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# DEVELOPMENT OF AUTOMOTIVE COMPUTER SYSTEMS BASED ON THE VIRTUALIZATION OF TRANSPORTATION PROCESSES MANAGEMENT

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*Запропоновано концепцію створення автомобільних комп'ютерних систем на основі віртуалізації управління транспортними процесами. Доведено, що упровадження основних принципів та правил віртуального управління підприємствами ринку транспортних послуг дозволяє підвищити ефективність функціонування транспортних та дорожніх підприємств України. Запропоновано новий підхід до створення єдиного інформаційного простору ринку транспортних послуг на основі використання Cloud Computing*

*Ключові слова: віртуальне управління, транспортні послуги, єдиний інформаційний простір, синергетика, автомобільні комп'ютерні системи, інтерактивний моніторинг, дорожній транспортний портал*

*Предложена концепция создания автомобильных компьютерных систем на основе виртуализации управления транспортными процессами. Доказано, что внедрение основных принципов и правил виртуального управления предприятиями рынка транспортных услуг позволяет повысить эффективность функционирования транспортных и дорожных предприятий Украины. Предложен новый подход к созданию единого информационного пространства рынка транспортных услуг на основе использования Cloud Computing*

*Ключевые слова: виртуальное управление, транспортные услуги, единое информационное пространство, синергетика, автомобильные компьютерные системы, интерактивный мониторинг, дорожний транспортный портал*

## 1. Introduction

Given constant information development of society and its industrial component, the new transportation systems and machines have achieved a high information

level of perfection. A new contradiction has emerged as a consequence, between rapid development of means and methods of informatization of complex objects and systems and heterogeneous nature of the existing subsystems and links of the transportation complex of Ukraine,

which is also characteristic of the market of transport services.

Resolving this contradiction will make it possible, at all levels of the transportation infrastructure, to improve the servicing of the inhabitants of cities and regions, to improve transportation processes, to avoid existing negative impacts. As a result, the following is eliminated: disruption of traffic organization, unsatisfactory condition of roads, non-rational use of funds spent on repairs, operation and arrangement of transportation highways. It will enhance traffic safety, improve the quality of transportation services, ensuring the comfort of the movement of people and the preservation of cargos. This is a general statement for transportation in general.

The relevance of resolving the specified problem is predetermined by the necessity of improving the competitiveness of transportation enterprises and organizations. Implementation, expressing and communicating the new rules and the concept of virtual management of the transportation market will ensure competitiveness of transport and traffic organizations.

At present, virtual logistics lacks conceptual definition of information development of heterogeneous components of transportation processes. A new approach is required to create a unified information space of the market of transportation services based on employing cloud computing. Additional computer resources must be allocated to carriers, forwarders, shippers and consignees so that they use the services of web-technology of the client part of transportation processes under conditions of constant cost constraints that practically dictate the capabilities of the transportation service customer.

The content of the relevant services should be based on spatial-temporal orientation, algorithmizing and routing of the rolling stock of enterprises and organizations that provide transportation processes. At present, however, virtual logistics only declares the necessity of such content, because it cannot eliminate respective cost limitations. That is why it is required to pay special attention to the introduction and implementation of key provisions of the virtual management of transportation processes.

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## 2. Literature review and problem statement

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The need for intelligent automobile systems is predetermined by insufficient informativeness and road safety [1], as well as substantial energy losses [2]. Studies [3, 4] identified problems of the integration of transport applications with the creation of intelligent transportation systems. Results of the experiments on the platform of a transportation vehicle [3] confirm the possibility of proper and reliable vehicle detection in real transport environment. Paper [4] outlined software operational strategy and estimated the appropriate content. However, the use of the Internet information portals, creating road web-sites, application of distributed computer systems in road industry are of experimental character only. That is why particular solutions on information management of transportation processes require generalization, standardization and unification, determining new specialized requirements to registration, accumulation and generalization of data on transportation processes.

Virtual management is considered as the basis for the application of basic provisions in the development of infor-

mation communication technologies (ICT), specifically for transportation processes [5, 6]. Study [5] employs fuzzy logic for this purpose. Paper [6] addresses solution to the problem of application of neuromathematics for transport applications. General theoretical and applied problems of information support for this development are given in results of [7, 8]. Paper [7] reports data on relationships in traffic. However, the idea of resolving the specified issue should involve all participants of road traffic to enable rapid response to negative changes in the parameters of transportation processes and to provide the necessary information for decision-making on maintaining automobile roads, rational allocation of needed resources from road operating enterprises and organizations.

The need to improve existing systems of information decision support systems (IDSS) is noted in studies [9, 10]. In contrast to the existing IDSS, not a simple model approach [9], improvement of marketing interrelations [10] are proposed, but synergetic combination of internal and external telematics of the rolling stock of a carrier. An attempt to define such a combination is made in the applied studies [11], and in the article that addresses optimization of the rolling stock traffic [12]. The above papers, however, fail to consider the fact that an interactive estimation of parameters of transportation processes and roads, as monitoring the changes in operational condition, should ensure appropriate dynamics, timeliness and predictability of adequate decisions.

The target of developing automotive computer implies resolving contradictions of general cost constraints and the required computer resources through rational organization of the client-server technology of a transportation process. Virtual management of transportation processes involves the optimization of decision making by the participants of a transportation process. Rational organization of the client-server technology requires provision of sufficient computer resources both for a transportation system as a whole and for each client.

Thus, the issue of virtualization of transportation process management using automotive computer systems requires further research into providing scalability and improvement of the overall throughput to match increased load on resources [13, 14].

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## 3. The aim and objectives of the study

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The aim of present research is to obtain additional computer resources to eliminate cost constraints through the application of cloud computing during virtual management of the transportation processes.

To achieve the set aim, the following tasks must be solved:

- to determine the mechanism of synergetic self-organization of virtual transportation process management using decision making on the estimation of current state of the road environment directly during car motion as an example;
- to study the interactive monitoring of the chosen route;
- to develop an artificial neural network for the route estimation.

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## 4. Virtual management of transportation processes

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The market of transportation services consists of different components. First, this is the economic part that defines

financial flows, and the technical part, which is the essence of transportation processes. Second, this is the transportation process as it is, determining spatial-temporal orientation of vehicles, algorithmizing and routing of the transportation process. Specific integration of these components into a single system implies information development, interactive character, constant customer interaction, joint work of participants: carriers, freight forwarders, shippers, consignees. Virtual management of transportation services is based on the sequence of activities that ensure constant testing, verification and validation of transportation processes, as well as their monitoring.

We shall consider the monitoring of transportation services as an information process that is a constituent part of decision-making on estimation. We shall represent this process in the form of generalized structural scheme of registration and data conversion on the state of a carrier motion route, as it is accepted in the theoretical foundations of information technology and in the problems on systems engineering.

In contrast to a conventional sequence of activities, the formal representation of the conversion of parametric information on a motion route is a sequence that implies recursive processing based on the results of obtained solutions on the current state estimation (Fig. 1). Primary to this system is the registration, namely the process of obtaining parametric information (a set of characteristics that determines the operational condition of the road). It precedes normalization, reducing the obtained road data to a single logical system of reference, recursive procedures of decision making and its estimation.

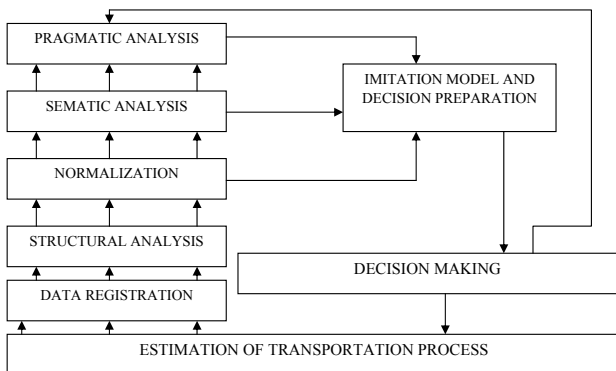


Fig. 1. Monitoring of transportation process

The introduction to this logical chain of the imitation model for preparing a decision on the road estimation is a certain logical element of the synergetic self-organization of the proposed estimation of operational condition of an automobile road. By employing the theory of information management, we shall define an interactive estimation and operational diagnosis as the observed dynamic process or simply the monitoring of operational condition of the road.

We shall consider the monitoring of transportation process as the conversion  $Q$  of existing state (totality of  $n$  variables:  $k_1(t), k_2(t), \dots, k_n(t)$ ) into the new totality of  $n$  variables:  $q_1(t), q_2(t), \dots, q_n(t)$ . Prototypes  $k_i(t)$  of operator  $Q$  are the characteristics of movement of vehicles in space and time;  $q_i(t)$  is the new totality of estimates of given movement. Then  $Q$  is such an operator that  $q_i(t) = Q[k_i(t), t]$ , where  $k_i(t)$  is the dynamic function that corresponds to the  $i$ -th object in the examined system regardless of its specificity. Inter-

pretation of  $q_i(t)$  is the efficiency of work of the  $i$ -th part of the system. The introduction of this parameter is not as productivity or throughput, but as efficiency, which generalizes properties of the process of monitoring a carrier's route according to a similar statement of the problem on the information development of transportation systems.

Assume that  $L$  is the set of points of the respective road, which consists of subsets of characteristics  $L^a, L^p, L^v$ , respectively, simplification of vehicles motion speed, smoothness, adhesive qualities. Then

$$L = L^a \cup L^p \cup L^v.$$

Accordingly, the state of the moving object, the process of its movement in space  $L$ , vehicle and characteristics of the road environment can be represented as the sum of three operators

$$S = S' \cup S'' \cup S'''.$$

$S, S', S'', S'''$  are the conversion operators of the observed dynamical processes  $k_i(t)$  at a certain point of time  $t$  (current characteristics of both the process of monitoring and the condition of the road).

Generalized estimate  $K_i$  of the state of any section of the automobile road can be simplified as a weighted average coefficient:

$$K_i = \frac{1}{m} \cdot \sum_i \sum_j b_{ij}^k \cdot \frac{l_{ij}}{L_j}, \tag{1}$$

where  $b_{ij}^k$  is the measured (estimated and normalized, reduced to a unified system of reference) value of parameter of the  $ki$ -th section of road  $j$  of length  $l_{ij}$ ;  $L_j$  is the length of road  $j$ ;  $m$  is the number of parameters that the road is assessed with.

The intellectualization of the monitoring process, creation of specialized equipment that should ensure solving functional tasks of operational diagnosis, is inextricably linked to the circuitry in this area and digital data processing. We shall consider a simple mathematical notation of such a data processing – the classic representation as a linear system with constant parameters, which is the ratio between the input and output sequence  $x(n)$  and  $y(n)$  in the interpretation for the road application:

$$y(n) = Y[x(n), t], \tag{2}$$

where  $Y$  is the operator of converting the prototype of operator  $x(n)$  into the image of operator  $y(n)$ , determined on the set of  $n$  responses in region  $T$  of current time  $t$ .

It should be noted that in this case  $Y: T \rightarrow T$ , where  $T$  is the numerical axis, which is matched by time  $t$ . In a general case,  $T$  is the space, which contains own sets of time responses  $T_i$  with their difference in time  $\xi_{Ti}$ , and  $\bigcup T_i = T$ , but  $\bigcap T_i = \emptyset$  (the empty set). In real systems, the one-dimensional conversion (2) is transformed into a two-dimensional transform, and in a more general case, into multidimensional transformation of sequences of the registered signals. This is the ratio of the convolution type

$$y(n) = \sum_{m=-\infty}^{\infty} h(m) \cdot x(n-m), \tag{3}$$

where  $h(m)$  is the response to a single jump or pulse characteristic of the appropriate data registration system.

Similar to a one-dimensional linear system, the following holds for a two-dimensional system with output sequence  $y(n_1, n_2)$  and input sequence  $x(n_1, n_2)$

$$y(n_1, n_2) = \sum_{m_1=-\infty}^{\infty} \sum_{m_2=-\infty}^{\infty} x(m_1, m_2) \cdot h(n_1 - m_1, n_2 - m_2), \quad (4)$$

where  $h(n_1, n_2)$  is the pulse characteristics of such a linear system. Then:

$$\begin{aligned} y(n_1, n_2, \dots, n_i, \dots, n_k) &= \\ &= \sum_{m_1=-\infty}^{\infty} \sum_{m_2=-\infty}^{\infty} \dots \sum_{m_i=-\infty}^{\infty} \dots \sum_{m_k=-\infty}^{\infty} x(m_1, m_2, \dots, m_i, \dots, m_k) \times \\ &\times h(n_1 - m_1, n_2 - m_2, \dots, n_i - m_i, \dots, n_k - m_k). \end{aligned} \quad (5)$$

Accordingly, it is possible to give the operator notation of this estimate:

$$y(n_i) = Y_i [x(m_i, t)], \quad (6)$$

where  $Y_i$  is the operator of a  $k$ -dimensional linear system of digital registration and processing of data on the state of the vehicles.

In order to physically implement transformation  $Y_i$ , it is required to satisfy conditions for the physical implementation and stability of the monitoring system of an automobile road:  $y(n_0)$  depends only on  $x(n_0)$ , if  $n \leq n_0$ . For the system to meet requirements of stability, it is necessary to foresee that

$$\sum_{n=-\infty}^{\infty} |h(n)| < \infty.$$

In temporal space  $T$ , sequences  $t_i$  can belong to zones with different time distinctions. The system “driver – vehicle – road environment” (DVRE) exists in the following temporal space: a car’s time zone  $T_1$ , a driver’s and a passenger’s zone  $T_2$ , a road’s zone  $T_3$ .

Determining and estimation of state of the subsystems, links and elements of the road must be carried out in the most informative points of time  $t_k = t_i$ . At present, the effect of this link on the system’s operation during monitoring interval acquires the largest value ( $q(t)$  is the monitored dynamic process (MDP) of change in the state of the road)

$$\frac{\partial q(t)}{\partial t} \rightarrow \max \frac{\partial q(t)}{\partial t}. \quad (7)$$

Statement  $T_1 \cup T_2 \cup T_3 = T$  is not always valid. It is possible to determine such a range of  $T_4$  from  $T$  for which:

$$\forall T_4 \exists T_4 = T_1 \cap T_2 \cap T_3. \quad (8)$$

One should take into consideration that the prototypes of MDP are the functions of time. Estimate  $q(t)$  of the road in general (result of the overall monitoring) is determined from operator ratio

$$q(t) = Q [h(l), t], \quad (9)$$

where  $h(l)$  is the dynamic function of argument  $l$ , determined in time  $t$  in temporal space  $T_3$ .

Operator  $P$  is the operator with a memory. In the specified statement, important is not only simple determining

or estimating  $h(l)$  at point  $l=l_i$ , which corresponds to point  $s=s_i$  and point of time  $t_i \in T$ , but an analysis of the ensemble of values  $\{x(t), y(t), z(t)\}$  on the set of counts  $x_j$  with its “weight”  $M_i$  or (in a general case of the functions) the coefficient of the benefits. The procedure for scanning the road for  $l=l_i$  will take the form

$$X_j = \frac{\sum_{j=i-n}^{j=i+n} M_i X_j}{\sum_{j=i-n}^{j=i+n} M_i}. \quad (10)$$

To determine the metric of space of the existence of a set of the registered functions, MDP  $x(t)$  should be considered as a totality of points  $x_i$  on the numerical axis. We shall consider the way the monitoring system (subsystem “Observer”) distinguishes between these points when determining the process of change in the states. For any pair  $x_i$  and  $x_j$  ( $i \neq j$ ), one can specify such magnitudes  $\xi$  for which values  $x_i$  become undetermined or lose their physical essence. This magnitude determines a threshold of distinguishing the states; in this case one can obtain a lot of values for the thresholds of distinguishing for a particular element. The magnitude of the lowest threshold  $\xi$  determines the lower bound of reliable distinction between the two values of MDP  $x(t)$  or their existence. This magnitude is the distinguishing threshold:  $\xi = \text{infsupp} (x_i - x_j)$ , for all  $i \neq j$ .

One should differentiate between physical and consumer distinguishing. The accuracy of data conversion is characterized by the “consumer” distinguishing threshold  $\xi_y$ , while  $x(t)$  by the “physical” distinguishing threshold  $\xi_x$ , and characterizes sensitivity of the system. In this case, a condition for the monitoring of object  $\rho(x_i, x_j) \geq \xi_y$ , because otherwise it will not be possible to notice a change in the state of the monitored process.

The considered mathematical procedure for monitoring a condition of the automobile road and the corresponding estimation are based on the methods of analogies, generalization and digital data processing to determine decisions on operational evaluation of conditions of vehicle motion. It should be noted that there is always such a time series  $t_i$ , over which commands of “control center”  $I(t)$  are missing, and the controlling influence  $U(t)$  is formed independently based on estimate  $Q(t)$  according to formal statement

$$\exists t_i \forall t_i \in T | Q(t) = Q_i [I(t), U(t)], I(t_i) = 0. \quad (11)$$

Autonomy implies systematic data acquisition in order to build a dynamic bank of information about previous and current state of an automobile road. Such information should be compiled by the intelligent monitoring system of an automobile road, which is an analog to relatively simple local systems for the interactive monitoring of condition of automobile roads. Instrumental means of such monitoring are the means of monitoring a condition of the road, computerized complexes that enable data acquisition about operational condition of the road. Thus, there is a peculiar link created from information devices of internal and external telematics at information-communication center (ICC) to the information server of information-communication technologies (ICT) of road maintenance. Its implementation means the creation of an interactive road system for the registration, accumulation and generalization of data

on the operational situation and the environment of road traffic.

It is logical to synergistically connect individual computers, such local systems, from the internal and external telematics of ICC to the information server of ICT. Road maintenance should be based on modern computer technologies of WEB 2.0 and the possibilities of the Internet. A logic basis of such heterogeneous computational environment is the information-communication technology for managing transportation processes.

To implement appropriate multilayered system, it is required to solve the problem of providing the proposed interactive system with a kind of intelligence. That is why it is expedient, when developing algorithms for making management decisions at different levels of decision-making related to maintenance of motor roads, to apply mathematical apparatus of artificial neural networks (ANN). From an engineering point of view, ANN is parallelly distributed information processing systems, formed by simple computing nodes, which are capable of accumulating experimental knowledge. A distinctive feature is the presence of a learning procedure. Such a procedure can be represented as a sequence of steps:

- estimation of the result;
- comparison to exact value;
- measurement of weight;
- estimation of results of transformations in terms of achieving the required level of accuracy.

In the negative case, repetition of a sequence of steps from the beginning (estimation of the result).

Designing such an interactive system of registration, estimation and accumulation, generalization of data on operational situation and the environment of road traffic, should be carried out using available solutions of authors [2, 13, 14] of development of similar computer systems for monitoring a rolling stock route.

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### 5. Interactive monitoring of the selected route

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Interactive monitoring is an instrumental means for observing a condition of the automobile road. The difference between monitoring and a regular observation is determining the prehistory of change in the operational condition of the road. The essence of interactive monitoring is constant observation, registration, accumulation and generalization of data on the operational situation in the environment of road traffic.

Interactive monitoring of condition of the automobile road is based on a combination of three components of physical implementation. First, they record speed and acceleration of a vehicle using an external system for identifying its location in space over time. Second, they perform continuous video recording using a video camera (WEB-camera) and a digital camera. The third component of the system is the direct estimation of the condition of a road by traffic participants (for example, recording of comments from the operator of a road car, an experienced specialist who takes part in maintaining an appropriate road section).

Such a monitoring is not an organizational-technical system only, but rather an interactive system where the main activity of monitoring the automobile roads is supervised by the human. It implies applying the experience of a specialist who controls respective situation on the road and in the road environment, as well as coordinates the course of operational

diagnosis. Thus, we obtain a synergetic system that combines technical and ergonomic components. Human operator becomes a kind of continuation of the computational complex and is actively engaged in the automated data acquisition on the motion of a test car – road laboratory. The main activity in such a system is the generalization of situation on the road, including visual estimation of the road cover state. It should be noted that a driver who is driving the car rather subjectively perceives the state of the road section in accordance with the analyzed package. However, this subjectivity brings about useful information, which makes it possible to make the right decision concerning the actual state of the appropriate section of the road.

At present, there are mathematical methods that make it possible to combine such subjectivity with a precise technical calculation. This is the so-called fuzzy approach or fuzzification, which is the process of matching human understanding to quantitative technical estimations.

The first step in using a fuzzy-based approach for modeling complex transportation objects and systems is the task of fuzzification, a formal description of the observed dynamic processes of motion. Fuzzy logic is widely represented now in the fundamental and applied scientific publications, starting from paper [1]. The theory and practice of applying a fuzzy approach were described in many studies, for example [5].

Reducing the description of the examined system to the fuzzy form starts with the defining of linguistic variables, notions – terms, conducting analogy between the quantitative estimates of subsystems and links of the system and their fuzzy description. This task is similar to determining a differentiation between the monitored dynamic processes in accordance with basic provisions of the theory of information control. We shall assume monitoring to be a result of analysis of the observed system: normalization of data, structural and pragmatic processing. Thus, we can define observation as monitoring of the road. According to the assumptions made, fuzzy description or the fuzzification of the examined processes and systems will be considered from positions of basic provisions of the information theory of differentiation, the fundamentals of decision making in complex systems for the monitoring of road machines transportation systems and communications.

Existing approaches to solving the task of fuzzification in transport applications are characterized by certain subjectivism. Even if this is acceptable in organizational systems, then technical and organizational-technical systems require accurate quantitative estimation, excluding a subjective opinion of the human. First of all, it concerns the new transportation applications employing fuzzy logic. Thus, the tasks on monitoring transportation machines, systems and communications previously utilized expert assessments, close to the use of the apparatus of linguistic variables. In this case, there occurs the contradiction between the capabilities of quantitative processing of data on technical parameters and the use of “inaccurate” logical conclusions. We shall consider the ways to resolve this contradiction by reducing exact characteristics of the transportation technical monitoring system to the “fuzzy” form.

Let a technical object or a system be formally described by the  $Y$  operator that converts the observed dynamic variable  $x(t)$ , the prototype of operator  $Y$ , which unambiguously defines the appropriate observed dynamic process. For a transportation system, such a dynamic process is the process of motion of a vehicle. In the simplest case, the result of the

transformation is the image of operator  $y(t)$ . It is logical to consider the process of observing such a system as a dynamic monitoring. In order to pass from subjective estimates of the observed object or a system, we shall assume that  $y(t)$  unambiguously matches a linguistic variable in the region of determining the fuzzy model of the observed dynamic process.

Then the limited multitude of terms of such a linguistic variable is determined by the characteristic of the observed dynamic process. Formally,

$$y(t) = Y[x(t), t], \quad (12)$$

where  $y(t)$  is the image of operator  $Y$ ;  $x(t)$  is the prototype of operator  $Y$ ;  $t$  is the current time.

If  $x(t)$  is matched with a certain point  $X_n$  from set  $X$ , then in the proposed statement specific meaning of the image of operator  $y(t)$  corresponds to one of the terms. This term comprises not only one value of  $y_m \in Y$ , but several adjacent values of  $y_m$ . If the process of observation  $x(t)$  is the monitoring, then in sequence  $2k+1$  of responses,  $y(t)$  is the quantitative assessment of one of the terms of the respective linguistic variable in the range  $\{y_{m-c}, y_{m-c-1}, \dots, y_m, y_{m+c-1}, y_{m+c}\} \in y(t)$ .

Thus, while considering operator transformations, it is necessary, along with quantitative correspondence  $X \rightarrow Y$ , to analyze also correspondence  $Y \rightarrow L$ , where  $L$  is the set of terms of the linguistic variable whose analog is  $y(t)$ .

We shall define  $P$  as the fuzzification operator of the observed dynamic process whose analogue is the value of image  $y(t)$  of the values of the registered function  $x(t)$ :

$$l(s) = P[y(t), s], \quad (13)$$

where  $s$  is the argument that characterizes correspondence between  $2k+1$  of value  $y_m$  in the range from  $y_{m-c}$  to  $y_{m+c}$  of term  $l(s)$  and the current value of time  $t$  at the moment of registration.

We assume that the fuzzification of the observed dynamic process represents the following dual transformation of the registered dynamic function  $x(t)$

$$\left. \begin{aligned} y(t) &= Y[x(t), t], \\ l(s) &= L[y(t), s], \\ s \in S &\rightarrow T, t_p \in T. \end{aligned} \right\} \quad (14)$$

A relatively simple system of operator relations (14) can be rather simply implemented if it is formalized and quantitatively estimated as a degree of belonging of the registered values of  $x(t)$  matching term  $l(s)$ , while current time  $t$  matches  $s$ . Thus, the problem of algorithmizing this procedure comes down to determining a correspondence between characteristics of the observed dynamic processes and the procedures of term estimation using a function of belonging of the linguistic variable that characterizes this process. Such a procedure implies finding a mechanism for calculating the number of terms, registration accuracy of  $x(t)$  and differentiation between the results of  $y(t)$  estimation of the required dynamic process. This is the fuzzification. In the applied statement that matches transportation applications, it represents a moving observer that performs direct operational assessment of the state of moving objects and the road. Formally, the image of the respective operator of this system, as well as the linguistic variables, are the result of dual transformation of values of the observed variable  $x(t)$

for a one-dimensional case. For example, during motion of a basic vehicle, continuous estimation is performed of either its speed in a transport flow  $v(t)$  or its rectilinearity  $r(t)$ . Thus,  $x(t)$  is a certain generalized estimate of both a transportation machine and a road if we accept that the transportation system is a combination of set of automobiles  $M$  and the road along which these vehicles move. Fuzzification operator converts values of the observed dynamic variables  $x(t)$  from the region of set  $x$  into one of the points of fuzzy sets  $S$ . A real prototype of set  $S$  is the sequence of certain fixed points from a respective transport communication (automotive road).

Physically, these processes are matched by the registration of values of the observed dynamic variable  $x(t)$ , the information reduced to a certain pre-defined system of responses  $y(t)$  and pragmatic processing of the values of linguistic variable  $l(s)$ . In this case, fuzzification as a process or estimation  $l(s)$  is performed not relative to time  $t$ , but according to the properties of the observed object in comparison to other similar objects.

It is fair to argue that monitoring is based on the method of analogies. Thus, experts use point estimates not only for complex organizational systems, but also when estimating technical objects by points, which is a prototype of linguistic variables. Then, in those systems where such evaluation is used, it is possible to pass from a certain subjectivity of an expert to a precise quantitative analysis of observation results based on linguistic variables. The result is a solution to the problem of determining physical differentiation of the observed dynamic process based on consumer distinction that is assigned by a point score.

According to the information theory of management there are physical and consumer thresholds for the differentiation of an observed dynamic process. If this is an operator  $Y$  of the prototype  $x(t)$  transformation into the value of image  $y(t)$ , then the differentiating threshold  $E_x$  is equal to the least difference between adjacent values

$$x(t): \Delta_x = \min(x_n - x_{n+1}),$$

it is a physical differentiating threshold of the observed dynamic process. Accordingly,

$$E_y = \min(y_m - y_{m+1})$$

is the consumer differentiating threshold of the observed dynamic process.

It is worth noting that for the clarity of presentation, an observed dynamic process is understood by the author as a one-dimensional case of change in the magnitude of  $x(t)$ , while the observations denote registration of the values of  $x_n \in x(t)$ . The number  $d_x$  of different values of  $x(t)$  or discrete counts is determined by the differentiating threshold  $E_x$  so that  $n=1, 2, \dots, d_x-1, d_x$ . By analogy, the number  $d_y$  of different values of  $y(t)$  is determined by the same procedure, which is why

$$\left. \begin{aligned} d_x &= \frac{\max_n X_n - \min_n X_n}{E_x}, \\ d_y &= \frac{\max_m Y_m - \min_m Y_m}{E_y}. \end{aligned} \right\} \quad (15)$$

In technical systems,  $E_x$  is defined by the physical properties of the observed process while  $E_y$  by the needs of the

user. There is no need to analyze adjacent values of  $x_n-x_{n+1}$  and  $y_m-y_{m+1}$  because there are no such adjacent values with  $x_n$ , which differ from  $x_n$  by the magnitude lower than  $E_x$ . The same applies in relation to  $y_m$ .

As far as the linguistic variable  $l(s)$  of the observed process is concerned, it is not possible to apply the appropriate differentiating threshold since logical estimates hold for it rather than the quantitative estimates. However, one can argue that the number of terms is equal to  $d_x$ , and the value of  $y_n \in y(t)$ , is a quantitative estimate, which matches linguistic variable  $l(s)$ . Thus, we received relations that make it possible to relatively easy solve the problems both on the fuzzification and on determining relevant characteristics of this process: differentiating thresholds, values of ranges of change in terms, and, respectively, accuracy of data registration.

This simple schema is the basis for solving a general problem on the conversion of data on the condition of the road environment.

Assessment of the condition of an automobile road is based on model representation, which allows choosing initial settings, characteristics of the observed objects, determining the list, estimating the significance and priority of measurement and registration. It is obviously the task of analysis of interrelation, of the possibility of analytical recalculation, of obtaining particular values of indirect, estimated and generalized estimates, which would make it possible to make specific management decisions. There is no doubt that such an analysis should be carried out not at the generalized level, but directly during assessment of the state of a particular section of an automobile road.

To do this, there is a whole range of analytical, graphical and certain heuristic methods. However, the experience of diagnosing various road situations shows that the most significant is the statement about the need to measure speed, geometry, evenness, and adhesion (coefficient of adhesion).

In order to analyze and properly algorithmize the process of state estimation, we shall describe these parameters and their interrelation using the above-determined operator ratios. The parameters considered for making decisions about the state of the roads represent a system of functions, about estimation results – a generalized criterion that determines technical-economical, operational properties of such a linear object as an automobile road. Thus, one can distinguish three layers of estimation: primary characteristics  $a_{ij}(t)$ ; parameters for estimating  $x_i(t)$ ; generalized estimate  $y(t)$ .

This corresponds to the following system of operator relations

$$\begin{aligned} x_1(t) &= X_1[a_{11}(t), \dots, a_{1j}(t), \dots, a_{1n}(t)], \\ x_2(t) &= X_2[a_{21}(t), \dots, a_{2j}(t), \dots, a_{2n}(t)], \\ x_i(t) &= X_i[a_{i1}(t), \dots, a_{ij}(t), \dots, a_{in}(t)], \\ x_m(t) &= X_m[a_{m1}(t), \dots, a_{mj}(t), \dots, a_{mn}(t)], \end{aligned} \tag{16}$$

or

$$x_i(t) = X_i[a_{ij}(t), t]; \quad i = 1, m; \quad j = 1, n; \quad y(t) = Y[x_i(t), t],$$

where  $Y$  is the operator of the road condition estimation;  $y(t)$  is the image of operator  $Y$ ;  $x_i(t)$  is the prototype of operator  $Y$ .

Interactive estimation suggests refusal of the typical mathematical idealization. A linear object, which is an auto-

mobile road, within the limits of this observation possesses resultant characteristics. Formalization implies determining differentiating thresholds. Accordingly, we shall consider possible ways to interpret the results of this estimation in accordance with the logic of human understanding.

### 6. Artificial neural network of route estimation

We shall denote geometrical characteristics of a road as  $a_1$ , of road surface as  $a_2$ , of motion intensity as  $a_3$ . Road condition estimation is  $k(t)$ . The following system of linguistic variables matches all possible values of this estimation:

$$\begin{aligned} a_1 &= \begin{cases} a_{11}, \text{if geometrical parameters match} \\ \text{permissible values;} \\ a_{21}, \text{if geometrical parameters are worse} \\ \text{than permissible values;} \end{cases} \\ a_2 &= \begin{cases} a_{21}, \text{if road surface matches permissible values;} \\ a_{22}, \text{if road surface is worse} \\ \text{than permissible values;} \end{cases} \\ a_3 &= \begin{cases} a_{31}, \text{if motion intensity matches the estimated;} \\ a_{32}, \text{if it is lower;} \\ a_{33}, \text{if it is larger.} \end{cases} \end{aligned}$$

In this case, the set of values  $k(t)$  is matched by matrix  $\|a_{ki}\|$ , where  $k=1, 2, 3; i=1, 2, 3$ , that is, at each point  $k_i$  the value of  $k(t)$  or the state of the estimated object is determined by a three  $\{a_{1,i}; a_{2,i}; a_{3,i}\}$ . In the considered example,  $i=1, 2, \dots, 12$ . We shall analyze a range of change for the magnitude, which corresponds to the nominal or estimated projected state of the object,  $K_i=K_{nom}$ . Then we accept for system  $K_{nom}=\{a_{11}; a_{21}; a_{31}\}$  that  $\{a_{11}; a_{21}; a_{31}\}=1$ . Similarly, we can define  $\epsilon_k$  – a differentiating threshold,  $N_k$  is the number of different values of  $k(t)$ , and assign  $D_k$  – a range of change in  $K(t)$ , for example, from 0 % to 100 %.

A transition from the “informal” description of such a complex object as the road environment to the “formal” description makes it possible to quantitatively analyze, and thereby algorithmize the considered estimation system of road condition. Any extended object characterizes a significantly greater number of parameters than it seems possible to measure. On the other hand, there is a constant measurement error of the controlled parameters, caused by physical difference between the estimated objects or elements. We shall combine measurement errors in the estimation of state of an object with the impact of uncontrolled parameters, assigning them to errors that occur during control of the parameters that are subject to measurement and subsequent registration. The problem on estimating a condition of the road corresponds to determining certain variable  $x(t)$  by the estimated value of  $y(t)$ . This is the task of indirect measurements employing an algorithm of minimizing the sum of squares of errors, corresponding to a mismatch between actual and estimated state of the examined object. We shall record

$$y(t) = f(a_1, a_2, \dots, a_k; b_1, b_2, \dots, b_r), \tag{17}$$

where  $a_1$  are the values of the measured parameters;  $b_1$  are measurement errors and deviations caused by the unaccounted parameters.

Let  $l=r$ ; then, if we accept  $\forall i: b_i=0, y(t)=x(t)$ , we shall obtain

$$y(t) = x(t) + \sum_{i=1}^r \partial x(t) / \partial a_i \cdot b_i, \quad (18)$$

where  $\partial x(t) / \partial a_i$  is the value of a partial derivative of function  $x(t)$  for parameter  $a_i$ .

Given this, the error of evaluating  $d_j$  at a point of time of measuring the parameters of  $a_i$  in the range  $[t_0, t_1]$  is equal to the following relation

$$d_j = \sum_{i=1}^r \partial x(t) / \partial a_i \cdot b_i, \quad t = t_j, \quad i = \bar{1}; \bar{n}, \quad (19)$$

where  $n$  is the number of measurements.

Solution to system (19) implies determining the errors of  $b_i$ , and, therefore, actual values of parameters  $a_i = a_i \pm b_i$ .

This algorithm is of a generalized character. It can be utilized both for determining the values of parameters that are not directly subject to measurement and for solving the tasks on control over a measuring process, over the work of equipment in the road laboratory. In the first case,  $a_i = a_i \pm b_i$  is the desired value of the estimated parameter, in the second – corrections that need to be taken into consideration during measuring. Because these tasks are solved under conditions of a relatively limited resource, then, instead of calculating using the least squares method, we recommend an iterative procedure whose implementation implies substituting value

$$b_i = \vartheta \alpha_j / W_{ij} | t = t_k$$

in expression (19).  $\vartheta$  is the coefficient that takes into consideration mutual influence of parameters;  $t_k$  is the moment of control or measurement, for which

$$t_j = t_k | W_{ij} | = \max | W_{ij} |;$$

$$W_{ij} = \frac{\partial x(t)}{\partial a_i}$$

are the values of function of weight  $a_i$  at the moment of measuring  $y(t)$ .

A separate case of the considered algorithm is the algorithm for the registration of values of one parameter  $\{z_i\}$  for  $i = \bar{1}, \bar{N}_z$ .

In order to minimize the number of stored values, that is, the memory of the counter, we shall apply the principle of control by deviation. In this case, only that parameter value will be registered, which is different from the preceding one by the magnitude of differentiating threshold  $\varepsilon_z$ .

The solution in this case will consist of the following steps:

- 1) measuring  $z_i$ ;
- 2) comparing  $z_i$  and  $z_{i-1}$ ;
- 3) if  $abs(z_i - z_{i-1}) > \varepsilon_z$ , then proceed to step 6, otherwise, step 4;
- 4)  $z_i - z_{i-1}$ ;
- 5) proceed to step 7;
- 6) registration (enter value of  $z_i$  and value  $t_j$  that corresponds to the measuring moment to the database);  $i = i + 1$ ;
- 7) if  $i \leq N_z$ , proceed to step 1, otherwise, complete the procedure.

Steps 1–7 represent a generalized procedure for the preparation of data on road monitoring. It should be noted that this very procedure, in accordance with previous relations (17)–(19), is the basis of an interactive system for the road condition estimation. We shall consider this using the identification of geometrical elements of the road (plan, longitudinal profile) as an example. Physically, geometrical elements of the route are a sequence of direct inserts and curves. When assessing geometrical elements of a road, as well as dimensions, direct insertions require certain parameters, the curves require different ones. Thus, given a plan of the route, it is required, for a direct insertion, to measure its length, for the curve, radius, angle, tangent, bisector, difference in length. That is why one of the first tasks when processing these data is determining the character of the road section, whether is it along a straight insertion or a curve.

We shall introduce the following notation system:  $\alpha$  is the measured azimuth of the estimated road section;  $\alpha_1$  is the measured azimuth of the preceding road section;  $g_1$  is the attribute that characterizes the estimated area in the following way:

$$g_1 = \begin{cases} +1, & \text{if } \beta > \xi, \\ -1, & \text{if } \beta < -\xi, \\ 0, & \text{if } |\beta| < \xi, \end{cases} \quad g_1 = \begin{cases} +1, & \text{if } \beta > \zeta, \\ -1, & \text{if } \beta < \zeta, \\ 0, & \text{if } |\beta| < \zeta, \end{cases} \quad (20)$$

where  $\beta = \alpha - \alpha_1$ ;  $\xi$  is the accuracy (differentiation) of measuring the azimuth.

Expression (20) is matched with graphical description, in which  $g_2$  is the attribute that characterizes the preceding section. The relation of  $g_2, g_1$  values is unambiguously determined by set  $S$  of (eleven) different situations  $s_i$  registered during motion of a vehicle:  $S = \{s_i\}, i = \bar{1}, 11$ .

The set of situations  $S$  is kind of the linguistic variable with the following terms:

- 1) turn to the left (L);
- 2) turn to the right (R);
- 3) direct insertion (I);
- 4) start of turn to the right (TR);
- 5) start of turn to the left (TL);
- 6) end of turn to the right (ER);
- 7) end of turn to the left (EL);
- 8) start of insertion (SI);
- 9) end of insertion (EI);
- 10) start of section (SS);
- 11) end of section (ES).

Thus, according to (20), the estimate of a road section either corresponds to the situation registered by the human {L, R, I, TR, TL, ER, EL, SI, EI, SS, ES} or is clearly determined by three measured values for azimuth  $J_j$

$$S = \begin{cases} S = f(J_j, J_{j-1}, J_{j-2}), \\ \alpha = J_j, \alpha_1 = J_{j-1} \text{ (section } j), \\ \alpha = J_{j-1}, \alpha_1 = J_{j-2} \text{ (section } j-1). \end{cases} \quad (21)$$

Accuracy of  $\xi$  is determined by dimensions of the basic section. In a particular case, this is a section of the road of length 100 m (picket). The minimum size of a basic section is the distance between two performed measurements  $j, j-1$  for the examined examples of conducting measurements using a road laboratory, this is the distance over which a wheel of a basic car rotates  $n$  times.



It is difficult to record analytically a functional dependence  $f$  in the form of typical arithmetic-algebraic relations. That is why we shall give  $f$  in a tabular form as a solution to the problem on the identification of road  $j$  sections and the situation – results of estimating  $S$ . We shall define in line with ratios (17)–(21) a procedure for interactive identification. It is easy to notice that determining the term, or rather its number  $N$ , is performed in the following fashion:  $N=Q_1+Q_2$  where

$$Q_1 = \begin{cases} 1, & \text{if } g_2 = 1; \\ 2, & \text{if } g_2 = -1; \\ 3, & \text{if } g_2 = 0; \end{cases} \quad Q_2 = \begin{cases} 0, & \text{if } g_2 = 1; \\ 3, & \text{if } g_2 = -1; \\ 6, & \text{if } g_2 = 0. \end{cases} \quad (22)$$

The use of computation (22) greatly simplifies the procedure of identification  $\{s_j\}$ , which is matched by the system of data identification given in Table 1, and which together with analytical relations (20), (21) is the analytic representation of the road plan.

In order to define a set of parameters that make it possible to estimate a road, a mechanism for diagnosis is required. The analogue of such a mechanism is an artificial neural network. Known diagnostic neural networks typically implement the ideas of the theory of classification; in this case, the presence of a training sample is assumed, that is, the emergence of the states unforeseen by a “trainer” can be left unrecognized by the network. However, neural networks are capable of tuning both under training mode and under self-learning mode. It is of great importance for solving the problems on monitoring in transportation systems. It is the application of the methodology of neural networks for monitoring that allows us to define it as an intelligent and, accordingly, interactive monitoring.

The difference of neural networks is that they have the capability to learn based on a set of examples, to remember, to form associations, to reconstruct and reproduce data and knowledge, they are resistant to failures and obstacles and are highly reliable. From an engineering perspective, artificial neural networks are the parallelly distributed information processing systems, created by simple computing nodes that have the capacity to accumulate experimental knowledge. The apparatus of representation of such knowledge for users is given in a form that is convenient for interpreting and making appropriate decisions.

Table 1

Notation system of identification procedure					
Name	Notation in text	Essence	Value		Note
			min	max	
$T$	$\xi$	Accuracy of the measured dimensions of geometrical elements	0.1	1	–
$Q_1$	$G_1$	Attribute characterizes the estimated road section	–	–	$g_1$ assumes three possible values –1, or 0, or +1
$Q_2$	$G_1$	The same for the preceding section	–	–	–
$A$	$A$	Azimuth of the section	0	360	–
$A_1$	$a_1$	Azimuth of the preceding section	0	360	–
$B$	$B$	Difference of azimuths of two adjacent sections	0	120	–

A distinctive feature of these formations is the training procedure  $T$ . It is the sequence of the following steps or algorithm  $T$ :

- 1) calculation of the result;
- 2) comparison with the exact value;
- 3) measurement of weight;
- 4) assessment of conversion results until reaching the required level of accuracy, otherwise, repeat steps 1–3.

Formally, procedure  $T$  is performed for system

$$\left. \begin{aligned} x_i &\rightarrow x(t), \\ w_i &\rightarrow w(t) = T[y(t), t], \\ f &\rightarrow f(t) = A[x(t), t], \\ c &\rightarrow c(t) = C[f(t), t], \\ y &\rightarrow y(t) = Y[c(t), t], \end{aligned} \right\} \quad (23)$$

where  $x_i$  is the input signal  $i=1, 2, \dots, n$ ;  $w_i$  is the weight for input  $i$ ;  $y$  is the output signal of the artificial neuron;  $f$  is the result of activation, analysis of input with respect to weight;  $c$  is the estimation of activation function to represent the result.

Fig. 2 shows a schematic representation of elementary components (artificial neurons) of the respective artificial neural networks.

As far as the construction of ANN is concerned, it will typically be a multilayered one, which is demonstrated by Fig. 3.

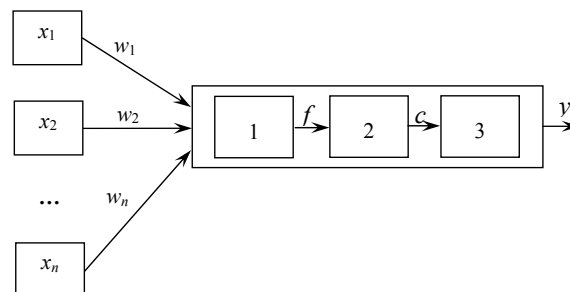


Fig. 2. Artificial neuron (AN): 1 – input operator; 2 – activation function; 3 – output operator

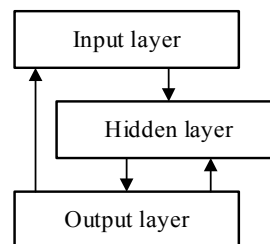


Fig. 3. Artificial neural network (three-stage)

The represented simplified description of the diagnostic neural network is a partial case of the more general mapping of intelligent monitoring in the form of a neural meta-network, in which there is interaction both between the layers of separate neurons and between respective diagnostic neural networks.

It should be noted that here we consider a diagnostic neural network as an instrumental means for monitoring a condition of the road. If we consider the information-logical model (ILM) of a road and match each parameter of the

estimation of the state of a transportation system to ANN, then we shall obtain a fully connected network according to the graphical scheme of its description (Fig. 4).

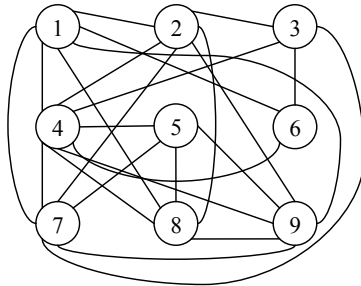


Fig. 4. Graphical interpretation of the links between ILM elements of road condition

All components of this graphical scheme  $m_i$  (nodes 1–9) are interconnected similar to the Hopfield network. It is a kind of analogue of links between elements of ILM (Table 2). The conclusion of the assessment of complexity of links between each element indicates that the greatest influence on making decisions about road maintenance is exerted by such indicators as: geometry, speed, evenness, and adhesive properties. One can confirm that the similar conclusion follows from analytical analysis  $D_i$  of the information logical model (ILM) of interrelation between these parameters  $\{d_i\}$

$$D_i = \sum_j b_{ij}, \tag{24}$$

where  $b_{ij}=\{1, 0\}$ , 1 are the linked parameters; 0 are the non-linked parameters.

Table 2

ILM for estimating transportation-operational road properties

Parameters/ $i/j$	1	2	3	4	5	6	7	8	9	$D_{ij}$
Safety (1)	0	1	1	1	0	1	1	1	1	7
Reliability (2)	1	0	1	1	1	1	1	1	1	7
Visibility (3)	1	0	0	1	0	0	1	0	0	3
Speed (4)	1	1	1	0	1	1	1	1	1	8
Cost, expenditures (5)	1	0	0	1	0	0	1	1	1	5
Throughput capacity (6)	1	0	1	1	0	0	1	1	1	6
Geometry (7)	1	1	1	1	1	1	0	1	0	7
Evenness (8)	1	1	0	1	1	1	1	0	1	7
Adhesion (9)	1	1	0	1	1	1	1	1	0	7

The presented estimates correspond to Table. 2, which quantitatively characterizes relationship between basic parameters of the examined system. Based on this estimation, it is necessary to determine the measurement of the following primary parameters: geometry of the road, evenness, adhesive properties, actual speed of the respective vehicle or a traffic flow.

In general, each parameter of the quality estimation of a road is matched with a component (node 1–9) of such a specialized ANN. Each node is a recurrent diagnostic neural network. It can be argued that such an interpretation of ILM is the intelligent model of interactive monitoring of

the road. ANN is a rather effective apparatus for the simulation of complex processes. It has universal approximating properties that makes its application appropriate to solve the tasks on monitoring, diagnosing, forecasting. The advantage of such ANN is the capability of learning, during which synaptic weights of the network are configured using one or another adaptive algorithm.

Underlying the ANN designed for the interactive monitoring of roads is not a specific implementation of this application, but the approach, a methodology for applying key provisions in order to construct a diagnostic ANN to identify the state of technical systems. An actual implementation of this ANN is the architecture, such components as a learning procedure, functions of neuron activations, were obtained based on intuitive choice, as it is commonly accepted in a number of practical studies into application of ANN in technical systems. Based on the mechanism of adaptation and self-learning, it automatically takes into consideration permanent changes in the environment of vehicle motion. It indirectly assesses initial characteristics of the road surface, summarizes the obtained information. It draws attention of the researcher to deviations in the values of standard indicators. Figure 5 shows a respective generalized architecture.

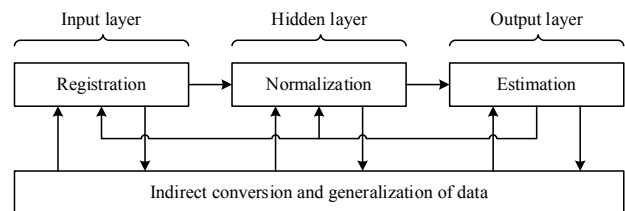


Fig. 5. Generalized ANN architecture

The respective ANN architecture comprises three functional layers: registration (the input layer); normalization (the hidden layer) and estimation of generalization (the output layer). This scheme is matched with a sequence of structural components or measuring activities, registration, analysis and processing of initial data:

- 1) registration – retrieval of values for data from the sensor input of system;
- 2) normalization of the retrieved data – reducing them to the required logical system of reference;
- 3) determining primary characteristics of the road;
- 4) generalization of data, formation of the logical conclusion on reliability of the registered primary data;
- 5) estimation of operational condition.

The architecture of such ANN can be represented in the form of block diagram shown in Fig. 6.

The procedure for converting data (Fig. 6) implies the existence of a link, which operates in a training mode: calibration – correction – change of values of weight coefficients of sensor input and the procedures of normalization of the calculation of primary data. Nodes of ANN are separate neurons that register data (B1–B4), estimate primary characteristics (P1–P4), indirectly evaluate and generalize data (O1–O3, Y). The conversion is ensured by feedbacks from the sensor input, logic output to each artificial neuron of this network.

The data processing sequence corresponds to the functional diagram shown in Fig. 7.

A procedure of operator transformation implies obtaining results of the normalization  $x_j(t)$ , the calculation of separate parameters  $y_i(t)$  and the generalized estimation  $q(t)$

$$\begin{aligned}
 q(t) &= Q [y_i(t), S], \\
 y_i(t) &= Y [x_j(t), S], \\
 x_j(t) &= X [a_k(t), S],
 \end{aligned}
 \tag{25}$$

where  $q(t)$  is the generalized characteristic of the road;  $y_i(t)$  is the estimated parameter of the motion environment;  $x_j(t)$  are the normalized characteristics of data registration.

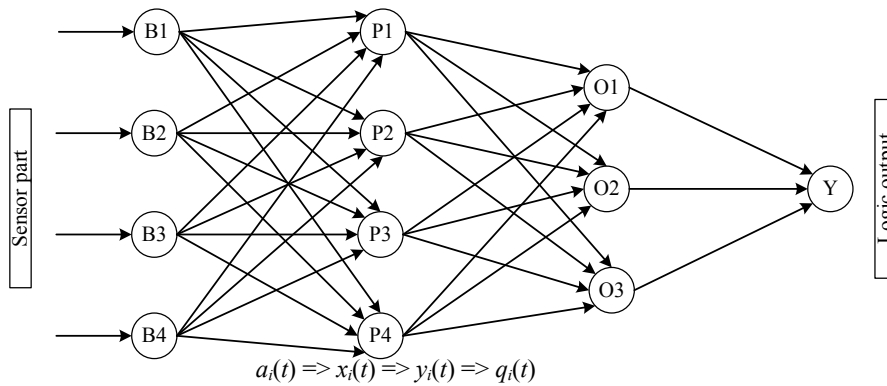


Fig. 6. ANN block diagram

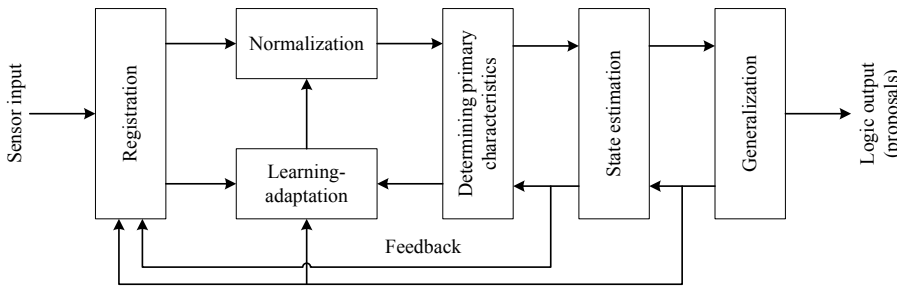


Fig. 7. Sequence of ANN data conversion

This system is a kind of interactive road tester (IRT). It makes it possible to assess evenness, road adhesive properties, motion speed of the observer along the road. To assign the values of the registered and estimated indicators to road coordinates, IRT employs data from a GPS receiver. IRT consists of the measuring part and data registration system and enables keeping of an electronic archive as well as the possibility to transmit data to a traffic situational center.

A separate solution is to create a unified chain – from an individual car to the transportation situational center. Equipping automobiles with the proposed ANN, which can work autonomously, will make it possible to implement the idea of an original automotive matrix. The vehicles equipped with such ANN may serve a permanent source of information about condition of automobile roads. Such an information-communication technology (ICT) for the road monitoring is based on a two-level automotive information-communication system, which comprises an information-communication center, built-in into a car, and a road portal in the information environment of the Internet. Thus, we obtain an intelligent transportation system – ITS.

Intelligent transportation system (ITS) is an intelligent system that utilizes innovative developments in the modelling of transportation systems and regulation of traffic flows. This provides end users with enhanced informative-

ness and safety, as well as qualitatively improves the level of interaction among road traffic participants compared to conventional transportation systems.

Despite the fact that ITS may comprise all kinds of transport, the European definition of ITS in accordance with the EU directive 2010/40/EU dated 7 July 2010 denotes ITS as a system that employs informational and communication technologies in the field of automobile transport. ITS includes infrastructure, vehicles, participants of the system, as well as road and transportation regulation; along with this – a possibility to interact with other kinds of transport.

### 7. Discussion of results of studying the virtualization of management

The main result is the identification of synergistic mechanism for obtaining unlimited computer resource by the participants of transportation process. The interaction among all links of both cargo and passengers transfer is based on the development of ANN. Equipping automobiles with the proposed ANN can implement the idea of an original automotive matrix. The cars equipped with such ANN can serve a permanent source of information about state of routes of the relevant transfer. The basic information-communication technology for the monitoring of such a system will be based on a two-level intelligent ACS that comprises an information-communication center, which is built-in into the car and a road portal in the informational environment of the Internet.

The mechanism for obtaining additional computer resource that is almost not limited by capital costs required for creating such an intelligent ACS implies the use of cloud computing for the virtual management of transportation processes. The proposed ANN is an instrumental tool for the continuous monitoring of each carrier based on the state of the chosen route.

The scientific result of the virtualization of management of transportation processes is the confirmation of possibility of a significant increase in the level of interaction between all persons involved in the transfer, and in the combination of their computer resources compared with conventional heterogeneous transportation systems. Thus, virtual management becomes a means for resolving an existing contradiction between rapid development of means and methods of the informatization of complex objects and systems and a heterogeneous character of the transportation market.

The practical result is bringing down the cost of transfer through the use of existing tools of ACS, their new application based on the client-server technology of a transportation process. The application of ANN is proposed as an original interactive road tester that measures acceleration,

motion speed, its direction, solves the problem of continuous monitoring of the route chosen by a carrier. ACS of client-server technology of the transportation process becomes a unified instrumental means of decision-making by both a separate carrier and by all participants of road traffic, by road and transportation enterprises.

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## 8. Conclusions

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1. Synergetics of informational development of the market of transportation services involves bringing together available computer resources of transportation and traffic organizations, all participants of the new transfer, on the basis of client-server technology. Such a technology enables interactive monitoring of all components of the transportation process and represents a two-level intelligent, smart transportation system of the carrier that comprises an information-communication center, which is built into a vehicle of the rolling stock of a carrier, and a road transport portal in the information environment of cloud computing. A special feature of such a synergistic approach to the informational development of a transportation services market will be zero

capital investment for their implementation and introduction to the transportation and traffic organizations.

2. A distinctive feature of the new transfer of customers of transportation and traffic organizations is the virtual management of both the transportation process, routing of the motion of vehicles, and of improvement of the level of joint interactivity among all the participants of the new transfer. A transition from the existing level of interaction 1:1 for the scheme customer-carrier or the more convenient 1:m for the scheme customer-freight forwarder-carrier must meet the conditions of using cloud computing m:m interactive monitoring over all components of the transportation process.

3. Improving the efficiency of virtual management at all levels of the system of development of the market of transportation services is based on the creation of a specialized artificial neural network (ANN) using fuzzy logic. Equipping the rolling stock with the proposed ANN can implement the idea of an original transportation information matrix. Transportation information matrix will be a permanent source of information about the state of routes of the respective transfer of both cargo and passengers compared to conventional transportation processes.

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