4 \text{ s}, \quad (3a)$$

$$\text{a sharp turn} - \; KE = 580 + 2{,}075 \text{ s}, \quad (3b)$$

$$\text{a satisfactory line} - \; KE = 335 + 1{,}2 \text{ s}, \quad (3c)$$

where: s – the distance from the view point to the evaluated point, (m). In graphic form, this correlation is shown in Fig 1.

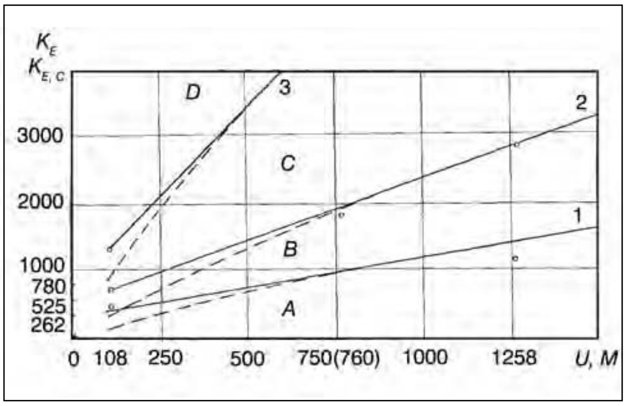

Fig 1. Visual fluency criterion according to [3], where U – the distance to the evaluated element, 1 – threshold for a satisfactory line (3c), 2 – for a sharp turn (3b), 3 – for a break (3a)

All visual quality criteria described herewith are obtained by evaluating the impact of the static image from the stand alone viewpoint. However, in a real driving process the viewpoint moves along with drivers' eyes. Therefore, the image quality analysis should consider the viewpoint movement and the image parameter change determined by this movement, that is – the dynamic properties.

3. Image analysis

In the design practice, the 2D central projection for the road visual image analysis is derived from the road alignment description with the help of the linear transformation operator. This operator has, as the original, the road alignment and the image – the road alignment central projection or the perspective image. Considering that the transformation is linear, it retains the original first stage differential features. It means that the straight alignment in the 3D model is depicted as the straight line in the 2D image, the parabola is depicted as the parabola, the ellipse – as the ellipse etc. However, to secure the visual clearness condition (1), also the higher stage differential features are required to be retained [2, 3]. Besides, interruptions are possible, and namely the plane line stage can be degenerated as a straight line, or the straight line as a point etc. In addition, such interruptions are formed in places, where the nearest road alignment elements in the image cover up the furthest ones. Interruptions of the second stage differential parameters are understood also as non-corresponding to the visual clearness criterion (1). As seen in this criterion, the horizontal projection meaning is accentuated via the layout radius R presence correlation, as proceeds from the car movement dynamics and stability terms, because the horizontal curve parameters influence much more considerably the traffic stability, than vertical parameters.

As determined in [2, 3], the perception threshold of the line direction change, changes depend on the line orientation of the image plane. The threshold value increases

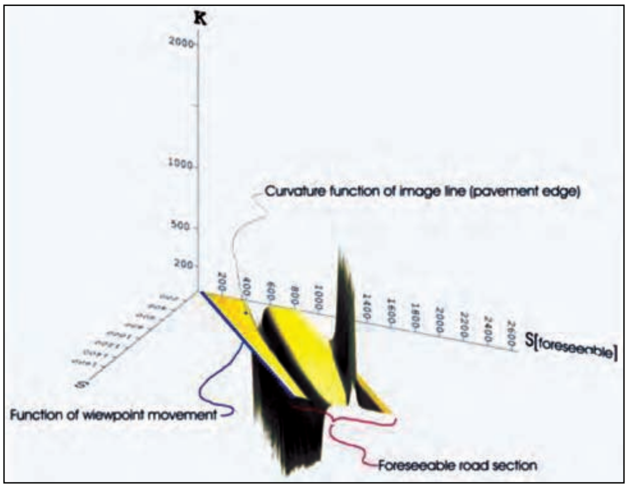

Fig 2. The line curvature function of the road visual element

with the line orientation inclining to the vertical direction. It means that a small change of the vertical mark at the carriageway left side can much more significantly influence the image visual clearness, than the change of a similar value horizontal parameter. Thus, with the help of the visual clearness criterion, the requirement is defined to exclude the impact of those vertical elements from the image, which, dominating over horizontal elements, change its nature (direction) to the opposite, determining in this way the inadequately perceived image. Contour parts with a larger curvature or smaller curvature radius carry the main information on the image contents [5]. For visual image of the driver, it is at places of maximal curvature of the road alignment leading lines, which also predominantly attract the driver's attention [4]. Therefore the value and nature of leading lines' curvature and its derivatives are considered to be the basic criteria for evaluating visual quality of the road image.

In conformity with [5], the perception process, in case of car driving, is dynamic. The image, where information for the driving process is obtained from, is changing all the time. Therefore, to analyse contents of information obtained from such an image, evaluation of static perspective images is insufficient.

The line curvature function of the static image can be obtained deriving it from a mathematical description of the motor road alignment or by numerical methods directly from the image. The changing image line curvature function needs the third dimension, which in this case represents the change of the observation point location. It can be determined as displacement S along the possible observation point path, which is previously defined. For the analysis, the observation point path is accepted to be fixed 2 m away from the carriageway right side and 0,9 m above the carriageway. At each observation point, the curvature function is obtained for the seen road image line, which, in conformity with the criteria (3), is to be used for evaluating the visual fluency of the separate image line. To analyse the changing image line, the curvature function is used, which is obtained from the line curvature values, where a specific observation point moves along a specific path. The function obtained in this way is described as a surface (Fig 2).

4. Numerical method for the curvature evaluation

As follows from the definition, the curvature is the image line tangent turning the angle value φ, when the point of contact moves along the line from s to $s + \Delta s$. The curvature K is expressed through the correlation:

$$K = \lim_{\Delta s \to 0} \frac{\varphi}{|\Delta s|}. \tag{4}$$

In order to obtain the K curvature value in this way, it is necessary to know the analytical expression of the corresponding road perspective image element. It can be obtained from the project data. Such solution for the static road image analysis is considered in [2, 3]. However, in order to successfully apply such an approach for processing the dynamic road alignment data, it is required to express all elements, used in the road alignment solution, in a unified system (3D). Furthermore, it requires data in the open parametric form, that is difficult to implement in practice by observing the inconvenient nature of the classical road alignment description model.

Within the framework of the work, the numerical method is created to evaluate the seen road image line curvature by using coordinates of the points forming the image lines, which are obtained from the project data. The line direction change is determined between the three line points (Fig 3). Dividing it by the distance between the points, the curvature approximate value $\hat{K}$ is obtained, where the approach degree depends on the distance between the points. The line curvature determined in this way shall have the final value, as long as the line fragments at both sides do not coincide with the line point. It means that by this method it is impossible to determine the precise curvature value in the infinitely close vicinity of the function fluxion break points. Hereto, the sharper is the line turn (break) and the larger the step between the points, the lower is the precision to be reckoned with. However, in this case it is required to indicate that, in case of the motor road alignment image analysis, it is not necessary to fix the curvature's absolute value at the break place, but to fix the threshold surpassing fact; thus, the curvature value at some distance from the extreme place is the most essential. It means that in this way it is possible to evaluate the curvature with a precision required for the criterion.

In the given case, the image lines are preset with the set of points in the form of the line image coordinates. If we assume that by connecting these points, an optically smooth line is received, where separate line segments can-

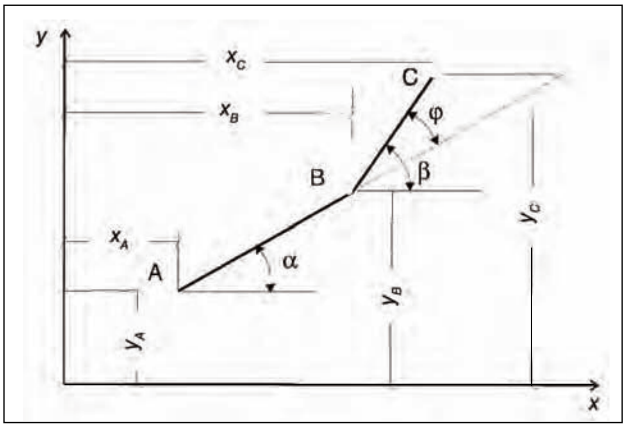

Fig 3. Scheme of determining the image line curvature *K*

not be visually marked out, which is also an indication of the line's adequacy; then we can consider that the line length between two focal points equals that of the straight line segment connecting these points. The distance between two points A and B for the plane (image) coordinates is determined by the formula

$$|AB| = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2}\,. \tag{5}$$

If the line points A, B and C are connected by straight-line segments (Fig 3), they form an angle $\varphi = \beta - \alpha$. If coordinates of the points A, B and C are known, then tangent of the angle φ is equal to

$$tg(\varphi) = tg(\beta - \alpha) = \frac{(y_C - y_B)\times(x_B - x_A) - (y_B - y_A)\times(x_C - x_B)}{(x_B - x_A)\times(x_C - x_B) + (y_C - y_B)\times(y_B - y_A)}. \tag{6}$$

On the basis of this line curvature evaluation method, a computer program is created, with the help of which the line curvature data on changing (dynamic) image are obtained, that allows to create the curvature function surface of the corresponding line. And according to (4), the image line approximate curvature $\hat{K}$ is:

$$\hat{K} = \frac{\angle(\varphi)}{|AB| + |BC|}\,. \tag{7}$$

To evaluate the line's curvature, there are methods too, based on the approximation of separate points with some simple functions, from where then the curvature is determined analytically. The work [14] describes the algorithm for the curvature evaluation by using image data approximation with the smallest square method. However, it must be acknowledged that such an approach artificially "flattens" the line, whereas, in the road image analysis case, it would be necessary to evaluate the worst case.

5. Analysis criteria

As clarified earlier, the impact of the road visual quality on the driver's working environment can be better evaluated in a real situation, driving along this road and determining the role of each visual element and their mutual interaction in these or other processes of consciousness. It is important to secure visual quality already at the design stage. Up to now a spatial solution quality of the motor road has been secured by evaluating results of the perspective image analysis, or subjectively – according to a visual evaluation of the seen image or according to familiar visual quality parameters quantitatively too by the defined criteria.

Similarly, as a curvature function, the image line's fluency criterion can be also expanded in the third dimension S and the criterion function surface can be received. According to (3), these criteria are depicted as planes. Matching the surfaces of curvature function of the seen road image lines and of the criteria function, compliance of the corresponding lines to the criterion can be evaluated along the whole evaluated road alignment span (Fig 4). Due to the image fluent line is demonstrated. The same criteria, symmetrically to the surface $K = 0$, are related also to the clearness, only the positive criterion of the satisfactorily negative curvature surface part (for the opposite bend spans). Such a visually demonstrative depiction excludes the possibility not to notice some critical place, as it is possible, when evaluating separate perspective images. Thereto, it is possible to evaluate development of visual parameters of the determined road element according to it.

To clarify visual clearness of the road's seen image according to the correlation (1), it is required to compare values of the image curvature and the original curvature. It can be done by matching the image curvature surface to that of the original – road alignment. This matching shall definitely demonstrate deviations from this criterion at places, where corresponding surfaces shall be located at each side of their plane $K = 0$. In the ideal case, both sur-

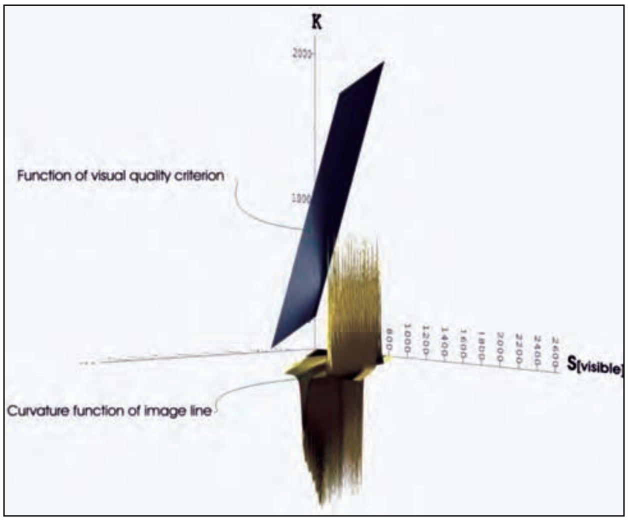

Fig 4. Curvature function matching with criterion

faces shall coincide at places, where they cross the plane $K = 0$.

When analysing the curvature model surface, without the curvature values, it is also possible to determine the velocity and uniformity of the maximal curvature evolution. Wherewith, opportunities are opened for the image dynamic evolution investigations, which had not been performed before.

6. Algorithm and example of the dynamic image analysis

By using the described analysis method, an algorithm is created to evaluate and to optimise the visual quality of the image lines of the road's leading elements.

In case value of the image line curvature in some of its points exceeds the criterion conditions, then, at the image, this curvature surface part rises above (or in case of the negative curvature – under) the criterion surface. In this way it is easy to determine the precise localization of the visual defect (Fig 5).

As a successful indication of the optimization process, the volumetric integral is determined by the difference between the curvature surface of image line and the satisfactory curvature criterion surface:

$$\Delta = \iint_{S,S_{view}} (\hat{K} - K_{criterion}) dS dS_{view}. \qquad (8)$$

And, as the optimization target function, the correlation is determined:

$$Ä \leq 0. \qquad (9)$$

In the test example, the condition (3c) is determined as the criterion. The test example is based on the design standard corresponding to the motor road alignment solution [15]. At the initial condition, as seen in the image, a break is observed at the side line of the road image left carriageway. It is reflected in matching of the curvature function and the criterion surface, where the impact boundaries of this defect are seen, too. Optimization is performed by manipulating with the corresponding roundup radius of the alignment turn. The situation, when the successful indication (8) meets the condition (9), is fixed in Fig 6.

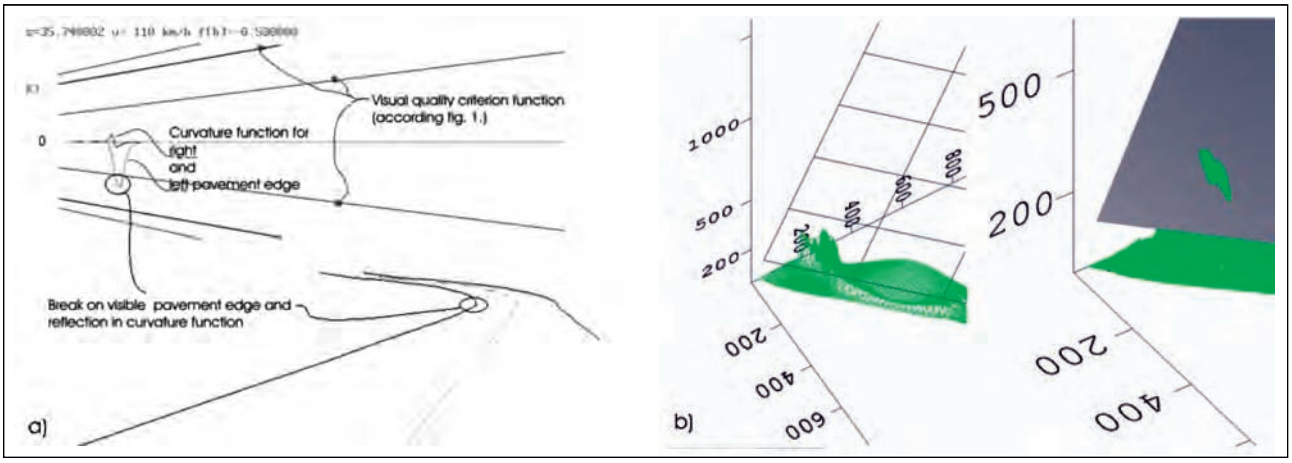

Fig 5. Optimization example. Initial condition: a) the perspective image and the corresponding curvature graph, b) the lines curvature function is matched with the criterion function

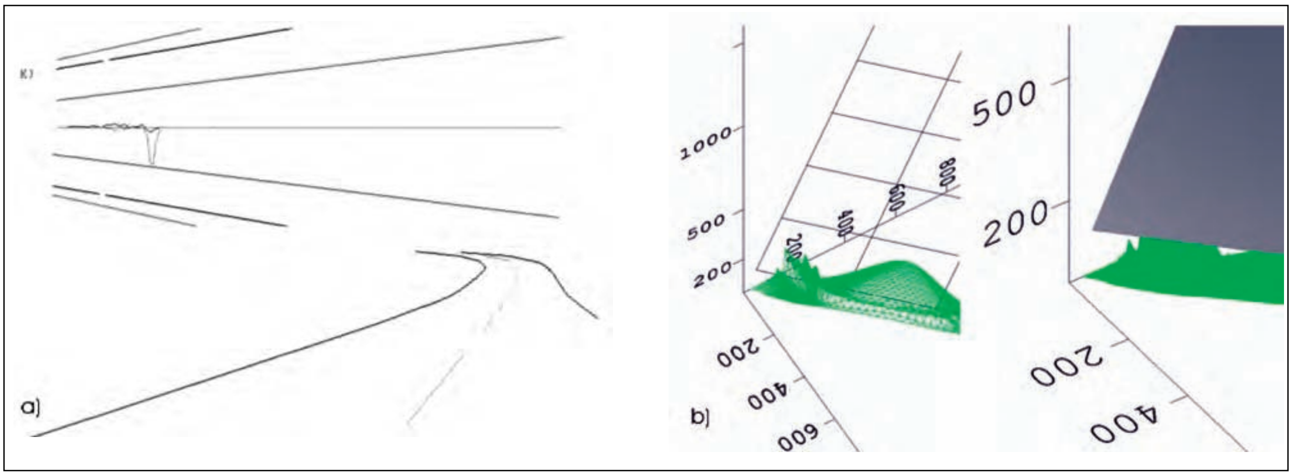

Fig 6. Optimization example. Final condition

7. Conclusions

1. Evaluation of the motor road alignment visual quality, of which, as earlier investigations show, the adequacy of the managerial decision taken by the driver depends up to now has been made following the visual parameters of static images. However, in accordance with the investigations, the real perception process of the driver's situation has a dynamic nature. Hence, the evaluation of static images cannot give a full value idea about the evaluated situation. The dynamic model of evaluating the road visual quality, described in the work, provides an opportunity to evaluate and, hence, also to create the real observable (dynamic) motor road image from the driver's observation point.

2. Usage of the classic motor road description model determines the inconvenient and analytically complicated opportunity of the image function analytical processing; therefore, the most real opportunities to obtain the required parameters (curvature and its derivatives) for the image evaluation are to make use of the numerical method according to coordinates of the image lines.

3. By applying the image curvature surface, it is also possible to investigate the element line curvature changes at the determined road alignment point, when the observation point (a vehicle) moves along the defined trajectory.

4. Matching the image line's curvature function surface with the criterion function surface, it is possible to determine the corresponding element visual quality and to clarify the required changes.

References

1. LORENZ, H. Trassierung und Gestaltung von Strassen und Autobahnen. Wiesbaden: Bauverlag, 1971. 440S.
2. DZENIS, P. Geometric Relationship of the Central Projection and the Plan of Road Turns, as a Condition of Visual Clearness. In: Issues of Design and Operation of Buildings and Constructions (Вопросы проектирования и эксплуатации зданий и сооружений). Issue 3. Riga, 1975, p. 135–141 (in Russian).
3. NAUDZUNS, J. Spatial Design of Curved Sections of Motor Roads Providing Esthetic Quality (Пространственное проектирование криволинейных участков автомобильных дорог с обеспечением эстетического качества). Doctoral Thesis. Moscow Automobile and Road Construction Institute. Moscow, 1987. 22 p. (in Russian).
4. LOBANOV, E. M. Road Design and Traffic Arrangement in View of Psychophysiology of Driver (Проектирование дорог и организация движения с учетом психофизиологии водителя). Moscow: Transport, 1980. 312 p. (in Russian).
5. ZARIŅŠ, A. Traffic Safety and Driver's Psychophysiology. In: Proceedings of the Nordic-Baltic Transport Research Conference, Vol 2, Session 3, Riga, 2000, p. 3–8.
6. BENDA, H.; HOYOS, C.G. Estimating Hazards in Traffic Situations. *Accident Analysis & Prevention*, Vol 15, 1983, p. 1–9.
7. TRÄNKLE, U.; GELAU, C.; METKAR, T. Risk Perception and Age-specific Accidents of Young Drivers. *Accident Analysis & Prevention*, Vol 22, 1990, p. 119–125.
8. BELLA, F. Verification of the Coordination of Horizontal Alignment and Profile at the Driving Simulator. In: Proceedings of 3rd International Symposium on Highway Geometric Design. Chicago, 2005.
9. TILGER, K.; APPELT, V. New Complex Solutions for the Real Time Spatial Road Design. In: Proceedings of 3rd International Symposium on Highway Geometric Design, Chicago, 2005.
10. APPELT, V. New Approaches to the Assesment of the Spatial Alignment of Rural Roads – Apparent Radii and Visual Distortion. In: Proceedings of 2nd International Symposium on Highway Geometric Design. Mainz, 2000.
11. ZIMMERMANN, M.; ROOS, R. Increased Safety Resulting from Quantitative Evaluation of Sight Distances and Visibility Conditions of Two-Lane Rural Roads. In: Proceedings of 3rd International Symposium on Highway Geometric Design. Chicago, 2005.
12. DZENIS, P. Design of Spatial Alignment of Roads Providing Visual Fluency and Clearness (Проектирование пространственных кривых на автомобильных дорогах с учетом зрительной плавности и ясности). Doctoral Thesis. Moscow Automobile and Road Construction Institute. Moscow, 1976. 34 p. (in Russian).
13. ZARIŅŠ, A. Analysis of Shape Line Functions Used for Road Routing. In: Scientific Proceedings of RTU. Architecture and Construction Science, Vol 2, Riga, RTU, 2001, p. 191–194 (in Latvian).
14. CRAIZER, M.; LEWINER, T.; SILVA JR, J. D.G.; LOPES, H. C. V. Curvature and Torsion Estimators Based on Parametric Curve Fitting. *Computer & Graphics*, Vol 29, No 5, 2005, p. 641–655.
15. LVS 190-1:2000 Road Alignment. Design Code (Ceļa trase) VSIA Latvijas Standarts, Riga, 2000 (in Latvian).

Submitted 27 March, 2006; accepted 22 May, 2006