Reduction of traffic risks applying cybernetic methods

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The immense progress of the automobilism, in addition to conventional problems such as motor vehicle design, road construction, traffic control etc., poses a series of new questions to the traffic science. Among these the oppressive problem of road accidents can be named as one of the most important ones. The transport is a social phenomenon to-day, its risks are imminent for any member of the society. Thus, it is not surprising that the need of studying and introducing new effective methods to prevent road accidents presents itself on a social level in our days. The mortality of road accidents hits such a level to-day and the future predicted by estimations based upon extrapolation is so dark that the experts are becoming more and more aware of the fact that the efficiency of the conventional methods in preventing road accidents is unsatisfactory. The appearence and the spread of a new science, the cybernetics have yielded the objective basis for this recognition. A lot of results of cybernetical research, and primarily the computers have already found wide-spread applications in the solution of conventional problems of automobilism (motor vehicle design, road construction, traffic control etc.). This is not the case, however, regarding the new problem just said above. Research aimed at the prevention of road accidents and based upon cybernetical methods is carried on only at a few places isolatedly from one another. The results of the research usually do not get published. In spite of all these, we are firmly convinced that the defending reflex of the society will soon make this work more intensive, more efficient and better organized in order to bring down the road transport risks to a tolerable level.

One of the aspects of problems of road traffic studied from the viewpoint of cybernetics consists of the fact that in its focus the running man, the driver of the motor vehicle stands as the most important subsystem of the complicated man-machine system. In view of the operating reliability with respect to the road traffic, this system is of essentially smaller output that the other subsystems of the whole and so, like other man-machine systems, it represents the operating reliability of the whole system. The major part of the road accidents is caused by the subjective mistakes of the driver and only a few of them by the failures due to the vehicles and roads. The transport risks can be interpreted as the probability of erroneous functioning of the optimal algorithm belonging to the man-machine-road system. The research aiming at reducing the value of this probability has to take the following factors into consideration:

1. The possibility of constructing high ways for the overland transport is limited.

2. The number of vehicles taking part in the traffic is not limited.

3. The capacity of the driver functioning in the traffic on the basis of a right algorithm is limited.

These viewpoints are strongly connected, but it is the third of them that promises results for the most part.

We have formulated two questions as the basis and starting point of our research. The first one concerned the possibility of increasing the capacity of the driver by mechanization of certain activities of the driving process, the second one the possibility of a dynamic measurement of the capacity i.e. the change of capacity of the driver. We are aware of the great importance of the first question and we do not consider the research on automata and automaton system acting in the driver's capacity at certain points of the driving process as of second rank. However, we are going to study the second question here in detail.

One of the consequences of the enormous progress of the automobilism is the fact that the number of non-professional drivers is rapidly increasing. Consequently, among the drivers there appear people of most various types whose responses to the stress due to driving a motor vehicle get going on a very wide scale. Furthermore, howsoever rapid is the improvement in the road conditions, the increase of the number of vehicles and that of the traffic speed result a traffic density of such a measure that, together with the decrease of the time intervals disposable to certain actions, makes demands on the fatigue tolerance of the driver to a greater extent and in a more sensitive way. Thus, it seems to be important to develop such an apparatus (both theoretical methods and technical installation) with the aid of which different specific factors involved in the fatigue of the driver could be measured and evaluated.

Some questions of the psyhophysiology of fatigue and questions of measurement of specific factors causing fatigue

First of all, we have to point out that the definition of the fatigue as condition comes up against a difficulty. According to present modern conception, the fatigue is primarily a psychic phenomenon. Certain authors mind that it is nothing else but a subjective experience of the fatigue which is not necessarily accompanied by physiological symptoms referring to a decrease of output. This should mean that it is not possible to characterize the tiredness as conditioned by any of its symptoms. The most known and significant fatigue symptoms such as lengthening of the opto-motoric reaction time, regression observable in a test of a longlasting manual skill, the increase of the amplitude and frequency of the vegetative tremor neither individually nor together give a good agreement with the subjective feeling of fatigue and do not yield satisfactory correlation with the objective output.

Without making an effort to give a generalized definition of the fatigue, in accordance with the majority opinion of the experimental psychology, we will consider the fatigue as an internal change of condition being reflected in the mind, the consequences of which affecting the work are determined by the general psychosomatic condition of the whole organism (physiological fitness, motivation level) and the dynamical equilibrium of factors causing fatigue during the work. In this sense, the fatigue is a kind of self-adaptation of the human being which is aimed at reestablishing the inner equilibrium formerly overbalanced by factors being cause of the fatigue. On the one side of this fatigue-accomodation complex, one can find the decrease of the just beginning fatigue feeling performed by means of an automatic increase of the motivation level, on the other side, in turn, the work interrupted by an unbearable feeling of fatigue stands.

We ask now the following question: can the fatigue be measured? On the present level of physiological experiences, there is a great probability of the fact that the inner changes of conditions happening in the central nervous system and in the other parts of the body, which we know in fact quite imperfectly, cannot be measured at all or they can be measured only by means of their non-significant projections. The subjective feeling of fatigue, though objectively not measurable, can be however studied. More precisely, one can study the measure of it given by people's self-estimation which, under appropriate experimental conditions, linearly increases with the time devoted to the work in question.

The consequences of the fatigue as condition affecting the work have been attempted to track down in many ways. Based upon the physiologically well-known process of the simple muscle tiring, the designers of the measurements had been starting above all with the assumption that, according to the analogy of the tiring muscle, the quantity of the work done would decrease. But, this view, as it turned out after many decades, did not proved to be fruitful. It did call, however, the attention to the decisive role of the factors acting against the fatigue, since it became plausible that one of the most significant properties of the tiring process was the compensation. It is obvious that at the final phase of the tiring process, even in case of an inexplicit activity of muscle work character, the output can be decreased. It would be, however a mistake to identify the measure of this decrease with that of the fatigue by overemphasizing the quantity side of the output. In fact, it can happen, and not only in separate cases, that the output can increase in the state of an ultimate effort. From the comprehension of the fatigue as a complex accomodation reaction just explained, it follows that research methods of measuring the fatigue are to follow not only the quantitative but the qualitative aspects of the work, too. This requirement means, of course, that always a concrete work situation is able to answer the question asked about the qualitative aspect of the work and to tell the method of studying them under an acceptable objectivity. In the literature of experimental psychology studies of this kind are very rare, a fact probably due to the uncleared notion of the fatigue and difficulties appearing in the measuring technique.

In connection with the research aimed at an objective approach of the fatigue there is an other aspect of the problem which can be also measured. This is the reveal of the quantitative terms of the fatigue-causing factors during the work and the experimental determination of their correlation with the change of output and subjective feeling of fatigue. In this work we try to approach the problem from this direction.

The driving of a motor vehicle is an occupation of sitting-work character mostly with psychic demands in which, from the viewpoint of the fatigue, the sui generis muscle work has only a very subordinate role. Since in this activity a higher degree working of the nervous system is prevalent, it would be difficult to measure the quantitative side of the work simply by the output. Still, it can be seen that its usual approximating estimate is represented by the formula: average speed $\times$ time (if accident-free driving is supposed). The description of the actual situation given by these factors is, however, very inaccurate. The following gives a good account of it. In virtue of our formula, the output of the driver while running a route of low traffic at an average speed and the output of the driver on a route of heavy traffic have to be considered as equal, a fact which is, of course, not true. It is apparent from the example that the special aspects of the work done by the driver are not at all or just from very far away reflected by the so-called "output characteristics" having their roots in the muscle work analogies.

Does it really mean that these quantitative characteristics as those characteristics of the driver's output which play a role in the reasoning well approximating the reality should be turned away? In our opinion, this is not the case. We will arrive to measuring quantitative characteristics much more exact than those taken into consideration up to now, the data of which, under suitable transformations, will lead to values being in a good accord with the experience.

We repeat again that, when characterizing the work of the driver, not only the quantitative but the qualitative sides of the activity have to be studied. It is clear that driving a motor vehicle is a dynamic control-like activity in the characterization of which the qualitative sides cannot be left out of consideration. The ultimate purpose is the objective evaluation of the "goodness" of this activity. We think that this can be carried out in the following way: the actual driving activity is compared with an activity ideal in every possible travelling situation (i.e., which satisfies all the rules and results in an optimal speed) and the difference obtained is determined. The deterioration of the activity caused by fatigue could be measured by this difference. (We have to point out, however, that by means of the present apparatus of the control theory the description of the activity of the ideal driving encounters immense difficulties. These difficulties can be prevented if it is succeeded in determining experimentally the characteristic features of a driving style close to the ideal one. Then, in fact, the has-to-be value of the control activity could be replaced by the style determined experimentally.)

The facts said above imply that to the approximately objective measurement of the fatigue caused by driving we can arrive in several steps:

1. We experimentally determine the qualitative characteristics of the algorithm of the ideal driving.

2. We examine the factors causing fatigue during the trip, the measurable proportion of them, as well as the level they have to accumulate up to the ensuing of the impairment of activity.

3. Concerning the persons examined, by using a psychological test model reflecting the aspect of the control activity of driving we determine qualitative parameters characteristic for the level of fatigue.

4. These parameters are used as correcting factors for the computation of the factors causing fatigue.

A possible cybernetical model of the problem

We are going to describe the main characteristics of the driving work by means of cybernetical notions in order to make the setting up of the model of the problem possible.

We start with the fact that, from the viewpoint of participating in the traffic the driver and the vehicle constitute one complex system, i.e., we do not consider this couple separately as directing and directed system. The central figure of this system is the human being who is in a mutual effect, in a mutual regulation with the vehicle driven by him. At the same time, there is also a mutual effect between the man-vehicle system and the outside world. The effecting elements of the outside world are the traffic, road and meteorological conditions etc. The effect on the outside world of the system is performed by the conscious and unconscious activity of the driver through the vehicle as an intermediating unit. (See Fig. 1.)

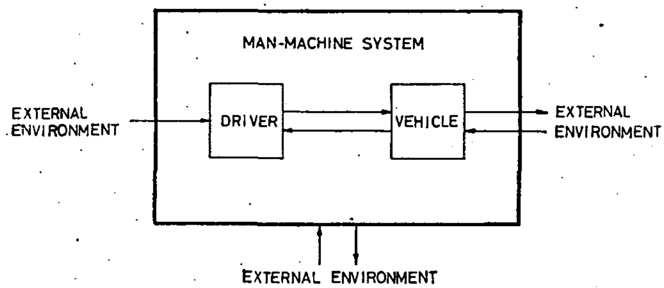

Fig. 1

The sequence of the moments, i.e., the behavior of the system can be characterized by certain parameters of time. These parameters are the elements of the effect on the outside world of the man-machine system. Their mutual effect reflects, in turn, the style of driving. In the cybernetical characterization of the system a very important element is the fact that the parameters of moments as physical quantities are of output character, and in the same time they are fed back through the driver's sense organs as information characteristics for the style of driving. (See Fig. 2.)

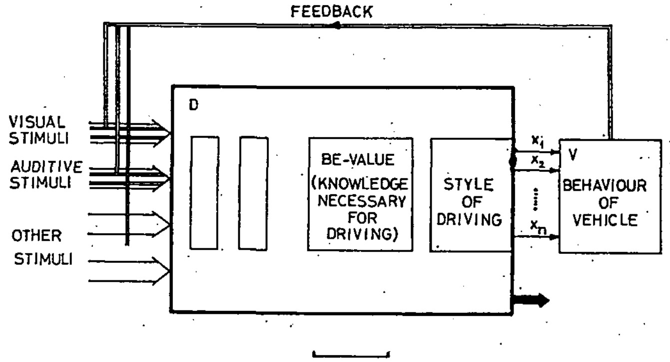

Fig. 2

In our opinion, the feedback-information (together with other informations coming on the driver) effects as a factor causing fatigue on the physique of the driver and it has a decisive role of both the instantaneous and long-lasting change.

We note that other factors causing fatigue of the driver such as the noise, the temperature of the cabin of the car, its humidity and ion-concentration, the driver's activity of other kind (conversation, other mental activity etc.) can be characterized in a typical travelling situation by means of a monotoneously increasing function. Thus, in our study aiming at the measurement of fatigue they can be considered as constants or weight-factors. The most visual information produced by the traffic and road conditions, such as the motion of the vehicle to be left behind, will appear yet in the feedback-information deduced from the parameters of moments, hence their actual values can be determined by not only an experimental estimation but by an actual measurement.

From these we can conclude that from the point of view of fatigue the examined persons can be considered in the driving activity as adaptive automata of black-box character which reestablish their inner equilibrium destroyed by factors causing fatigue in such a way that in favour of the stabilization of the output structure they alter the parameters of their subsystems.

Under a given level of fatigue (which is of course determined by specific peculiarities), the change mentioned above first appears often in an improvement of the efficiency degree (the output is approaching the ideal style of driving) which, later on, may happen at the cost of other adaptive functions of the organism and as a result of this the output deviates more and more from the ideal one. It is important to note here that at this stage of fatigue the driving still can be good for a long time (lower average speed, less risk etc.), and it is even very likely that the professional drivers stay on the quasi-optimal level and they leave this level just in a very few cases. But if the factors causing fatigue do not come into an equilibrium with the output though the quasi-optimal style has already entered (it can be seen, in fact, that the quasi-optimal style puts the brake on the increase of the factors of fatigue), the style of driving begins to grow worse steeply (the steepness of the deviation from the ideal case also changes) and then comes the state when a minimal additional claim for an output pushes the adaptive automaton into an instable stage.

The facts said above imply that the (regulating) scale of the driver's nervous system has to be of different width on the different level of fatigue. Our task is now to encounter experimentally this scale-width by psychophysiological measurements.

The possibility of describing the driving activity by an algorithm

Our primary studies, starting with the model above, have been based upon the hypotheses according to which the driver's work and every subactivity of it aim at a certain purpose well traceable; every action performed to this purpose are encountered by well-describable rules. Thus, the algorithm of every travelling can be set up at least theoretically. In other words, to every travelling there can be given such a sequence of instructions which, supposing all drivers obey, results that the driver leaves the road interval behind in the shortest time under the given travelling conditions.

In the most suitable way, the set up of the algorithm can be done in some formal language of the computer science. We choose the operator method of Liapunov which will turn out to be excellent for our purpose. In the frame of this method, i.e. the formal language corresponding to it, it is enough actually to use two signs (composed in general), so-called operators:

a) The sign of the so-called physical operators which represents a certain part of the driver's activity requiring mechanical work (e.g., turning the steering-wheel, operating the gas, brake and clutch pedal, etc.). These correspond to the arithmetic (valueing) operators used in the programming-theoretical application of Liapunov operators.

b) The sign of the so-called logical operators. These represent the driver's activity in deciding whether some condition important from the viewpoint of a partial activity of driving is satisfied or not (e.g., is there any traffic sign in front of the vehicle, is the vehicle going in front of him overtakeable? etc.) and depending on the fact that they are satisfied or not, he decides about the further operator (meaning physical activity or a newer decision) on the basis of which the driving activity should be continued. These latter signs correspond to logical operators used in the theory of programming.

Besides these we are going to use also another auxiliary sign, the so-called label in the setting-up of the algorithm of driving. The labels serve for marking the operators, more precisely for marking each occuring place of them in the algorithm.

Other operators appearing in the application of the Liapunov method trace to the above two kinds. The use of these serve merely for shortening the setting-up. In the algorithm of driving, among the latter ones only the so-called cycle-operators have to be taken into consideration, which refer to the driver's activity repeating itself (possibly under different values of certain parameters) several times again.

We note that, differently from numerous programming-theoretical applications, not only discrete but continuous parameters can also occur here.

As an example we present the algorithm of the overtaking in case of a two-way traffic road

$$p \overset{1}{\uparrow} I_b L_b q \overset{2}{\uparrow} \underset{t=t_0}{\{G^+\}^S} G^+ I_j L_j G^- I_0 L_0 \underset{2}{\downarrow} I_j G^- B L_j I_0 \underset{1}{\downarrow},$$

where p is a logical condition saying that with my vehicle denoted by W_0 I am in the position to prepare to overtake the vehicle W_1 going just in front of me, i.e.

$$p = \exists W_1((x(W_1) > x(W)) \wedge (v(W_1) > 0) \wedge$$
$$\wedge (v_{max}(W_0) > v(W_1)) > (x(W_1) > (x(W_0) + 3b(v(W_0))))),$$

where $x(W)$ is the distance of the vehicle W from the start of the way; $v(W)$ is the speed of the vehicle W; $v_{max}(W)$ is the top speed of the vehicle W; $b(v)$ is braking distance at a speed v; I_b is the operator of the left-turn indication; L_b is the operator of a turn to the left.

p says that on the road, in front of my W_0 vehicle going in the same direction as W_1 such that its top speed is higher than the speed of W_1 and its distance from W_0 three times longer than the braking distance belonging to the speed.

L_b itself also is a complicated operator: the vehicle W_0 has to be steered to the left to an extent which makes it possible for the driver to see both tracks of the road (the angle between the steered wheels and the linear axis of the car depends on the speed in this case), and then the vehicle has to be brought again in its original direction by means of the steering-wheel again. q is the logical condition saying that there is no obstacle in the overtaking.

$$q = \exists W_1 [(x(W_1) > x(W_0)) \wedge (v(W_1) > 0) \wedge (v_{\max}(W_0) > v(W_1)) \wedge$$
$$\wedge \forall (W_2((x(W_2) > x(W_1)) \wedge (v(W_2) > 0)) \to ((x(W_2) > x(W_1) + 3b(v_{\max}(W_0)) \wedge$$
$$\wedge (v(W_2) < 15\,\mathrm{km/h}) \to (x(W_2) > x(W_1) + 6b(v_{\max}(W_0)))) \wedge$$
$$\wedge \forall (W'(x(W') > x(W_0)) \wedge v(W') < 0) \to (x(W_1) + v(W_1) \frac{x(W_1) - x(W_0)}{v_{\max}(W_0) - v(W_1)} <$$
$$< (x(W') - v(W') \frac{x(W_1) - x(W_0)}{v_{\max}(W_0) - v(W_1)} + 3b(v_{\max}(W_0)))) \wedge \ldots]$$

i.e. in front of the vehicle W_1 to be overtaken, for all vehicle W_2 going in the same direction $(v(W_2) > 0)$ the condition says that

1. the distance from W_1 is three times longer than the braking distance belonging to the maximal overtaking speed $(v_{\max}(W_0))$.

2. in case the speed W_2 is less than 15 km per hours, a sixfold of the braking distance belonging to W_0 is needed and then after overtaking it is possible to range behind W_2 safely.

As far as the vehicle W' passing in the opposite direction is concerned, the condition says that during the time

$$\frac{x(W_1) - x(W_0)}{v_{\max}(W_0) - v(W_1)}$$

needed for the overtaking (at top speed), the vehicle W_1 running a way

$$v(W_1) \frac{x(W_1) - x(W_0)}{v_{\max}(W_0) - v(W_1)}$$

does not get closer to the vehicle W' running, during the same time, a way

$$v(W') \frac{x(W_1) - x(W_0)}{v_{\max}(W_0) - v(W_1)}$$

than three times the braking distance belonging to the maximal overtaking speed.

To the place ... such a logical condition has to be written which says that there is no further obstacle in the overtaking (e.g., there is no traffic sign forbidding overtaking or speed-limit etc.).

t_0 is the moment of beginning of the overtaking, s is a logical condition saying that the overtaking has happened in such a way that I can begin to go back to my lane without forcing the W_1 vehicle overtaken to diminish its speed, hence

$$x(W_0) > x(W_1) + 3b(v(W_1)).$$

G^+ is the operator of accelerating by gas; I_j is the operator of the right-turn indication; L_j is the operator of steering to the right; G^- is the operator of slowing down by taking the gas away; I_0 is the operator of the turn indication of zero-setting; B is the operator of braking; $\downarrow_1$ is turning back to the main program (usual way of travelling).

All the partial activities of driving can be set up in an analogous way and from these it is possible to synthetise the complete algorithm.

The above method of writing algorithms requires an analysis of such a deepness which fully takes into consideration the micro- and macro-situations of the traffic, the established and regulated traffic order, and which closely reflects all of these, meanwhile it fulfils the fundamental rules of the construction of algorithm. It was especially important to strive to a high-level precisity, since, it was doubtful that among the reasons causing the driver's fatigue, the repeated functioning of the operator occuring in the algorithm is of central importance. This means that in principle we should somehow (we think here, of course, of artificial receptors) experience the functioning of the different operators and we should lay down the extent to which the functioning of each operator contributes to making the specific factors of fatigue active, and in addition we should know how many times the operators have been functioning.

The functioning of physical operators are obviously indicateable, but the logical decision as a product of the functioning of the driver's mind cannot be perceived by our present means. Thus, in the man-machine system we have to look for such connections with the aid of which one can conclude to the functioning of a logical operator without trying to follow the psychological process leading to decision with our conventional instruments. Our related studies have shown that between the physical and logical operators there exists a connection such that the system sketched above will also work in case the logical operators i.e. their functioning are traced back to physical operators. In connection with this our argument is as follows: the functioning of the driver's mind effects to each directing organ of the vehicle through a sequence of mechanical reactions (physical operators). To processes of consciousness important from the point of view of the driving there always corresponds a certain state of the directing organ of the vehicle i.e. change of condition which is represented as consequences of mechanical reactions.

The study of any subalgorithm leads to similar results, if we want to indicate the functioning of the operators, it is enough to be confined to physical operators. They fully reflect the functioning of the logical operators. This is one of the most important results of the construction and study of the algorithm of driving by means of Liapunov operators.

It is easy to see that the driving activity represented by physical operators consists of three parts: 1. advancing with constant speed, 2. acceleration and slowing down, 3. change of direction. (All these are to be taken in a certain state of speed.)

Any activity necessary for the solution of a problem raised by a subalgorithm consists of these or of their combination. There exists no partial activity which could not be decomposed into the parts just mentioned.

The characteristic parameters of any of the three parts as well as the speed are quantities easily measurable: a is the acceleration, φ is the angle of steering, v is the speed. For example: on Fig. 2, let $n=3$, thus let $x_1 \approx v$, $x_2 \approx a$ and $x_3 \approx \varphi$.

We have to observe that there is a possibility of giving each subalgorithm with the parameters in question i.e. their quantitized values and numerically determining a connection between the fulfilment of tasks imposed to the driver and their burdening effects on him.

Any of these three quantities varies in a well-defined domain. These are

$$v = 0—150 \text{ km/h},$$
$$a = +2— -7 \text{ m/sec}^2,$$
$$\varphi = 0 \pm 35°,$$

when considering a vehicle of an average make and output.

Let us consider a partition of these domains into parts as small as required

$$v_i \quad (i=0, 15, 30, ..., 150),$$
$$a_i \quad (i = +2, +1, 0, -1, ..., -7),$$
$$\varphi_i \quad (i = \pm 0, \pm 0{,}5, \pm 1, ..., \pm 35).$$

We get sets of elements of partition as parameters. (ν, $\mathfrak{A}$, $\mathfrak{B}$). Take the Cartesian product of these sets

$$\beta = \nu \times \mathfrak{A} \times \mathfrak{B}.$$

Each element of the product represents an activity of driving and the product space contains all the activities theoretically possible. It is obvious that during a travelling we get such a subset of the set of activities which can be studied by means of statistical methods and, in the same time, the time series of each element gives micro- and macro-samples.

As an example let

$$\nu\{15, 30, 45, 60, 75, 90, 105, 120, 135, 150\};$$
$$\mathfrak{A}\{+2, +1, 0, -1, -2, -3, -4, -5, -6, -7\};$$
$$\mathfrak{B}\{0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30\}.$$

As we have already said S_i $(i=1, 2, ... 1200)$ $(\in \beta)$ each represents a partial activity of driving.

Let $N_1, N_2, ..., N_{1200}$ the number of these ensuing during a way run.

At the end of the way let us perform a physiological measurement of fatigue. Let M the result of it.

Suppose that each of the activities S_1, S_2, ..., S_{1200} on every occasion whenever it comes to its turn, contributes to the fatigue of the driver with quantities depending on the activity, that M can be solved as a linear function of the variables, i.e.

$$M = p_1 N_1 + p_2 N_2 + ... + p_{1200} N_{1200},$$

where $p_1, p_2, ..., p_{1200}$ are constant values. These quantities (weights) are to be empirically determined by means of a special-purpose computer built in the vehicle. We store the samples by means of an appropriate built-in store. These informations, characteristic for the dynamics of fatigue, compared with modelling processes and experiences of direct psychophysiological measurements are used for individualizing the weights obtained when using statistical methods.

Снижение аварий в дорожном транспорте с помощью применения кибернетических методов

Опасность несчастных случаев в дорожном транспорте растет весьма быстрыми темпами. Старые методы защиты оказываются недостаточно эффективными. Центральным звеном исследования защиты нового типа, направленной на снижение аварийных ситуаций, является человек, управляющий транспортом. Предлагается новый аспект этой проблемы: водитель и автомобиль рассматриваются как типичный пример человеко—машинной системы, действие которой может быть описано с помощью основных понятий кибернетики.

Теоретически можно задать алгоритм действия шофера. Исследование этого алгоритма показывает, что значительная часть факторов, определяющих усталость водителя может быть задана по объективно измеряемым параметрам с помощью математико—статистических методов. Таким образом, появляется возможность квазиобъективной оценки последствий и изменений, вызванных в операторе.

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