АВТОМОБІЛЬНИЙ ТРАНСПОРТ

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Technology for Controlling the Serviceable Condition of Vehicles in Operation

The existing model of technical exploitation of cars in Ukraine is analyzed. It is proved that the transition to an “adaptive” system of vehicle maintenance and repair allows using of built-in on-board diagnostics, existing satellite navigation and mobile communication systems, and modern information technologies for remote assessment of their performance. It is shown that the use of the *Torque* software module is the first step towards the *FRACAS* system and, accordingly, *IPR/CALS/PLM* technologies. An experimental verification of the proposed technology was carried out and the results of assessing the performance of a C-segment passenger car in operation were obtained.
car, serviceable condition, technical operation of cars, adaptive maintenance and repair system, operating conditions, method, mathematical model, monitoring

Problem statement. Automobile transport (AT) is the most important sector of the Ukrainian economy, which serves almost all sectors of the economy and segments of the population, contributes to the growth of mobility and quality of life.

Currently, the Ukrainian vehicle fleet includes more than 14 million vehicles, the structure of which is as follows [1, 2]: trucks - 15.5%, buses - 2.6%, cars - 81.9%.

Technical exploitation of automobiles (TEA), as defined by [3], is one of the most important ATs, which is a set of organizational and technical measures to ensure the maintenance of automobile performance.

The existing system of maintenance and repair (M&R) was formed on the basis of a simplified model of transport infrastructure functioning: the car mainly operated with reference to its own enterprise. At the same time, the entire service and repair base was concentrated within a particular road transport enterprise (PJSC) and all types of technical interventions were carried out by it. The existing system of MRO is inflexible in terms of ensuring the trouble-free operation of the vehicle during operation, which is manifested in the uniformity of the approach to vehicles of different ages: the list of operations and the frequency of MRO are identical for a new vehicle and for a vehicle before its refurbishment and write-off. Such a system of vehicle maintenance and repair provides for average mileage rates and labor intensity of their technical impacts and allows for the application of a number of adjustment factors for a particular vehicle, which leads to a significant increase in costs to maintain their performance.

The gradual development of new types of transportation led to an increase in the time spent by vehicles away from the main production base, and, as a result, the role of preventive maintenance of vehicles increased. Therefore, the creation of a flexible “adaptive” system for monitoring and managing the technical condition of a vehicle with elements of an individual approach to each specific vehicle has become a priority [4].

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Due to the use of built-in on-board diagnostics in cars, the development of satellite navigation and mobile communication systems, and modern information technologies, it is now possible to carry out remote monitoring and assess the level of vehicle performance. This, in turn, makes it possible to move to an “adaptive” system of vehicle maintenance and repair, the key point of which is the development of information and communication technologies and relevant information software systems (ISC) that provide remote receipt of the necessary current information from vehicles, its processing and development of corrective actions during maintenance and repair through monitoring.

An adaptive vehicle maintenance and repair system is a system that can adapt to changes in internal and external conditions by changing its structure and parameter values. The level reached by modern technical diagnostics (TD) allows for the implementation of almost any task to detect and predict the technical condition of vehicles during TEA. For example, the adaptive system proposed in [5] provides for the need to carry out maintenance and repair according to an individual program. Such maintenance and repair is conventionally called individual maintenance (IM). The type of work in this case is assigned based on individual diagnostic data.

The purpose of the article is to improve the technology for assessing the serviceability of vehicles in operation.

Analysis of recent research and publications. The emergence of “systems with full responsibility” in transport, for example, in aviation, such as FADEC (Full Authority Digital Electronic Control system) [6], allows to neutralize the existing difficulties. The FADEC concept is aimed at creating a unified structure of on-board systems for controlling the work processes of units and assemblies, monitoring and diagnostic systems, systems for organizational and functional support of vehicle operation processes, which allows the formation of information systems for organizational and functional support (collection, analysis and management of information flows) of operation processes, that is, allows the implementation of IPR/CALS/PLM technologies in practice.

IPM / CALS / PLM technologies, i.e., information support for the supply and life cycle (LC) of products, is a modern approach to the design, manufacture and operation of high-tech and high-tech products, which consists in the use of modern information technologies at all stages of the LC of products [6]. In the field of public road transport companies (PTCs), the integrated information environment of IPR / CALS / PDM technologies is only being implemented. An example is the Torque software module as the basis of the “automotive” FADEC concept, which is the first step towards the FRACAS system and, accordingly, IPE / CALS / PLM technologies, which are designed to receive and display diagnostic information of the onboard self-diagnostic system. Today, it already “knows” how to display the current operating parameters of the engine, other systems, components and assemblies, display and decode “error codes”, “erase errors” from the electronic control unit (ECU), automatically send the values of the parameters controlled by the sensor to the integrated electronic information meta-space, where within six months you can see not only the current values of the controlled values at different times, but also see the entire route of cars during this period on the map [6].

No less important for IPE / CALS / PLM technologies at AT are such simple (in terms of the tasks performed at AT) electronic information systems as GPS-Trace Orange, M2M, CCWT, Teletrack, Dynafleet® [6].

Statement of the problem. To achieve the goal, it is necessary:

- to employ a systemic interaction “driver – vehicle – road environment (DVR), which includes the following monitoring components: the vehicle (including driver and the onboard information complex, OIC); the operating conditions of the vehicle (road, traffic, atmospheric–climatic conditions and work culture), the transport infrastructure, and the infrastructure of highways;

- to form a unified information model that describes the vehicle's interaction in terms of parameters of its technical state obtained via the OIC; and the driver, linked to the process of transforming information about technical-state parameters and to processes depending on the driver's physiological capacities, the technical data of the vehicle, and the degree of their resistance to negative influences from the external environment; and the vehicle's operating conditions;
- by means of morphological analysis to distinguish the features of the monitoring information system for different vehicles under operating conditions;
- to perform an experimental verification and obtain results regarding the operation of the authors' proposed information–software complexes for assessing the functional state of the vehicle under operational conditions.

Summary of the main material. The use of cars in non-stationary operating conditions requires constant monitoring of their actual condition, carrying out the necessary technical maintenance actions to ensure proper working condition. Such an interpretation of the conditions of use of cars is possible only through monitoring of their technical condition, which is based on the processing of a priori information, continuous diagnosis and forecasting of the parameters of their technical condition. In this regard, there is a problem of ensuring a full-fledged connection between the processes of car operation and the parameters of operating conditions [7], as well as generalization and improvement of methods for predicting their technical condition [8]. Most of the tasks in the process of forming a method for assessing vehicle performance, which are solved by technical services of vehicle operation, have an information component of assessment: road conditions of vehicle operation, longitudinal profile (terrain), type and condition of road surface; repair, construction and maintenance of road infrastructure facilities; their monitoring; predicting possible emergencies, transport conditions in terms of traffic saturation and intensity, cargo characteristics, traffic mode and speed; atmospheric and climatic conditions, fuel consumption, vehicle operation culture, etc. [6].

The formation of a model for assessing technical condition parameters is based on a general approach to the study of the classical "driver-vehicle-road environment" (DVRE) system, which includes the systematic interaction of the monitoring components: a car with a driver and an onboard information complex (OIC); vehicle operating conditions (road, transport, atmospheric and climatic conditions and work culture) [3]; transport infrastructure and road infrastructure (Fig. 1).

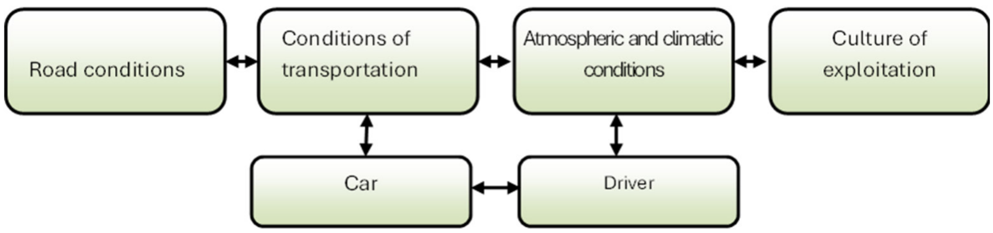
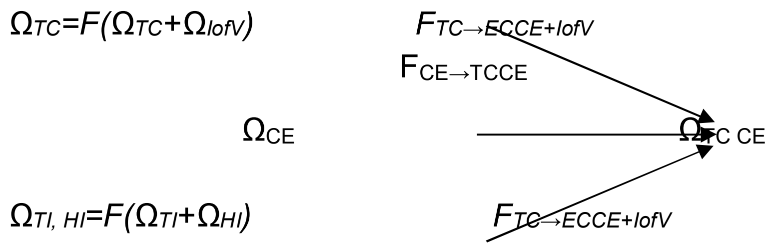


Figure 1 - General scheme of system interaction of the DVRE system in the context of ITS
Source: compiled by the authors

The process of controlling the technical condition of a car under operating conditions is the process of forming a single information function that describes the interaction of a car in the form of parameters of the technical condition of the car obtained using BINC; the driver, which is associated with the process of transforming information about the parameters of the technical condition and processes that depend on the physiological capabilities of the driver, the technical data of the car and the degree of their counteraction to negative environmental influences; vehicle exploitation conditions [7, 14] and the interaction of models of transport infrastructure and road infrastructure parameters. Formally, this mapping has the form [9, 10]:



(1)

where Ω_V is a set of models of vehicle technical condition parameters, as $\Omega_V = F\ (\Omega_V + \Omega_{DV})$ system interaction of vehicle and driver technical condition parameters, which in turn is associated with the process of transforming information about vehicle technical condition parameters and processes that depend on human physiological capabilities, vehicle technical data and the degree of their resistance to negative environmental influences; Ω_{DV} is a set of models of the car driver's state; Ω_{CE} is a set of models of the parameters of the car operating conditions; $\Omega_{TI,\ HI} = F\ (\Omega_{TI} + \Omega_{HI})$ is a set of models of the parameters of the transport infrastructure and road infrastructure; $\Omega_{TC\ CE}$ is a set of models of the parameters of the technical condition of the car under the relevant operating conditions; $F_{TC \to TCCE+DV}$ - functional display of models of parameters of the technical condition of the vehicle and its driver; $F_{V \to VCE}$ - functional display of models of parameters of the technical condition of the vehicle; $F_{TI,\ HI \to TI+HI}$ - functional display of models of parameters of transport infrastructure and road infrastructure.

We consider it expedient to combine into the set of models of Ω_{TC} parameters of the technical condition of the vehicle under operating conditions exactly Ω_{TC} in interaction with Ω_{DV}. In this case, we proceed from the fact that the functioning of a single system of car and driver $F\ (\Omega_{TC} + \Omega_{DV})$ changes under operating conditions in the form of technical and economic indicators of the car. At the same time, we understand that the system adapts to different operating conditions by changing its operational properties [7]. Also, we consider it expedient to combine all environmental influences on the car in the form of changes in the models of operating conditions, models of parameters of transport infrastructure and road infrastructure in the form of a set of models Ω_{CE} of parameters of car operating conditions. Based on the foregoing, in a general unified form, the process of monitoring the technical condition of a car under operating conditions is a process of transforming information about the state and processes of the car's functioning and operating conditions. In the process of analysis and synthesis, formation of possible variants of schemes of the information system for monitoring cars in operation in terms of ensuring the following: identification of the car, collection of data on the technical condition of the car, monitoring and forecasting the parameters of its technical condition, identification of the conditions of its operation, diagnosis of its condition, verification of compliance with its condition, morphological analysis was used [9, 10].

The peculiarity of this analysis is that in the experimental system of DVRE, to form the basic morphological formula of the information system for monitoring a car in operation, several characteristic features of functional elements (morphological features) were identified, for each of which the most complete list of various relevant technical expressions of the above features was previously compiled [3]. For each morphological feature, the characteristic properties of classifications, vehicle design features, monitoring system components, operating conditions, etc. are given, on which the solution of the research problem and the achievement of the main goal of the functioning of the DVRE system in operating conditions depend.

In the morphological matrix of the schemes of the information system for monitoring a car in operation, 12 features are allocated for the functional element “Car (V)”, with 4 additional features for the classification element “passenger car”, 1 for the classification element “bus”; 2 features for the classification element “truck”. For the functional element “Vehicle engine (V)” 4 features are allocated. For the functional element “Equipping the vehicle with information and communication equipment” - 3 features. For the functional element “External networks” - 1 feature in 4 variants. For the functional element “Monitoring of vehicle condition and exploitation conditions”, 3 features are also identified. For each of the 23 morphological features of the system, the main variants of their implementation (from 2 to 10) were selected. Changing the constructive expression of a particular variant of any of the 23 features forms a new scheme for providing an information system for monitoring vehicles in exploitation conditions.

In accordance with the provisions of [9], the research method is based on the morphology of the component objects of the monitoring system and allows systematic analysis of various structures of the object - the monitoring system, which follow from the regularities of their structure.

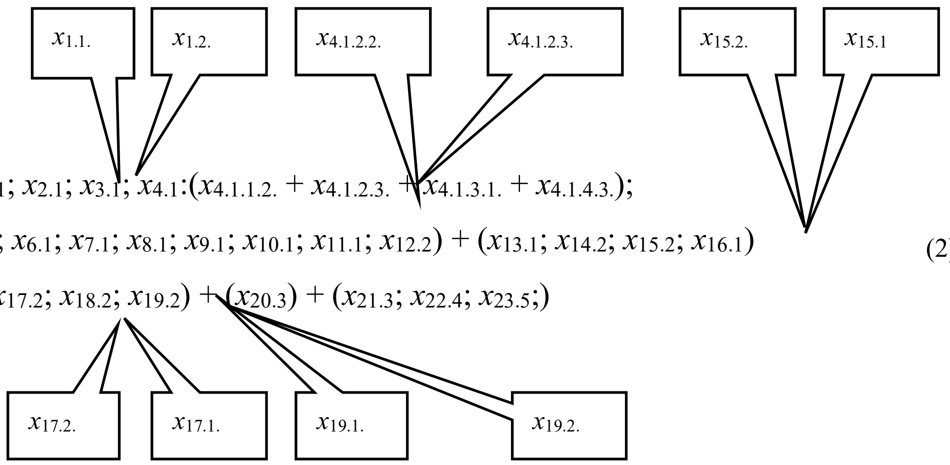
The number of possible schemes of the information system for monitoring a vehicle under exploitation conditions in the case of using the created morphological matrix is:

- *for a passenger car:* $\boldsymbol{N} = 8 \cdot 4 \cdot 7 \cdot 9 \cdot 4 \cdot 3 \cdot 6 \cdot 4 \cdot 10 \cdot 3 \cdot 4 \cdot 4 \cdot 4 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 4 \cdot 4 \cdot 4 \cdot 6 = 4{,}749 \cdot 10^{13}$;

- *for a bus:* $\boldsymbol{N} = 8 \cdot 4 \cdot 7 \cdot 5 \cdot 4 \cdot 10 \cdot 3 \cdot 4 \cdot 4 \cdot 4 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 4 \cdot 4 \cdot 4 \cdot 6 = 1{,}691 \cdot 10^{12}$;

- *for a truck):* $\boldsymbol{N} = 8 \cdot 4 \cdot 7 \cdot 10 \cdot 7 \cdot 4 \cdot 10 \cdot 3 \cdot 4 \cdot 4 \cdot 4 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 4 \cdot 4 \cdot 4 \cdot 6 = 2{,}368 \cdot 10^{13}$, and for one variant of the vehicle when using the morphological matrix in terms of its equipment with information and communication equipment, external networks, monitoring its condition and exploitation conditions: $N_I = 768$. For a similar variant with the additional use of the morphological matrix in the part of the vehicle engine: $N_{II} = 12288$.

Thus, the scheme of the monitoring information system for a passenger car of the C segment with a gasoline engine under exploitation conditions includes the following combinations of certain features:



$$(x_{1.1}; x_{2.1}; x_{3.1}; x_{4.1}{:}(x_{4.1.1.2.} + x_{4.1.2.3.} + x_{4.1.3.1.} + x_{4.1.4.3.}); x_{5.4}; x_{6.1}; x_{7.1}; x_{8.1}; x_{9.1}; x_{10.1}; x_{11.1}; x_{12.2}) + (x_{13.1}; x_{14.2}; x_{15.2}; x_{16.1}) + (x_{17.2}; x_{18.2}; x_{19.2}) + (x_{20.3}) + (x_{21.3}; x_{22.4}; x_{23.5};) \quad (2)$$

When formulating possible variants of the information system for monitoring vehicles in operation, the scheme is considered as an effective way to ensure their efficiency, which today form the basis of the existing fleet of cars, trucks and buses in Ukraine.

Modern on-board systems for monitoring technical condition parameters in *ITS* conditions allow for the identification of vehicles, continuous automatic measurement of parameters characterizing their technical condition, diagnostics, namely, monitoring the performance of vehicles and its components, recognizing and preventing the development of failures in its operation, and ultimately ensuring the functioning of an adaptive system of vehicle maintenance and repair according to technical condition [3]. The work of the developed *IPC IdenMonDiaOperCon* “HNADU-16””, regarding the state and exploitation conditions of cars includes a set of stationary and mobile (on-board systems for the car, vehicle) systems for collecting and transmitting information.

The basic principle of information exchange between *ITS* elements, namely the vehicle and the transport infrastructure, is that the vehicle is not only an object of control and management, but also a source of constantly updated information about the state of its exploitation conditions. That is, it is a modern control and measurement system that accumulates and stores information about the technical condition of the vehicle, the conditions of its exploitation within the traffic area, and also makes decisions in case of detection of a dangerous, emergency situation or malfunction.

The general task of forming a methodology for applying the classification of vehicle exploitation conditions in the information environment of *ITS*, as a complex system, is based on obtaining information about the actual technical condition, methods and means of its implementation in solving specific scientific and technical problems, evaluation, verification.

Providing a system of information on the exploitation conditions *(EC)* of the vehicle $S_{EC.\Sigma V_i}(t)_i$ built on the basis of server solutions $S_{EOV_i}(t)_i$ according to the principles of [4, 12], a local source of information $S_{ECVd_i}(t)_i$ and network databases $S_{EC.Net_i}(t)_i$:

$$S_{EC\Sigma V_i}(t)_i = \left(S_{ECV_i}(t)_i, S_{ECVd_i}(t)_i, S_{ECNet_i}(t)_i\right). \quad (3)$$

This makes it possible to create a single centralized repository of information distributed in space, support a multi-user environment for obtaining information (editing), the ability to access remote users, systematize information and visualize it in a single complex. In the process of developing information support for the processes of monitoring the parameters of the technical condition of the vehicle, taking into account the operating conditions, the available sources of information were collected in terms of the vehicle's coordinates on the ground in real time, a model of the road, models of road infrastructure facilities, territorial natural and man-made systems, and the results of vehicle tracking. Sources of information to ensure the operation of the information system for monitoring the technical condition of a car are presented in [14].

In the process of studying and evaluating the conditions of vehicle exploitation, a geographic model of a highway in *Torque, Yandex.Maps* [8] was used, which was the basis of the analysis system and is a layer of linear objects with parameters of information interaction:

$$F_{ts}\left(RV_{Road}\right)_i = \left(Ident_{RV_i}, Cat_{RV_i}, Cod_{Dil_i}, Distanse_{Descr_i}, Type_{RVn_i}, Type_{Roadn_i}, Track_{V_i}\right),$$

where $F_{ts}(RV_{Road})_i$ - information is similar to the relevant parameters of the technical condition of the vehicle under the relevant operating conditions at the appropriate time for the road information system; $Ident_{RV_i}$ - identifier i of the vehicle's driving area; Cat_{RV_i} - category i of road; Cod_{Dil_i} - code of the road section, $\text{Distanse}_{Descr_i}$ - description of the road section, $Type_{RVn_i}$ - number of traffic lanes, $Type_{Roadn_i}$ - type of road surface, $Track_{V_i}$ - width of the traffic lane.

The information model of a car's position on a road was developed on the basis of a geographical model of the road. Each section of the model is described by the following vector of parameters:

$$F_{ts}\left(RV_{Traffic}\right)_i = \left(Ident_{RV_i}, Ident_{PRoute_i}\right), \tag{5}$$

where $Ident_{RV_i}$ – identifier of i the vehicle's driving area; $Ident_{PRoute_i}$ – identifier of sections of the vehicle's route.

The route sections of the information model of the car's position on the road are used to form the route. It represents a certain path of movement of the car, realized as a linear object and accompanied by the following vector of parameters:

$$F_{ts}(RV_{Marshrut})_i = \left(Ident_{RV_i}, Ident_{Route_i}\right), \tag{6}$$

where $Ident_{RV_i}$ – identifier i of the vehicle's driving area; $Ident_{Route_i}$ – dentifier of the vehicle's route.

The high-speed model of vehicle driving modes is a table of linear events superimposed on the driving route and has the following structure:

$$\begin{aligned} &F_{ts}\left(RV_{Route_{\text{Properties}}}\right)_i = \\ &= \left(Ident_{RV_i}, Ident_{Route_i}, Route_{Pr\,operty_i}, Ident_{SR_i},\right. \\ &Coordinate_{First_i}, Coordinate_{End_i}, Value_{V_i}, Date_i, Base_{Speed_i} \end{aligned} \tag{7}$$

where $Ident_{RV_i}$ - identifier i of the vehicle's driving area; $Ident_{Route_i}$ - identifier of the vehicle's route; $Route_{\text{Property}_i}$ - type of vehicle route; $Ident_{SR_i}$ - identifier of the section of the vehicle's high-speed mode; $Coordinate_{First_i}$ - the beginning of the high-speed section of the vehicle; $Coordinate_{End_i}$ - the end of the section of the high-speed mode of movement of the car; $Value_{V_i}$ - the established permissible speed of the vehicle; $Date_i$ - date of setting the vehicle speed; $Base_{Speed_i}$ - the established (base) speed on the vehicle's movement area.

Along with the road model, the information model can describe the coordinates of road infrastructure objects. With the help of the ISM map, it is possible to record the coordinates and features of the impact on vehicle traffic in the operation of bridges, crossings, traffic lights, etc. Also, the peculiarities of the exploitation conditions are influenced by the existing adjacent man-made objects or natural territorial systems. All of the above objects are typified by characteristics and contain a parameter for assessing the impact on the processes of vehicle movement and its exploitation conditions.

In the process of studying the operating conditions of a vehicle in interaction with the driver of the vehicle and the ISS, it is possible to solve the problems of road, transport and atmospheric and climatic conditions. At the same time, the condition of the road, road infrastructure facilities and adjacent territory is assessed.

The assessment of the type and condition of the road surface is carried out as a result of processing the data of the remote survey of the driver using the on-board OIC and then an assessment of the type and condition of the road surface during the operation of the vehicle is formed. The parameters that characterize road conditions, according to which the classification signs of limiting the permissible speed or closing the traffic of vehicles are: longitudinal profile of the road, altitude, width of the roadway and pavement condition, wheel adhesion, etc. The data on the types and magnitude of defects are compared with the standard indicators for vehicle speed, the degree of deviation is determined, and a score is formed for the state of road conditions (based on the condition of the road surface):

$$O_p(t)_i = \left(O_{p_1}, O_{p_2}, O_{p_3}\right), \quad (8)$$

where O_{p_1} - excellent and good condition, O_{p_2}- satisfactory condition, O_{p_3} - unsatisfactory condition.

To determine the value of the assessment in the *TPC* of the analyzed road surface section, a table of point events is formed, containing a point assessment of the state of road operating conditions for each detected defect, of the following form:

$$F_{ts}\left(Event_{Point}\right)_i = \left(Ident_{RV_i}, Date_i, Distans_i, Defect_i, Discribe_i\right), \quad (9)$$

where $Ident_{RV_i}$ - identifier i of the vehicle movement area; $Date_i$ - date of setting the speed of the vehicle; Distans_i - distance from the starting point of the route (linear coordinate); $Defect_i$ - point estimate of the defect; $Discribe_i$ - type of defect.

Combining the estimates of the pavement condition according to the detected defects is carried out for the sections of the high-speed model of vehicle traffic modes in accordance with the expression of the form:

$$O_{p_i}(t)_i = \max_{J=1.N} O_{p_{ij}}(t)_i, \quad (10)$$

where $O_{p_{ij}}(t)_i$ - is the score of the *j-th* defect on the *i-th* section of the model of vehicle speed regimes; *N* - the number of defects found on the site; *t* - time factor.

The condition of transport infrastructure facilities is assessed as a result of inspections and audits. This determines whether the detected defects affect traffic safety and whether special attention should be paid to the condition of these facilities. The assessment is carried out by drivers in the process of moving vehicles, other participants in vehicle monitoring and road users. The results of inspections and checks are entered into the database of measured parameters and ISM objects. Each transport infrastructure object is characterized by a vector of parameters:

$$F_{ts}\left(RV_{TransInfluence}\right)_i = \\ = \begin{pmatrix} Ident_{RV_i}, Type_i, Discribe_i, Objectid_i, \\ ObjectId_i, DateUpdate_i \end{pmatrix}, \quad (11)$$

where $Ident_{RV_i}$ - identifier i areas of vehicle movement; $Type_i$ - type of transport infrastructure object (transport crossings, transport constructions, roadside structures, etc.); $Discribe_i$ - description of the transport infrastructure object; $Objectid_i$ - identifier of the transport infrastructure object; $ObjectId_i$ - assessment of the condition (impact indicator) of the transport infrastructure object; $DateUpdate_i$ - date of assessment.

The assessment of the condition of transport infrastructure objects in accordance with regulatory documents is carried out according to a three-point system:

$$O_c(t)_i = \left(O_{c_1}, O_{c_2}, O_{c_3}\right), \quad (12)$$

where O_{c_1} - normal condition, O_{c_2} – needs attention, O_{c_3} - needs to be repaired.

A fragment of the map showing the possibility of identifying transport infrastructure facilities using *ISS* based on *ISM* and allowing to identify objects that have a direct impact is presented in [8]. Combining assessments of the state of transport infrastructure objects based on the results of impact is carried out by sections of the high-speed model of traffic modes in accordance with the expression:

$$O_{c_i}(t)_i = \max_{J=1.N} O_{c_{ij}}(t)_i, \quad (13)$$

were $O_{c_{ij}}(t)_i$ - is the score of the *j-th* object on the *i-th* section of the model of vehicle speed regimes, *N* - number of objects found on the site; *t* - time factor.

Assessment of the condition of the adjacent road territory is carried out as a result of the analysis of the level of danger of natural and man-made objects on the condition of the road surface and traffic, taking into account their distance from the road. The level of danger is assessed by drivers in the process of vehicle movement, other participants in monitoring vehicles and road users as a result of periodic inspections, and the impact assessment is formed on a three-point scale:

$$O_t(t)_i = \left(O_{t_1}, O_{t_2}, O_{t_3}\right), \quad (14)$$

where O_{t_1} - low impact, O_{t_2} – medium impact, O_{t_3} - high impact.

The third category is assigned to hazardous industries located near a highway that require repair or reconstruction work that is likely to cause emergencies on the road in the conditions of vehicle operation. These can also be natural emergencies (collapses, landslides, mudslides). The presence of such objects requires adjusting the speed limit on the road section.

The assessment of fuel consumption by cars under exploitation conditions is carried out on the basis of server solutions and a local source of information in the process of comparing with the linear norms of car fuel consumption established by regulatory indicators [3, 11], and is determined by the dependence:

$$Q = \frac{g_e}{36000 \cdot \rho_m \cdot \eta_m} \cdot \left(G \cdot \psi + \frac{\kappa \cdot F \cdot V^2}{13} + \frac{G}{g} \cdot \delta_j \cdot j \right) \quad (15)$$

where g_e – specific fuel consumption; . ρ_m – fuel density; η_m – mechanical efficiency of the transmission; *G* – Gross vehicle weight; ψ – coefficient of total road resistance; $k \cdot F$ – streamlining factor; *V* – speed of the vehicle; δ_j – a coefficient that takes into account the influence of the inertia of rotating parts of the vehicle; *j* – vehicle acceleration.

An approach to the application of the classification of vehicle exploitation conditions in the ITS information environment in the process of forming the general information support of the monitoring system for assessing the parameters of the vehicle's serviceable condition, built on the basis of server solutions, a local source of information (car, driver, etc.) and network databases, is proposed [12, 13]. This approach ensures the full collection and processing of information in real time from the BINC placed on the vehicle and from the information collection system working in conjunction with the driver and transport infrastructure based on the current state of road, transport, climatic exploitation conditions and technical constructions, in the processes of comparison with regulatory data and data of previous control; displaying the situation on the road section and the results of the analysis in real time and on request; identification of pre-emergency and emergency road conditions; archiving of monitoring results; development of recommendations for the speed regime on road sections based on the results of the analysis.

To implement the "adaptive system" of maintenance and repair in the TEA, the following information and software systems ("ISS") were developed and experimentally tested at KhNADU: "Virtual mechanic "HADI-12", "Service Fuel Eco 'NTU-HADI-12', 'MonDiaFor 'HADI-15", "IdenMonDiaOperCon 'HNADU-16' [15, 16, 17, 18], which are integrated into the system of the virtual PJSC 'KhNADU - TECA' for processing the received data. ISS operate in the context of intelligent transport systems (ITS) and have the organizational and functional capabilities to manage the operation of PJSC, assess the impact of exploitation conditions on the technical condition and environmental safety of the vehicle, the current state and the ability to predict the vehicle's performance, as well as to assess the technical and economic performance of the vehicle.

Experimental verification and results of the ISS operation to assess the vehicle's serviceable condition in operation. The main object of experimental research on monitoring technical condition parameters is a passenger car of the C segment (Fig. 2) equipped with information monitoring devices between ITS elements.

Figure 2 - Segment C car during monitoring of parameters
technical condition under exploitation conditions

Source: developed by the authors

The structure and interconnection of the functionality of the OIC for obtaining information on the operating conditions of vehicles within the virtual Road Transport Enterprise are given in [19]. It provides for information exchange between the elements of the ISS ITS of a vehicle to perform a remote study of rapidly changing work processes of vehicle exploitation in the process of changing operating conditions [19]. The system interaction is based on the following main functions of the BINC, namely, determining the position of the vehicle (tracking the position of the vehicle), monitoring the parameters of its technical condition, solving the problem of assisting the driver in the process of its exploitation, ensuring the transport safety of the vehicle.

The functioning of the main functions of the BINC is ensured by the fulfillment of its functions through the systematic interaction of the vehicle design features and the constituent elements of the ITS. The results of monitoring the parameters of the technical condition of the vehicle under operating conditions by means of ITS are shown in Figure 3.

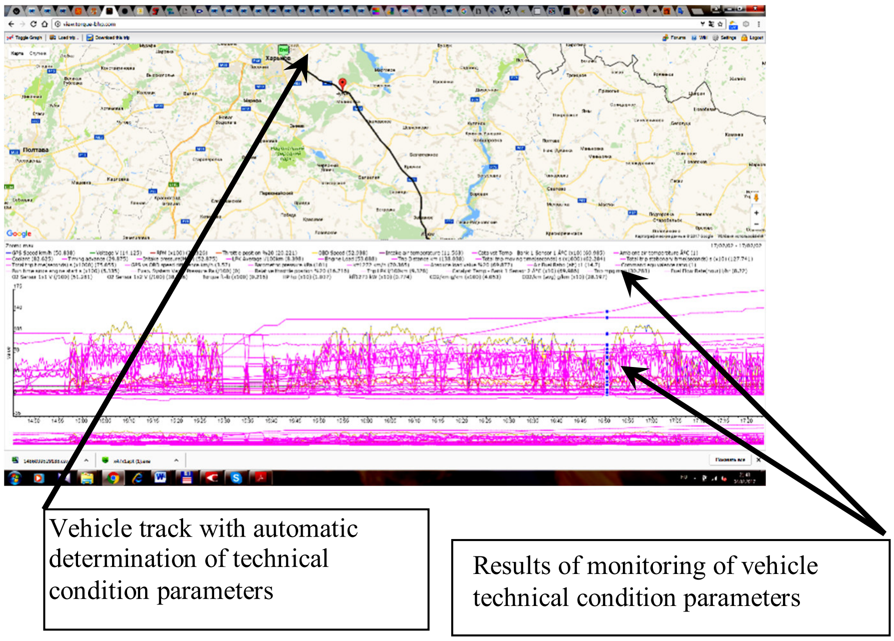


Figure 3- *Torque* working window with parameters for monitoring vehicle technical condition parameters
Source: developed by the authors

The working window of the *Torque* software module (Fig. 3) displays the current parameters of the vehicle engine, other units and systems, “error codes” from the vehicle's ECU, automatically sends the values of the parameters controlled by the sensor to the integrated electronic information meta-space, where within a set time it is possible to see not only the values of the controlled values at different times, but also to see on the map the entire route of the vehicle for the set period [20]. The reports allow you to find out where the vehicle was located, where and at what time the vehicle's scanner-communicator could not get in touch, etc. The service has the following types of tracks: tracking the vehicle track on the map (Fig. 4); export to *.gpx* format; export to *.xls* format. If the event line is highlighted in red, it is possible to drain the fuel, and if it is highlighted in green, it is possible to refuel.

The process of diagnosing and determining the fault status of the vehicle using DTCs was carried out automatically according to the algorithm developed by the authors using the *Torque* module within the developed ISS in ITS conditions. The final report on the results of diagnosing the technical condition and determining the status of faults in interaction with the user's computer through the ISS can also be accessed in the form of a summary table - DTCs of the vehicle [20].

The speed of the vehicle has a great influence on the main technical and economic indicators of work. It is known [4] that the determination of the average technical speed of a vehicle is possible if there is a total mileage of the vehicle S on the speedometer and the travel time t_{mov}. The relative coefficient of change of speed (RCCS) of a vehicle, which is adopted as the main criterion for determining a group of operating conditions and further adjusting the terms of MRO, can be determined by the following dependence:

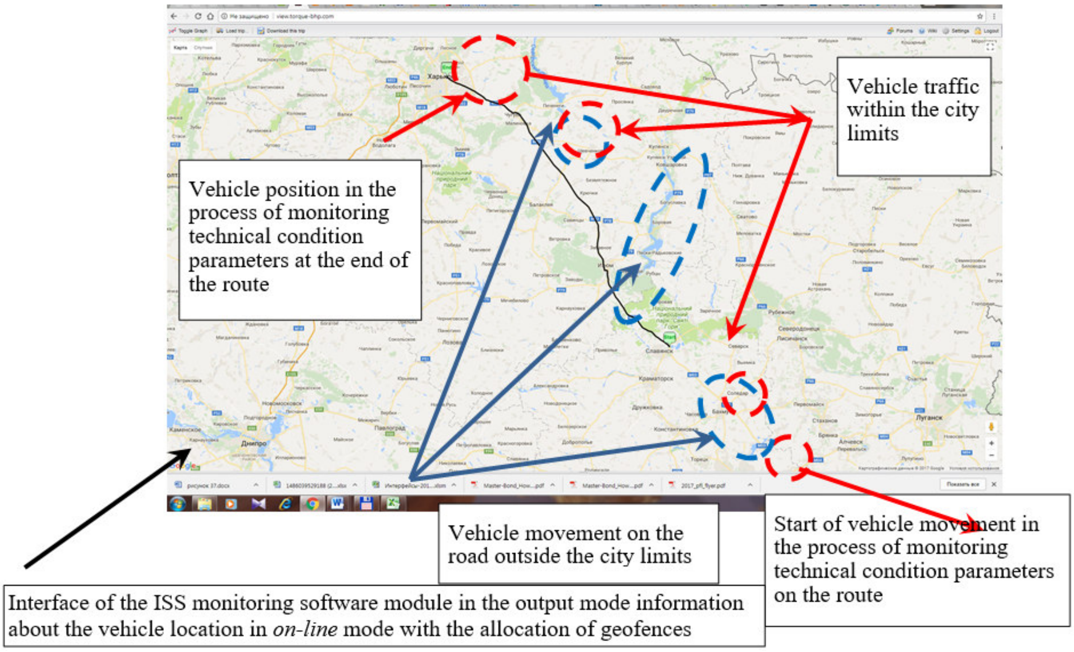


Figure 4 - Formation of geozones of the experimental site

Source: developed by the authors

$$K_C = S / (t_{mov} \cdot V_{a1}) \approx 1.43 \cdot S / (t_{mov} \cdot V_{max}), \tag{16}$$

where V_{a1} – the speed of this car on the road of the *1st* group ($0,7 \cdot V_{max}$).

Let's analyze the results of the study on the example of one vehicle route on the sections of driving distance using geophones (Fig. 4).

In this case, the determination of the vehicle speed in the conditions of operation by *ITS* was carried out in several stages. We formed 8 geofences with the coordinates of the beginning and end of the movement. The vehicle speed in the geofences was set in accordance with the provisions of [5]. To generate the final report on the movement of the vehicle and determine the operating conditions of the vehicle by speed, we analyzed and determined the technical and economic performance indicators (fuel consumption) and parameters of the technical condition of the vehicle under the relevant operating conditions as a result of monitoring by *ITS*.

The results of a detailed analysis of the vehicle movement conditions and the determination of the initial data for further calculation of the parameters were presented by comparing the monitoring results (Fig. 5) and as a result of processing the research protocol, a change in the vehicle speed was obtained.

Figure 6 shows a diagram of changes in vehicle speeds depending on the section (Fig. 5), obtained on the basis of the analysis of the report, where for each section we calculated (in the order of calculation) according to the following dependencies:

$$V_{med} = S_{\Sigma i} / t_{\Sigma mov\ i} \tag{17}$$

$$V_{med} = S_{\Sigma i} / (t_{mov} + t_{park})_{\Sigma i} \tag{18}$$

$$V_{med} = \Sigma\ (S_i / t_{mov\ i})_i / n_i \tag{19}$$

$$V_{med} = \Sigma\ (S_i / (t_{mov} + t_{park})_i)_i / n_i \tag{20}$$

$$V_{med} = \Sigma\, V_{GPS\ med\ i} / n_i \quad (21)$$

$$V_{med} = \Sigma\, V_{OBD\ med\ i} / n_i \quad (22)$$

where V_{med} - medium speed of the vehicle within the driving distance; $S_{\Sigma i}$ - is the sum of the distances of the *i* sections; $t_{\Sigma mov\ i}$ - Σ vehicle movement time at *i* - sections within the driving distance; $(t_{mov} + t_{park})_{\Sigma i}$ - Σ time of movement of the vehicle and stopping, parking at *i-th* sections within the distance of movement; n_i - number of polling stations; $V_{GPS\ med\ i}$ - is the average GPS speed of the vehicle within each *i-th* section received from the report; $V_{OBD\ i}$ - is the average OBD speed of the vehicle within each *i-th* section, which was obtained from the report.

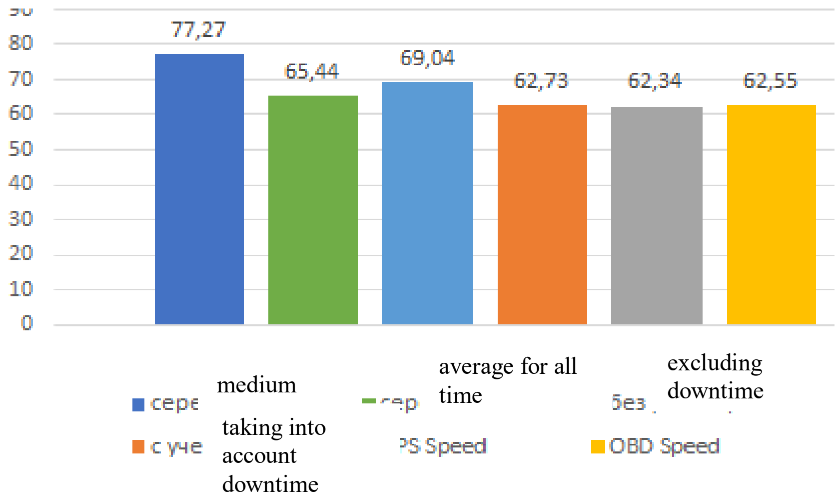


Figure 5 - Results of determining the change in the average speed of the vehicle based on the results of processing the report

Source: developed by the authors

The results of the change in fuel consumption depending on the distance and time of movement of the vehicle are shown in Figure 7. As a result, we obtained the average fuel consumption of the vehicle for the entire distance of movement, taking into account geozones, which is equal to $G_{med} = 7.23\ l/h$. This value is chosen as the actual fuel consumption of the vehicle.

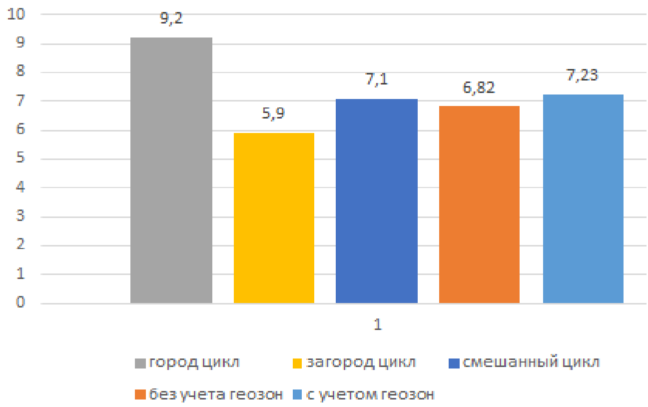


Figure 6 - Results of determining the change in vehicle fuel consumption during movement based on the results of report processing

Source: developed by the authors

Figure 7 shows the definition and research of the RCCS. The peculiarity of the definition of RCCS is as follows:

- 2 V_{max} speeds were selected as the maximum speed limits in the relevant section, taking into account the formed geozones, respectively: a - the maximum possible V_{max} speed of the research vehicle on the road of group 1 (outside the city) - *130 km/h*; b - the maximum possible V_{max} speed of the research vehicle on the road of group 1 (in the city) - *60 km/h*.

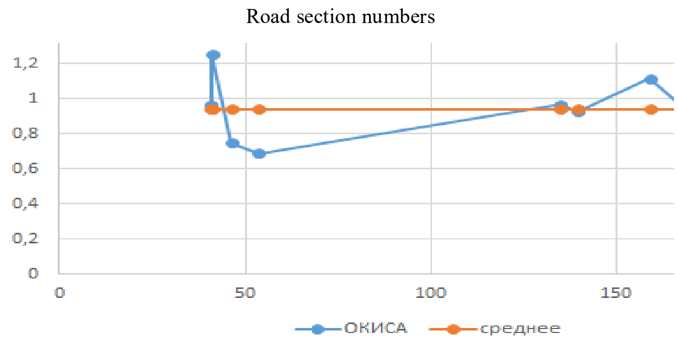


Figure 7 - Results of the study of RCCS at the experimental site depending on the distance of the path

Source: developed by the authors

Vehicle RCCS for each site, taking into account geophones: determined by the following dependence

$$K_{m\ m} = S_{section\ i} / (t_{mov} \cdot V_{a\ med\ section\ i}), \quad (22)$$

The average value of the RCCSR was determined as the average for the entire distance of the vehicle movement. As a result of the study, we obtained a value of $K_{m\ m} = 0.94$, which belongs to the first group of operating conditions [4], $K_{m\ m}$ varied on sections of the vehicle's path within the range of $K_{m\ m} = 0.69\text{-}1.25$.

Conclusions. In connection with the analysis of the state of the *TEA*, it can be concluded that the traditional system of maintenance and repair, which has been formed in road transport for many years, no longer meets modern requirements.

A new technique for road transport in assessing the operability of vehicles is the creation of information systems for organizational and functional support of their operation processes. The introduction of new basic principles of the “adaptive” system of management of the operability of vehicles in the *TEA* is the development of an information and communication system and a base of forecast models that provide, through monitoring, remote receipt of the necessary current information from vehicles and its processing, as well as the development of corrective actions.

An information technology for monitoring the state and operating conditions of vehicles is formed, the general information support of the system is proposed, and the following are described: processes for researching and assessing vehicle operating conditions; information model of vehicle position; speed model of vehicle traffic modes. In addition, the means of assessing: the type and condition of the road surface; the condition of transport infrastructure facilities; the condition of the adjacent road territory; vehicle fuel economy in exploitation conditions, as well as the algorithm for adjusting the vehicle speed are presented. The method for assessing the serviceability of vehicles in exploitation conditions has been improved. To implement it, the work of the structured information model of the ISS “IdenMonDiaOperCon ‘HNADU-16’” was tested, which makes it possible to assess the technical and economic performance and parameters of the technical condition of the vehicle under operating conditions on the example of assessing the average speed of the vehicle and fuel consumption. The assessment of exploitation conditions was carried out according to the value of the RCCS in accordance with the provisions of the theory of vehicle exploitation.

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Технологія контролю працездатного стану автомобілів в умовах експлуатації

Виконано аналіз технології моніторингу технічного стану автомобілів під час експлуатації. Проведено аналіз існуючої моделі технічної експлуатації автомобілів в Україні. Існуюча модель технічного обслуговування і ремонту сформована на основі спрощеної системи функціонування транспортної інфраструктури і вже не відповідає вимогам часу.

Новим методом оцінки справного стану транспортних засобів є створення інформаційних систем організаційно-функціональної підтримки їх експлуатації. Перехід до «адаптивної» системи технічного обслуговування і ремонту транспортних засобів дозволяє використовувати вбудовані засоби бортової діагностики, існуючі мережі супутникової навігації та мобільного зв'язку, а також сучасні інформаційні технології для дистанційної оцінки рівня їх працездатності. Використання програмного модуля *Torque* в удосконаленні технології моніторингу експлуатаційних характеристик транспортних засобів як основи «автомобільної» концепції *FADEC* є першим кроком на шляху до системи *FRACAS* і, відповідно, технологій IPV/CALS/PLM. Модель оцінки рівня експлуатаційних характеристик транспортного засобу враховує дорожні умови експлуатації транспортного засобу в частині висоти дороги над рівнем моря, поздовжнього профілю, типу та стану дорожнього покриття; ремонт, будівництво та утримання об'єктів дорожньої інфраструктури; їх моніторинг; прогнозування можливих аварійних ситуацій; умови дорожнього руху в частині насиченості та інтенсивності руху транспортних засобів, характеристик вантажу, режиму та швидкості руху; атмосферно-кліматичні умови, експлуатаційну витрату палива, культуру експлуатації транспортного засобу.

У статті представлено удосконалений метод оцінки працездатності транспортних засобів в експлуатації. Проведено експериментальну перевірку запропонованої технології та отримано результати оцінки працездатності легкового автомобіля С-сегменту в експлуатації.

автомобіль, працездатний стан, технічна експлуатація автомобілів, адаптивна система ТО і Р, умови експлуатації, метод, математична модель, моніторинг

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