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SYSTEM ANALYSIS OF INFORMATION RECEPTION AND PROCESSING FOR DRIVING TASK

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Abstract. Traffic safety can be defined as the quality of driving task outcome, which in its turn depends on factors within the system "Driver–Vehicle–Road". Therefore, if analyzing concept of traffic safety from viewpoint of driving task, it must include relationships following from interactions among all the system elements. To understand these relationships and fix essential factors and elements, which must be taken into account, when making design solution or analyzing it, the system model was established. Based on this model the system functioning was analyzed. Results obtained explain importance of content and quality of information in sources from which driver obtains it for decision making. It was also established, that visual road image is the main information source for decision making in situation, where the traffic flow influence is small. Therefore, content and quality of this information, contained in road image, visible for driver, is formed and must be checked during design process.

Keywords: road design, control system, information processing, decision making, system model, design quality.

1. Introduction

As appears from relevant studies (Elvik *et al.* 1997; Дзенис 1975; Лобанов 1980) the quality of information received from road image, visible for driver, is essential while selecting the road alignment solution. Information received from visible image of road elements and surrounding is the main source from which driver obtains essential part of data necessary for decision-making, in situation where the traffic flow influence is small (Zariņš 2000). In turn, from adequacy of selected managerial decision, the result of its realization, and hence – road safety, is dependent.

The issue of the information quality within road visual image and of the producing geometric parameters properly perceivable for driver usually has been based on static road image analysis and some quantitative criteria derived from here (Kelly *et al.* 2010; Zakowska 1995; Дзенис 1975; Науджунс 1987). The central projection from driver position (road perspective) usually has been used for this purpose. However, such approach has never been properly proved. Some studies have also been based on analysis of a changing perception scene of near real driving situation (Bella 2005; Tilger, Appelt 2005). In these cases the aim has been to look at individual situations instead of quantitative parameters of road visual quality. Many other studies were based data obtained on driving simulator. In most cases these research methods allows to detect problematic stretches or points in the road or road alignment. However they didn't give a direct answer – how to improve? Proposed system model and analysis based on it can help indicate to the parameter linked with fixed error and quantitative estimate it, if possible.

There are at least two aspects, which cause doubts about suitability of static road image for visual quality assessment:

- the continuous information flow, perceived by driver conditionally, can be divided into discrete episodes or amounts which have so far assumed to associate with the central projection from driver position. In fact driver has limited time for the analysis of each of them. Such observation conditions are inevitably ignored by analyzing static images;
- perceived is rather than a static scene, but the movement, and hence could be important the situation before, resp. character of changes in the parameters of elements in scene.

It follows from the considerations listed, that the road alignment design parameters used for the visual quality criteria must be determined on the basis of the appropriate dynamic analysis of the changing visible situation. In order to check the reasonableness of this hypothesis, the perceptual process structure should be clarified, as well as the role of their constituent elements.

As one of the elements of this structure is the driver – a human being, there is relatively little opportunity to explore the process using direct experiment. Therefore, this

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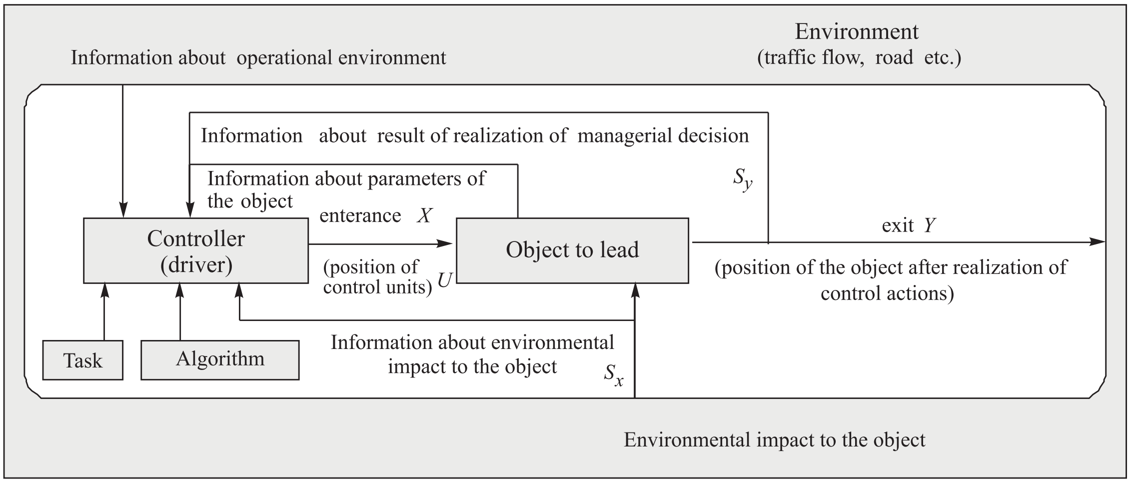

Fig. 1. The process model of the vehicle control system

case study is based on the system analysis using driving process model.

2. The concept of control system of the driving process

Considering the control system theory (Rastrigin 1974), we need to fix the object to control, the controller, which in this case is the driver, and the environment in which the action takes place (Roelofs *et al*. 2010). Proposed structure of the control system is shown in Fig. 1.

The following four conditions are necessary for the existence of driving process:

1 – option (a canal) to control the object (*U*);
2 – option (channels) for obtaining information (S_x, S_y);
3 – the control objective (task);
4 – the control algorithm.

With the exclusion of even one of these elements, controlling becomes impossible.

Although driving is conducted by very complicated biological system, unlike many other biological systems, it is possible to model part of the process mathematically, taking into account possibility of discrete mathematical interpretation of the subsystem vehicle–road (as object of control). This means that road – the controlled part of system, has the quality *Q*, as a quantitative dependence of its parameters.

3. The control algorithm

In simplest case the control algorithm can be depicted as cyclic process (Fig. 2) of a sequential request to the two operators – identification or information extraction and decision making. It should be noted that the control in this context must be understood as the car driver's self-orientation in unknown space around him, instead of a manipulation with steer and levers (now, it is part of the channel for action to the controlled item). In this case visible image of the road, from which the basic information of the system is derived from, is considered as part of controlled object, rather than the environment, as it is in the case, if the road and its image considered as a static object. Environment in this case contains all kinds of incidental details and conditions that affect the process. Then visible road image is part of starting position *X* of the controlled object (Fig. 1) before control operation *U*, but output *Y′* – the visible image after control operation (de facto). Output *Y* is considered here as the expected (desired) situation.

Difference between *Y′* and *Y* then characterizes success of control operation.

3.1. Identification

The identifying operator collects and processes information from the controlled parameters of the controlled object, necessary for deciding in the next step.

Since the aim of managerial decision is to bring the controlled object into desired position, then, it is necessary to know which operator *F*, from all possible ones, supports this, considering given initial conditions. *F* can be determined from identified information on controlled object's response to the experimental (or imagined) control operation *U′*. This can be received via the channel *S* (Fig. 2). The experiment in this case is necessary to obtain the required information for the decision making about possible beha-

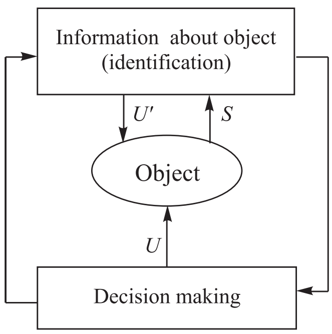

Fig. 2. The control algorithm

vior of operator F. However, experiment in the exact sense, is not made. Instead, it is possible to use data on the object behavior in analogous situations, which are recorded in the past and exists in the driver's mind (Лобанов 1980). Then, the essence of the identifying process is in assessment of eventual control operator F as accurately as possible from the identification data on object entrances and exits. Effectiveness of identification process is characterized by the operator Φ, which reaches a min if $F' = F$, where F' – necessary control operator according to the driver experience. If reducing the identification task to the minimization task in space of all appropriate situations Ω in drivers experience, then

$$\Phi(F, F') \rightarrow min, \; F' \in \Omega_F. \tag{1}$$

But, as the operator F is complex, then based on the intuitive judgment: "same causes trigger the same consequences", the identity detection of adequate operators may be replaced with the identity detection of the final positions i.e. images – desired Y and de facto Y':

$$\Phi(Y, Y') \rightarrow min, \; Y' \in \Omega_Y. \tag{2}$$

However, as one and the same result can be obtained in various ways, in order to the task Eq (2) solution would be equivalent to the task Eq (1) solution, it is necessary to satisfy a series of conditions, most important from which is sufficient diversity of the input X, which in this case implies a broad range of analog situations in the driver's experience (Лобанов 1980).

Hence, the essence of identifying operator is acquisition of adequate description of the controlled object, which, as noted above, is the system "Driver–Vehicle–Road". In this case it means as establishing of consequences between car motion and road visible image parameters, identified together with the situation benchmarks being kept in driver's mind (experience). Managerial decision is dependent on the identification results; therefore, the identification error is likely to turn further into control error.

3.2. Decision making

Task of decision making operator is the synthesis of action that guide object closest to the objective. Objective of driving task demands for synthesis of satisfactory car movement parameters. If the control objective is expressed as the vector Y^*, it can be said, that control process must realize the expression $Y \xrightarrow{U} Y^*$. Deviation of resulting situation from the preferred then characterizes as the function:

$$f(Y - Y^*), \tag{3}$$

where f – a function, min of which satisfies the condition for $Y = Y^*$.

Then, the decision-making can be considered as task of finding the control action U, which minimizes (3), i.e.:

$$f(F'(X,U) - Y^*) \rightarrow \min, \quad U \in \Omega_U, \tag{4}$$

where F' – the object description obtained in identification stage; Ω_U – the set of permissible control actions.

Thus, the decision stage requires the control object (model), an objective, and a number of options (algorithms) to achieve this objective. The decision in that case will be that action from Ω_U, which, according to the analogy with F', leads controlled object closest to the desired objective Y^*.

3.3. The control objective

In this case the control objective can be considered globally – to achieve the destination, and directly – to maintain a safe trajectory according to the driving conditions. Direct control task can be formulated as follows: adjust desirable position of controller on the road, while control object (the road, or rather – the visible image of the road) continuously changes. Basic information required for synthesis of necessary control decisions driver obtains from the information which, in accordance with the aforesaid, consists of:

- information about the identified situation F', which is dependent on the input features X, and possible control actions U, and which consists of:
  - the information on the car motion parameters (from instrument indications, sensually perceived, etc.),
  - the situation observed on the road (road condition, traffic flow, etc.),
  - the observed road alignment parameters and their changes (differential properties);
- information on the appropriate standard situations (benchmarks) in drivers experience Y^*. It contains a description of the object responses in situation with similar indications, and either it exists in driver's mind, if such situation have been in his experience, or he generates it through extrapolation.

In some way information and motivation assumptions explained by risk allostasis theory and process of risk homeostasis (Fuller 2008; Walker, Broughton 2010), also can be considered as necessary for decision synthesis.

If driver adjusts their trajectory according to the car position on the road, i.e., according car location relative to the roadway edges or any other leading feature (road strips, etc.), then next control decision shall follow again from the information on this location relative to the same feature in next moment. Clearly, a driver will seek to get the safest of all possible trajectories on the road. In order to determine and be able to identify who is the "best" it is necessary to distinguish between the object positions and be able to compare them. This means that there exists a quality measure of the control process performance. As an example of this is the situation, when the driver seeing doubtful or visually dangerous road scene, probably will take actions to guarantee his safety – decrease in speed, focus attention, etc. Thus, comparing the apparent scene (image) with the existing quality criteria, he will find the difference between them and will try to minimize it while making a managerial decision. The quality Q in this context is the emotional comfort level of driver, which in turn is a function of the visible road situation, and other output parameters. The control objective, then, can be defined as problem of the extreme:

$$Q(x_1, ..., x_n) \rightarrow \text{extr}, \quad (5)$$

$$x_1, ..., x_n \in S,$$

where $x_1, ..., x_n$: controllable parameters of the object; S – the set of permissible positions of controllable parameters.

Assuming that doubtful scene is only optical deformation (no adequate control actions), an inadequate result for the task Eq (5) will be obtained. Furthermore, the shortcoming in corresponding road visible image (scene) should be the only cause of error in such a situation.

4. Process dynamics

If the level of the resulting emotional comfort is denoted by y:

$$y = F(X_v, A_v), \quad (6)$$

where X_v – control operations; $A_v = (a_1, ..., a_k)$ – parameters of visible road image, and level of the satisfactory emotional comfort – with Y^*, then it can be assumed that driver generates control x based on information about the object position. By realizing it gives the chance to determine the difference $y^* - y$. From here, the control x can be expressed as a function of the difference (Fig. 3):

$$x = \Phi(y^* - y) \quad (7)$$

and control x at time t can be described as the sum of

$$x = \int_0^t (y^* - y)dt. \quad (8)$$

The process dynamics is determined by differential Eq (9), obtained from Eq (8) and Eq (6):

$$\frac{dx}{dt} + F(X, A) = y^*, \quad (9)$$

where $\frac{dx}{dt}$ – change of impact to object in time t; $F(X, A)$ – driver's emotional comfort level, which in general case mostly depends on the visual parameters A and on system input state X. In theories developed up to now assessment of the quality of visual image A was associated with a static image analysis data, obtained from road central perspective image from driver's viewpoint. This corresponds to a situation where the member X is equal to 0, i.e. the control does not take place. Essence of equation Eq (9) can be expressed as follows: in order to achieve a balance of the system the control action is required to equalize the difference between desired and existing system conditions.

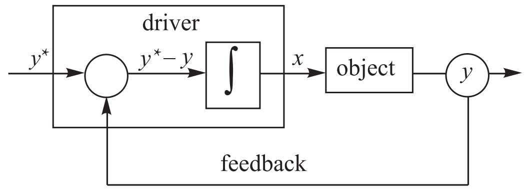

Fig. 3. Scheme of control synthesis cycle "The Control Algorithm"

The first member of the Eq (9) – $\frac{dx}{dt}$ in the case of driving a car could be described as the intensity of control action. Again, it should be noted that this member is also ignored, if a static image is used for analysis.

It must be mentioned that any control action in this case is limited by specific physiological, psychological, mechanical, etc. features of particular process. So, knowing y^*, allowable values of $\frac{dx}{dt}$ and their cross-functional relationships, according to Eq (9), it is possible to determine the acceptable value of parameter A. In general case it can be assumed that the value y^* is constant, assuming it as the lowest safe level of psychological comfort.

More remarkable is the fact that the present state $y(t)$ is dependent on previous control decision, which, in its turn, depends on $y(t-1)$. Thus, any two successive visions correlate to each other, and the driver's psychological comfort y is dependent on this correlation. This is the reason why an analysis of the single road perspective image is essential to do so in the context of the past one, that is – to assess a dynamic scene.

5. Conclusion

Regarding the possibility to interpret some elements in the system "Driver–Vehicle–Road" mathematically, there is the possibility to model part of the whole process mathematically. This means that there's the quantitative dependence of control Q quality from a parameters of road alignment, meaning it as controllable system.

According to the control system theory, driving is classified as a very complex biological system. Its leading feature is the driver. The control process requires information not only on the system positions before the execution of managerial decision, but also on the degree of adequacy of expected or desired system state. Such a system structure is based on categories like standard situations (benchmarks) in driving experience. The categories, mentioned, are created in driver's mind during mastering driving skills (learning process), and expanded during his experience. In accordance with the established model, a successful process, without properly established benchmarks is not possible.

Unequivocal benchmark collection formed in the mind of driver, and therefore, a stable driving experience depends on existing of visually clear and unequivocal information, which ensures consequences in the further process. The apparent road image is the main information source. So it must be provided with adequate visual quality of the road alignment and its spatial solution.

Road quality function is continuous and cyclical, as each subsequent managerial decision will depend on the result of previous one. The essence of both – the dynamic perception of the situation and information for the managerial decision is expressed in relationship. It follows, that the visual quality of the road alignment is determined by two components, of which up to now only one has been quantitatively evaluated – the driver's psychological comfort level, but the second – intensity of parameter change – is ignored. This confirms the hypothesis of the dynamic nature of perceptual process in driving case.

Consequently, the road is to be assumed as communication structure, from solution of which depends on the success of the control process, in a system with human directly involved. Its outcome depends on correlation of human managerial decisions to actual situation, while respecting the functioning of the system parameters (mass, velocity, visibility, and other conditions, including those depending on human's perceptional psychophysiology). Such design conditions are not characteristic for any other engineering structure.

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