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THE DYNAMIC CHARACTER OF VISUAL PERCEPTION OF MOTOR ROAD AND OPORTUNITIES TO EVALUATE AND OPTIMISE ITS VISUAL QUALITY

Specialization: Transport and Communication
Branch: Land Transport and Infrastructure
Summary of Doctoral Thesis

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GENERAL DESCRIPTION OF THE THESIS

Actuality of the Thesis

Fast evolution of technologies and improvement of life quality of the society is the obvious indication of modern civilization. Direct consequence of these inevitable processes is the continual increase in the amount of vehicles. With the increasing amount of vehicles, and in this case - cars, their design, capabilities and functional parameters are developing as well.

Alongside with growth in the amount of cars, the number of drivers is continuously growing as well; thereto, in place of experienced and professional car drivers new ones are coming, having no experience and the minimal driving skills.

As follows from statistics, each year hundreds of thousands people involved into road accidents, died, and 20 -30 times more - get injuries. On average, the 1-3 % of national income of each state, are spend for eliminating of after-effects of these accidents. Only fulfilment of well focused activities during last decades provides reducing of growth of indices. As follows from studies, 65 % of accidents results from inappropriate driver's action, and 25,5 % - from inappropriate action together with environmental impact. Therefore they can be estimated as significant accident reasons. Thus, the visible road situation and drivers road perception consequences plays essential role for road safety.

Observing these correlations, simultaneously with progress in mechanisms and technologies, it is also required to appropriately develop and maintain the environment, where vehicles are functioning and where they are operated by drivers, i.e. motor roads.

For full-fledged motor transport traffic, a corresponding environment is required - a motor road. A motor road in this context is to be considered both as one of the elements of the physical system *vehicle -road*, and as a significant constituent part of a driver's work place. If in the first case it means observing requirements of the car movement dynamics, then in the second case it is determined by the system *a driver - a vehicle - a road*, where the most significant element is, undoubtedly, the driver. A motor road, as no other engineering structure, is linked with presence of the human features of psychological, physiological and also aesthetic nature in it. And, what is by far more significant, these factors, similarly to other engineering structures, need to impact the road construction. Safe traffic, as well as people's health and life, depend on observing them. As proceeds from the earlier research,

when choosing the motor road alignment solution, the quality of visible road image is of primary importance. This gathers from fact that from the visible information the car driver obtains the most essential part of information required to take the managerial decision in the situation, when there is little influence of the traffic flow.

The current designing practice determines only general requirements to secure appropriate work environment of a driver in the above mentioned context. It pertains to insufficient accenting of the road functioning aspect both in regulatory documents of designing, and in scientific and training spheres of the industry. Up to now, there have been no clear and well argued criteria and their evaluation capabilities have been not solved, which would allow to fully evaluate the above mentioned road function aspects during designing, as well as to check the already operating motor roads in accordance with these.

Investigations conducted up to now in the direction of securing the road alignment quality have encompassed comparatively narrow subdirections of the problem. Many important details have been clarified, but they have not been systematized and their interconnection has not been determined.

Aim and Tasks of the Thesis

This thesis aims at clarifying opportunities to secure horizontal and vertical planning parameters of the current and designed motor roads, in conformity with evolution tendencies of technical parameters of vehicles, and simultaneously to establish the safer work circumstances, by observing the driver's perception features and other aspects pertaining to his psychophysiology. To clarify impact of the motor road alignment parameters on the amount of information required for a driver and its quality, it is necessary to define the concept of the motor road quality, including into it categories, which evaluate the driver's perception features, as well as the dynamic nature of the perception process itself. The hypothesis has been defined within this work, according with which, the road environment perception process of driver during driving is based on dynamically changing scene. This has been based on conclusions, which made during analysis of previous investigations, and design practice. If this proves, then it leads to change of meaning and implementation of already established criterions of visual quality and appearing new ones. The task of this work, is to verity this hypothesis, and according with result to improve the criterions and conditions of

road visual quality estimation.

To secure opportunity of the motor road alignment optimization, which aims at achieving improvement of the road's quality, the required and possible trends of improvements are to be clarified, and, on the basis of definition of the road quality concept, hierarchical relations of the used criteria are to be specified.

The currently used mathematical model for the road alignment description is to be evaluated, as well as suitability of the designing methods to implement the required optimization solution. Appropriate methods and mathematical models for further development and implementation into practice of the optimization solutions are to be elaborated.

Scientific Novelty of the Thesis

Scientific novelty results from the complex systematic approach to achieve the set up aim, uniting in the concept of the road alignment quality both correlations of physical nature, and those arising from psychophysiological peculiarities of human perception. To evaluate the tested correlations, models and criteria, the corresponding algorithms are created, as well computer programmes. Conception of the motor road alignment quality in this context is surveyed as a complex of relations and criteria, arising from the system *driver -vehicle - road,* the essence of which is based on its central object - the driver. In contrast to the previously defined quality systems, this one is based on the model of the biological control system, and hence is oriented on human values, which, as the thesis shows, are directly dependent on the motor road alignment quality.

To solve different tasks of the road geometry optimization, the methods are used, which, within the framework of this thesis, are adapted from various scientific fields, as well as are created to achieve the direct specific aim.

Practical Significance

The mathematical model of the road alignment, which is obtained within the framework of the thesis and which is based on using the rational spline function, considering its comparatively simple structure, noticeably simplifies creation and corresponding estimations of the road designing algorithms. This model allows to evaluate during designing also correlations obtained as a result of the earlier research, which up to now was mostly of

the theoretical value. The created computer programmes are useful for continuing research, as well as for evaluating and analyzing the elaborated road projects. By applying the optimization solutions of the clarified dimensional design into practice, it will be possible to achieve improvement of the road design quality, which shall be manifested both in expenditures on their construction and maintenance, and in the increased level of traffic safety.

There are three main ways of application of the obtained results:

- Practical use - analysis of designs and already existing roads,
- Scientific use - for accomplishing of theoretical basis and justification and task setting for forward research,
- Educational use - for perfection of methodology and theoretical basis of road spatial design course studies

The following research results are proposed for the defense:

- Description and analysis of the model structure of the road alignment conception and conclusions made on the basis of that with regards to:
  - Dynamic nature of the vehicle control process,
  - Content and quality of information required for the adequate managerial decision,
  - Nature and evaluation criteria of the motor road's visual quality.
- Description and justification of the structure of the road alignment quality system and conclusions made on the basis of that with regards to:
  - Cyclic nature of the road alignment quality function,
  - Driver's role as the managerial decision taking and the quality function determining element,
- Analysis of the described model of the motor road alignment and solution of the offered model on the basis of the heterogeneous rational B-spline function.
- The visual quality optimization algorithm of the motor road alignment.

Composition and Volume of the Thesis

The doctorate thesis consists of 5 chapters, the conclusion and the bibliographical index.

Volume of the thesis is: 132 pages, 48 figures, 4 tables, the list of literature, which contains 76 titles, 3 appendices.

Results of the doctorate thesis are announced and discussed at the three international conferences:

- The 42nd RTU International Scientific Conference (Riga, October 2001)
- Nordic-Baltic Transport Research Conference, (Riga, April 2000)
- IV Conference on Road Traffic Safety Problems in Roads and Bridges, (Pultusk, Poland, May 2000)

Problems and results of the research are represented in 5 publications (see p. 22).

CONTENTS OF THE THESIS

The first chapter presents topicality of the thesis and provides separate general indications on the research trends and opportunities of applying their results.

The second chapter is devoted to description of the current situation and information available from bibliographical sources on the subject of the doctorate thesis issues. These issues are dealt with in separate groups, depending on their defined research tasks.

Reconsidering reflection of the road alignment quality problem, it is established that there are numerous and often discontiguous definitions and interpretations of this concept. In most sources, the road alignment quality concept involves solely criteria of mechanical and economic nature. However, for the most part it involves also visual parameters of the road alignment, or the visible image quality of the road.

Evolution of the quality concept of the motor road alignment is clearly seen, and it is directly related to research on perception of the road and visual quality issues. Motivation and basic trends for this research were provided by the German architect A.Seifert, but they were further developed and contributed by V.Babkov, W.Pfeil, F.Freising, H.Lorenz, P.Dzenis, V.Lobanov, J.Naudzuns and many others. The literature survey demonstrates that comparatively comprehensive data have been obtained on the visual clearness and fluency, both for separately considered cases of the spatial road alignment (3D) curves, and for different configurations of these curves. All the above mentioned investigations are united

by the fact that analysis of the researched road image is made for static images or the ones from the fixed position. Such image is not characteristic for the situation, in which the driver is at the moment of taking the managerial decision. At the same time, it can be assumed, that conformities clarified in the earlier investigations remain in force also in the situation of the dynamically changing perception. Therefore, one is left to define additional conformities, which, including the already known model created by the static perception elements, shape the dynamic perception model.

In conformity with the current theory of visual conception of the motor road, three groups of the basic criteria can be pointed out to characterize visual quality of the road:

- *visual clearness*, by which adequacy of curvature of the image elements to that of the corresponding plan elements of the road is understood,
- *fluency*, where values of the curvature parameters of the road alignment elements are evaluated, and
- *harmony, rhythm and style*, which characterize mutual relations of elements of the road alignment and also separate elements of the background and their interaction parameters.

Each group of criteria is represented by correlations, which according to different parameters characterize the corresponding indication of the road image quality. The thesis provides analysis of criteria found in the literature and survey of their usage opportunities. As the most significant criterion of visual clearness, the one defined by J.Naudzuns is to be mentioned:

$$KR \geq 0 \text{ if, } |K| \leq |K_S| \qquad (1)$$

where; K - is curvature of the perspective projection (image) of the road element's line,

R - is the corresponding plan curve radius,

K_S - is the experimentally defined threshold of the curvature's visual perception.

As the most significant correlation characterizing fluency, the one formulated by P.Dzenis and J.Naudžuns is to be mentioned:

$$K = \frac{x_E^3}{ah^2R}$$

where; x_E- is abscissa of the extreme point of the image line curvature,

road alignment optimization opportunities. It is concluded, that in most cases the optimization problem is solved to the very narrowly defined problem. In a lot of cases, investigations ended with no specific offers to be practically implemented. At most part, it was due to the classical model of the road alignment description, which is inappropriate for the analytical research and processing and on which the current design practice is based. As the most significant solutions, the following are noted:

- Definition of the optimum curvature principle by B.Howard, Z.Bramnick and J.Shaw, with the help of which it is possible to analytically determine the minimal curvature of the curve, appropriate for the criterion function.
- The principle of longitudinal slope, formulated by P.Dzenis and J.Naudžuns. Later the same idea was practically implemented by M.de Smith.

It is noted, that there are no data obtained from the bibliographical sources on optimization methods of the 3D road alignment line. In place of these, there is a lot of empiric nature recommendations, observation of which must guarantee a certain level of the road's visual quality.

While drawing general conclusions about fixed questions from sources and results of previous research, at least two reasons is fixed, based on which, the static road image is inappropriate for valuable visual quality evaluation:

- if decomposing the drivers perceived continuous information flow, it can be separated into several episodes, which up to now are associated with central projection from drivers view point, then for perception of each of these, the limited spread of time is allocated. This fact is being necessarily ignored during evaluation of static image.
- the driver perceives movement, not static image. Thus situations before can be important for evaluation, i.e. character of parameters evolution in time is essential.

Based on these considerations, the hypothesis, which proposes that criterions, necessary for visual evaluation of visible road image, follows from analysis of adequate dynamic situation, was formulated.

The third chapter particularly considers the vehicle driving process, aimed at clarifying impact of the road alignment parameters on results of the process and the road alignment quality. The research task is formulated this way in order to obtain data on the nature and features of the road alignment perception, from where, in its turn, the quality definition arises and choice of the possible optimization target function.

To more precisely define the quality function, first of all, the quality conception

definition in the examined context is clarified. Two aspects are established, according to which the quality conception has been used up to now:

- The quality, as the total of features uniquely identifying roads or their separate elements, and
- The quality, as the instrument for evaluating the road features.

Essence of each aspect is determined and correspondingly further research of the process is advanced. It is concluded that, in order to obtain the general definition of the road alignment quality, it is required to systematically investigate each element of the quality system and, having clarified their hierarchical sequence, to form the complex quality concept appropriate for the situation. Based on analysis of the bibliographical data, indication is given to the facts, which indicate on impact of the road alignment visual quality on the traffic safety.

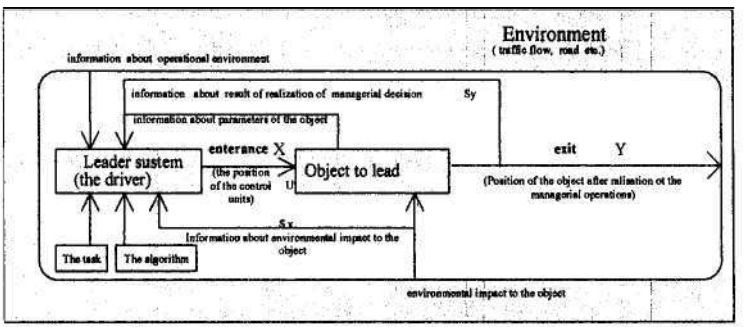

Fig. 1. The process model of the Vehicle Control System

In fact the one of the elements of structure analysed - the driver is human being, there exists comparatively few possibilities for direct experiment. Therefore the research was based on analysis of structure model, from the point of view of the control system theory. The process model presented at the Figure 1 is provided for analysis.

The managerial algorithm of the investigated process is formed as successive addressing of the two operators - the cyclic process of obtaining identification or information and taking a decision. It is demonstrated at Figure 2. Vehicle driving in this model is not understood as manipulation with a steering wheel and levers, but in a much wider meaning -

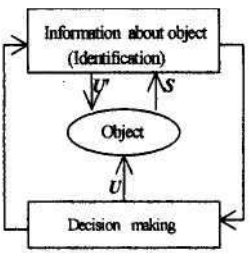

Fig.2. The Managerial Algorithm

as *self-orientation of a vehicle driver in the unknown environs.* In this case, a visual scene or an unknown area's image, he sees, is considered to be a constituent part of an unknown controllable object and not the environment, as it is, if viewing a road as a static object (environment in this case is accidental information of all sorts (circumstances), which impact the control system). In this case, the controlled object's entranced is considered to be the observed area's image prior to the control operation *U,* and exit *V is a really observed* image after this operation. Exit *Y* is the *expected* road image after operation. As an active experiment is not made, exit *Y'* is considered to be the result of the passive experiment (observation), and the control task can be reduced to minimizing the difference between the expected area's image Xand the observed image *Y'*\

$$f(F',(X,U)-Y^*)\text{-}min, \quad {}^{Ue\Omega} \qquad (\wedge$$

where; *F' - v* is depiction of the object received as the expected reaction at the identification stage,

Ω- are the acceptable managerial impacts in total.

Thus, at the stage of decision making, the object's model is required, the aim and *several* opportunities to achieve this aim. The decision, in this case, shall be an opportunity from the set of opportunities/? which, following the analogy with the model *F',* shall lead the object most closely to the desired situation (aim) *Y*,* thus providing safe traffic.

It is concluded from the above mentioned, that the information required to take the managerial decision during the vehicle driving process consists of:

- information on the identified situation *F',* which depends on the entrance features *X* and control opportunities *U,* and which consists of:
    - information on fixed parameters of the vehicle movement,
    - observed situation on the road (carriageway condition, traffic flow, etc.)
    - observed road alignment parameters and their changes.
- Information on the corresponding standard situation (from driver's experience) *Y*.* It contains description of the object's reaction in the situation with identical features, and it either exists in the driver's conscience, if such situations have been in his experience before, or he generates these extrapolating the situation.

Similarly, the conclusion is made, that the information flow, which the driver uses to synthesize the managerial decision, has a dynamic nature, as the current status *y(t)* depends on the managerial decision taken at the previous moment of time, which, in its turn, depends on

Y(t-1), etc. Therefore, in order to guarantee the sufficient amount and quality of information for driving, determining the road alignment parameters, one has to take into account dynamics of the perception process. This conclusion confirms the hypothesis, defined above

For fixing of road visible image evaluation criterions of visual quality, it context of hypothesis confirmed above, it is required to determine a lot of psychopnysiological parameters, which characterize the road perception dynamics. Such parameters are, for instance, the reaction speed, distribution of concentration of the glance, acuity of vision, depth, dynamics and other perception peculiarities. These issues are further investigated in the thesis.

On the basis of the psychophysiology theory, the hypotheses are confirmed on existence of standard situations in the driver's conscience, which directly influence the taken managerial decision, as well as on dynamic nature of the perception process of the road alignment. Analyzing conditions of the perception process in the case of vehicle driving, on the basis of the Yerkes - Dodson's rule, it is determined, that there exists the optimal driver's emotional condition, to which the highest working capacity corresponds. Similarly, it is indicated, that the emotional condition is directly influenced by the operation environment, and in this case - also visually perceivable parameters of the road alignment. Nonconformity of the road's visible image to the real situation can provoke the stress condition and, on the other hand, the poor information flow makes the driver's attention "drowsy". In both mentioned cases, his working capacity decreases, and, thus, the inadequate capability of taking the managerial decision is being formed. And in both cases, parameters of the road alignment figure as an argument in these correlations.

Psychophysiological investigations provide also the amount and quality of information required for the adequate managerial decision. As is determined, the observer obtains basic information on the visible image content and peculiarities from the image elements with the highest curvature. Thereto, values of these parameters are to be determined in conformity with the appropriate perception thresholds, which determine the perception limit of the corresponding parameter. In case of the road alignment image, values of these thresholds (for static situations) are determined. However, at the same time, it is indicated that tcday with the help of psychophysical methods it is possible to quantitatively compare only relations of feelings provoked by perception irritants and not their absolute values. Thus, also when evaluating the values of known perception thresholds, relations of the corresponding parameters are to be considered. A vehicle driver shall not be capable of determining absolute

parameters of the visible road alignment. Taking the managerial decision, he will orientate according to visible relations. In accordance with this research, it is the background that plays the essential role in the quality structure of the required information. Similar to the road alignment elements, the background also creates the emotional potential of the visible image, which significance is considered in other investigations as well. Background in the context with basic elements can be the source of optical illusions, which considerably reduce the informative quality of the image.

Observing the active nature of perception, i.e. active behavior is on the basis of any perception process, it is concluded that the one under consideration is also evaluated as the active perception process. Thus, the information flow results from the actives perception process. And it is to be such, with change of its parameters, one could *adequately* judge on parameters of the observed object (in this case - the road alignment).

In order to secure the opportunity of visual analysis of the road alignment, on the basis of the previously described dynamic perception model, the evaluation algorithm of the road's image is crated within the framework of the thesis. In accordance with the above said, as the most significant image parameters, curvature of its elements is considered. This is certified also by researches performed by now by other authors. Following the conclusions on dynamic nature of perception, the dynamic image is created, i.e. curvature graph of the image, which is observed from the moving observation point. In contrast to curvature graph of the static image, this one has three dimensions and it forms the 3D surface in graphical depiction (see Fig. 3). This diagram depicts dependence of the curvature K of the image line at the point S on the viewpoint location place $S_{viewpoint}$- The curvature graph received this way allows to evaluate:

- correspondence of curvature of the image line to the moving viewpoint,
- visual clearness criterion, and
- correspondence of curvature to the respective perception thresholds, or the fluency criterion.

As the evaluation criterion in this thesis, the fluency criterion developed in RPI is used, which is defined as the perception threshold of visual break of the image line. Its value depends on the distance to the break, and it is also depicted as a surface. Combining surfaces of both functions, non-conformity of the road alignment to the criteria is determined graphically, as well as their localization. The described principle is used to analyze parameters of the road alignment image, which is observed from the moving viewpoint. It is noted, that

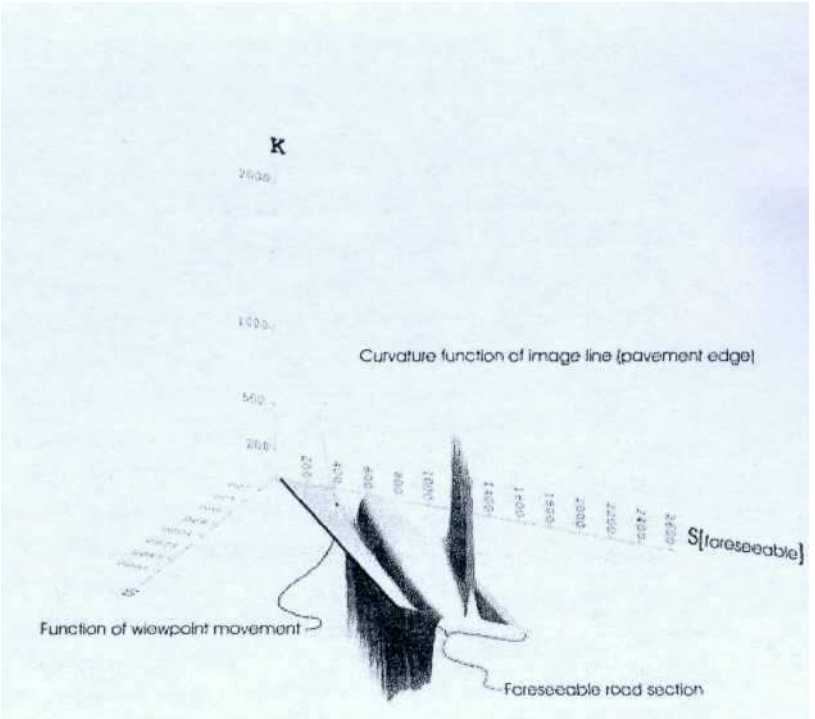

Fig. 3. The curvature function of the visible road element (carriageway contour)

the road image seen generally is spatial, and, thus, is to be investigated with the help of hologrammetry. To simplify the analysis and estimations, the spatial projection up to now has been degraded to the planar projection - perspective image. When evaluating visual properties, the changing with time image of the system is considered as the research object. And, therefore, analyzing its properties along with the static image characteristics Ψ differential properties are to be considered as well, differentiating according to the time

$$\frac{d\Psi}{dt}$$

Thus, dimension of the system in general case is 3D+1. Considering, that time is the parameter of motion, which exist in abstraction during design stage, then for analysis and evaluation needs the transitional consequence was obtained:

(4)

established, that for visible background road elements the adequacy of curvature direction must be estimated. In case of inconsistency, the distance from point of curvature direction change to corresponding road feature must be compared with distance necessary for decision making. This, in its turn, depends on speed. In the same way, it is established, that for extreme location of curvature of foreground visible road image elements must be in sufficient distance from corresponding road feature for taking decision. All these features are possible to find out using the curvature function of the visible road element (see fig.3.) established here.

The opportunity of using torsion in analysis of the road alignment is examined. Observing that it is not defined for a straight line, which up to now has been widely used in the designing practice and is an essential element of the road alignment, its all-embracing application is not forecasted also for the future. Torsion can be applied for the analysis, in case the road alignment is formed of at least C^2 of the continuously even, spatial (3D) line. Such line can be obtained by using spatial splines or chlothoids in description models of the road alignment.

The fourth chapter is devoted to construction of the description model of the road alignment and opportunity of evaluation. The most widely used description models are examined, as well as a new solution of the road's mathematical description is offered, which allows to use the examined designing and optimization opportunities and advantages in this thesis. Apart from the classical model, the spline road alignment model, as the most widely used one, is mentioned, where, depending on the used spline function's type, different modifications can be defined.

Classical description of the road alignment is based on three main elements:

- a straight line,
- a circle arc (horizontal projection), or a parabola (vertical projection), and
- other curved lines,

their fragments being sequentially laid in two independent projections. For the joins of fragments of elements, the C^2 continiuty condition is applied in horizontal projection and the C^1 straightness - in vertical projection. Layout of the fragments in each projection and their parameters are arranged in conformity with the known spatial projection recommendations. As is noted, the order of such line's description secures continuity of the curvature radius function for the layout elements, and continuity of the trend or drop for vertical ones, which is the precondition for correspondence of the road alignment to basic requirements of the car movement dynamics. However, when evaluating possibilities of analysis and optimization of

visual properties of the road alignment, it is to be concluded that the classical model does not secure sufficiently efficient method either for analysis of the visible road image, or for evaluating the required changes in description of the road alignment. For instance, if, as a result of the image analysis, it is determined that the form of some image line needs to be changed, then, in the classical model case, the direct analytical methods cannot be applied to determine correlations between the changeable parameters and those of the appropriate image line form, as the road alignment line in a certain determined point generally is formed of fragments of various elements and their properties in each projection are defined by different functions. Thereto, it is to be remembered, that chlothoid used in the classical model is characterized by a limited amount of freedom stages. Thus, manipulation opportunities with parameters of this element are limited too.

As an alternative to the road alignment description model, the spline road alignment models are examined, application of which up to now has been limited in practice only to separate cases. In conformity with the research, several definition types of the spline road alignment are to be separated, as well as more types of spline functions. The description task of the spline road alignment can be defined as:

- interpolation
- equalization (minimization), and
- approximation.

The most widely known, mentioned and analyzed spline functions and their application for the road alignment description are:

- the cubic spline,
- Bezier functions,
- Catmull-Rom functions,
- the B-spline
- the NURB-spline (Non Uniform Rational B-spline).

It is concluded, that usage of the cubic spline function, most often described in literature up to now for description of the road alignment, and the task of the road alignment description up to now has been defined as approximation or interpolation. The road alignment with definitions of the spline function is designed only for separate cases. In most cases, spline is used as an additional instrument for analysis of the road alignment elements that allows avoiding complications, which are determined in using classical description of the road alignment. The thesis examines spline functions in description of the road

alignment, advantages and deficiencies. Essential deficiencies, as mentioned in the former researches, as well as in the spline theory, are the indicated facts on observed oscillations in the case of the interpolation task. As deficiencies, lack of opportunity to describe the line form change at the wide area, as a result of separate local changes, and regular forms (a straight line, a circular arc) are noted, which at different stage are characteristic for separate spline functions. As an advantage, possibility of defining the 3D road alignment through one steady function with the required straightness degree, which is not provided by the classical description model, is noted.

On the basis of the analysis, it is also concluded that the NURB-spline is most appropriate description of the motor road alignment among the examined descriptions. With this spline function, it is possible to define a straight line and a circular arc, as well as it has comparatively elastic manipulation opportunities with the line's form.

- The fifth chapter examines issues related to optimization opportunities of the road alignment. To speak about the optimal road alignment, criteria are to be defined, in order to evaluate the corresponding properties. However, such criteria are used to contradict each other. In this case, to determine significance of each criterion, it is necessary to organize them in a definite hierarchy. In this case, it is done by defining the quality system of the road alignment. It is created on the basis of the road perception model, determined in this thesis, and the control system with its characteristic dynamic nature. Broadening the road's visually esthetic quality system and adding to this the criteria *a vehicle - a road* and *a driver - a vehicle*, the quality system of the road alignment is obtained, as shown on the figure 4. The demonstrated system is referable to the quality system of the road alignment *a driver - a vehicle - a road*. In accordance with this system, every stage of its evolution depends on the previous one. The created quality system of cyclic nature is also subdued to this principle. All the criteria determining the road alignment are divided into two groups:
- the primary, which directly impact quality of the managerial decision, and
- the secondary, which impact opportunities for implementing the managerial decision.

Observing amount and quality of the information, required for the adequate control decision, the primary criteria are those, which determine visual quality of the road alignment, and, hence, the final solution of the road alignment parameters results from them. Primary criteria arise from adequacy of the road alignment properties to the driver's psychophysiological capabilities, for instance, perception, reaction, etc., and quality of the road alignment, thus, determining possibility of their spatial elements both to secure the qualitative information,

and the optimal level of the driver's emotional excitation. The determining parameter, according to which the optimization can be performed, is curvature of the perspective image of the road's leading lines and values derived from it, which are directly dependent on geometry of the road alignment, and, hence, are considered as functional from it. In their turn, the secondary criteria are those, which determine compliance of the road alignment to requirements of the vehicle movement dynamics, and which are subdued to the primary criteria. Quality of the managerial decision in this case is considered to be the target function, which optimal value is to be achieved.

In case of optimization of (he road alignment, in practice it is possible to analytically unequivocally define solely elements of the secondary quality function. Primary elements are derived from the visual image of the road alignment, which now is transformed into the 2D model for analysis and evaluation. Univalent reflexive transformation in this case is not

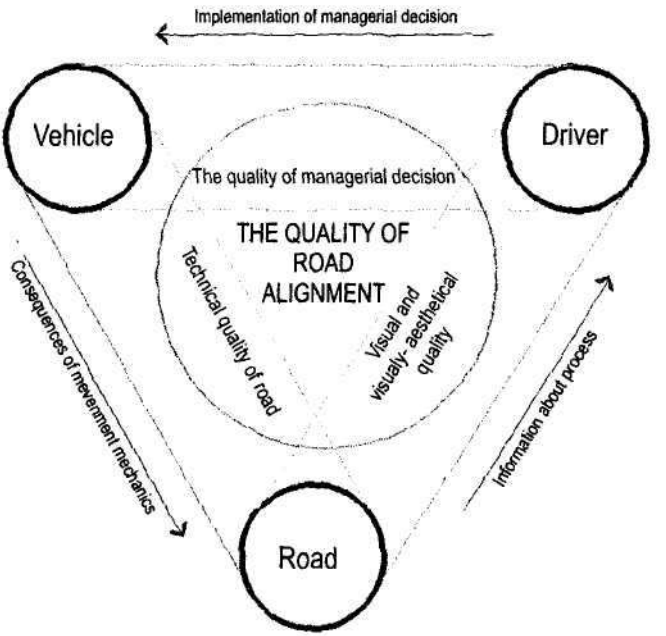

Fig. 4. The Quality System Model of the Road Alignment

possible. Hence, when the reflexive connection is lost, defining of such functional, which would reflexively connect the projection (the image) with the original (the road alignment), is also impossible. Thus, opportunities to use direct analytical methods, in case of the road alignment optimization, are restricted at the operation area of the secondary criteria. Increase of the usage limits also for optimizing the visual quality might be possible, on condition the analyzed and the evaluated image is obtained as the 3D object with the univalent possibility of reflexive transformation. Such solution could be for the analysis, by using possibilities of hologrammetry, or as well by obtaining and processing the image by the fotogrammetry methods.

Analyzing properties of the line's fragment, used for description of the infinitesimal road alignment, and on the basis of the *stationary value principle of the potential energy,* the line's potential energy expression is determined:

$$\Pi(S) = U - H = b\left(\int_0^S \left|\frac{du}{dS}\right| dS - s_0\right) + \frac{1}{2}c\int_S \left(\frac{d^2u}{dS^2}\right)^2 dS - \left(\sum_S P\Delta + \sum_S M\varphi\right), \quad (5)$$

where: Π - is the potential energy;

U - is the energy accumulated in the form, when deforming under external impacts;

H-is the energy lost by external impacts, when deforming the form;

b - is the coefficient, providing value of the extension unit;

c - is the coefficient, providing value of the curvature unit;

H_p - is the energy lost by external impacts from the road's trajectory extension;

H_M- is the energy lost by external impacts from the road's trajectory curve;

Δ- is the balanced extension of the external impact;

φ- is the balanced road's trajectory curve of the external impact,

P- is the tangential projection of the external impact on the searched function $u=u(S)$ for describing the road alignment, and

M- is the standard projection of the external impact on the function $u \sim u(S)$, The line of the road's trajectory shall have an optimal positioning, when its expression of the full potential energy (5) at the current conditions has a minimum. Thus, such line's equation $u(S)$ is to be found, which provides minimum to the potential energy expression. To make it in the direct way, this differential equation is to be integrated. Considering the complicated form of the function $u=u(S)$, in case of the classical description model of the road alignment, it is

simpler in practice to replace integration by searching for the equivalent to the line's equation function $\hat{u}(S)$, which provides the minimal value to 17 expression, or to find minimum to the functional $\Pi(\hat{u}(S))$:

$$\delta\Pi(\hat{u}(S)) = 0. \qquad (6)$$

In accordance with the above said, such approach is applied, when optimizing according to the secondary criteria.

To determine impact of visual properties of the designed or the already existing road on the driver's work environment, and, hence, on the traffic safety, it is necessary to obtain this road's image, thereto, the sufficiently adequate one to the real observation conditions. The absolutely real image can be obtained only, when observing the already existing road; however, it is important not only to reveal deficiencies, but also not to create them. Therefore, impact of visual properties needs to be evaluated already when designing a road. For this, an algorithm is determined to analyze the road's visual quality. Its operation is based on regularities established at this thesis. Visual quality of the road alignment is evaluated in

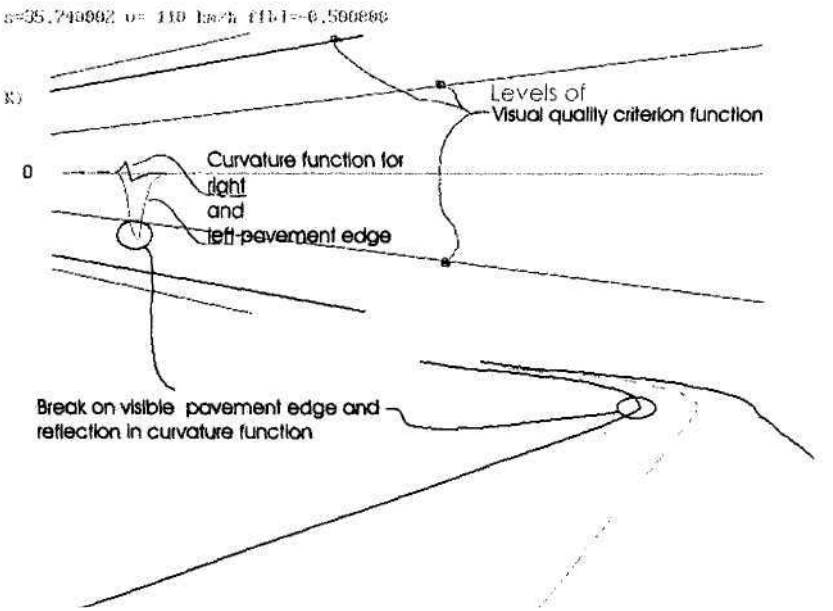

Fig.5• Example of Analyzing Visual Quality of the Road Alignment

conformity with parameters of the image curvature and their evolution nature, when the viewpoint moves along the determined trajectory. In conformity with the algorithm, the computer programme is prepared, where the tested road is intended to be evaluated visually, thereto evaluating not the static but the dynamic image. Parallel to the image, graph of the line's curvature of the tested image is shown, with the possibility to compare the line's curvature with the value of the perception threshold, in conformity with the criterion established in RPI (Fig. 5).

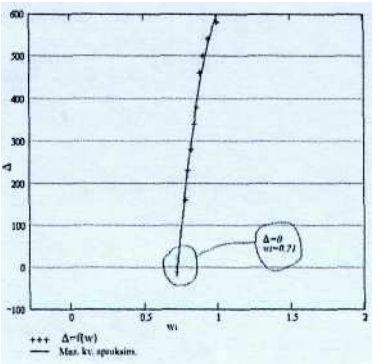

Fig. 6. Determining the Optimization Parameter

Simultaneously, data are prepared to create surface of the line's curvature function (see Fig. 3), which allows to perform the detailed graphic analysis.

The established analysis algorithm is used in solution of the optimization example. In the example, the road alignment is defined as the NURB-spline function. Within the framework of the thesis, to secure the NURB-spline description, the computer programme is created. In conformity with the chosen optimization strategy, improvement of visual quality of the road alignment is made, manipulating with the weight *wi* change of the support course height, closest to the place of the observed defect. In this example, the optimal $ic_{(}$ value is determined according to correlation of the regression from the determined resultative features of the freely determined factorial features *(w,)* with the help of the method of the smallest squares. The volumetric integral of difference of the surface of the image line's curvature and that of the satisfactory curvature was determined as the resultative feature:

$$\Delta = \iint_{S,S_{skata}} (K_{apm} - K) dSdS_{skata} \qquad (7)$$

And the following correlation is established, as the optimization target function:

$$\Delta \geq 0 \qquad (8)$$

In the test example, the requirement is determined to obtain the image line in conformity with the satisfactory evaluation, according to the J. Naudžuns criterion. The optimization algorithm is made, as shown in the Figure 7.

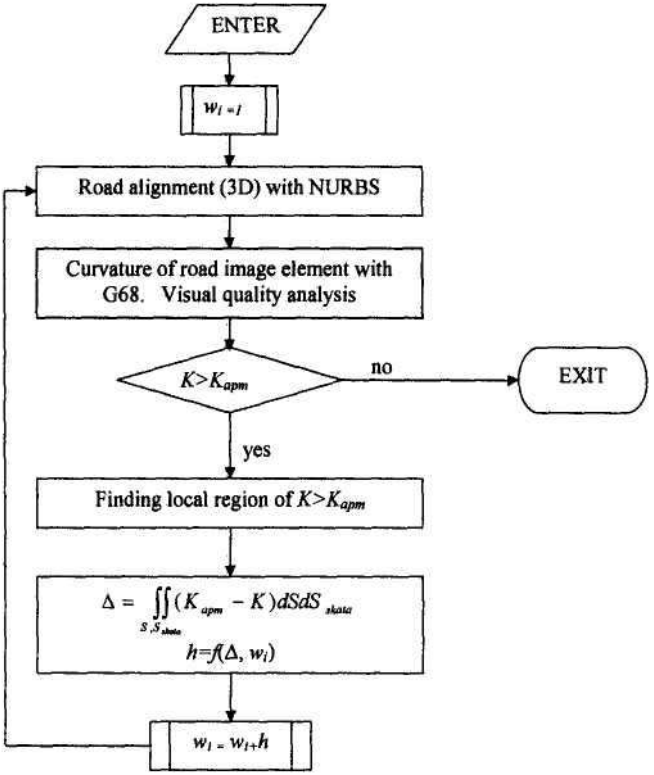

Fig. 7. The Optimization Algorithm

AS a result of the example's optimization, the value w_i (Fig. 6), appropriate for the visual cuality criteria, was determined and the corresponding function of the road alignment description was obtained.

CONCLUSION

1. In accordance with this research, the car driving process is considered to be the dynamic control system, which functions in the system *a vehicle - a driver - a road.* The operator taking the managerial decision is leading in this system. And designing of the road alignment in this context aims at securing such amount and quality of information, as required to take the adequate managerial decision.

2 The process of designing the road alignment usually is directed to achieving the maximal quality. Quality, in accordance with this thesis, is defined as the uninterrupted cyclic structure,

where each successive stage depends on the result of the previous stages. In conformity with the constructed control model (chapter 3), the driver is the leading element of the system, and the quality function is subdued to the leading element. From there comes division of the determining criteria of the road alignment solution into two groups - primary and secondary. The first in this context determine visual quality of the road alignment, but the other - requirements of the car movement dynamics. The hierarchic sequence of the criteria is also formed in this order, determining significance of their impact.

3. Evaluation of the psychophysiological aspects of perception certifies that visual image of the road is perceived and evaluated not as a static, but as a dynamic object, and its perception depends both on the movement parameters, and on formation of the road alignment. Thus, when evaluating visual quality of the road alignment, circumstances of adequate observation and evaluation of the parameters are to be secured, which are due for evaluation, subjecting dynamic image of the road alignment and correspondingly its parameters. The task of further research is to obtain the opportunity of subjecting to evaluation the dynamic, spatial (3D) image, which is closer to the really perceived road alignment image, than the currently evaluated 2D images. In its turn, to secure the opportunity of analyzing and evaluating the obtained solution and to determine the required improvements, a simple and analytically uniform model of the road alignment description is necessary.

4. For obtaining possibilities to evaluate road visual quality and analyse a design decision, the simple and compact road alignment description model is necessary. As the optimization algorithm, developed within this work, demonstrates, such an opportunity is secured by applying the NURB- spline function for the road alignment description.

LIST OF PUBLICATIONS

1. Zariņš A.Traffic safety and driver's psychophysiology. //In: *Proceedings of the Nordic-Baltic Transport Research Conference*, vol. 2, Session 3, pp. 3-8., Riga, April 13-14, 2000

2. Zariņš A. Ceļa trases projekta līnijas aprakstam lietoto funkciju analīze. //krājuma RTU zinātniskie raksti Arhitektūra un būvzinātne. 191-194.]pp., - Riga, RTU, 2001.

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4. Zariņš A. The dynamic approach to evaluation of visible road image. //In: The Baltic Journal of Road and Bridge Engineering, - Vilnius, VOTU, 2006, Vol 1, No.2

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CONFIRMATION

I confirm to have worked out the presented thesis, which is submitted for consideration to Riga Technical University for obtaining the doctor's degree of engineering science. The thesis has not been presented to any other university for obtaining the scientific degree.

Atis Zariņš ...

May 26., 2006.

The Thesis has been written in Latvian. It contains 5 chapters, conclusion, bibliography, 48 figures, 4 tables, in total 156 pages. There are 77 references in bibliography.