Information system for remote monitoring the vehicle operational efficiency

M. Smieszek¹, V. Mateichykk, M. Tsiuman², R. Symonenko², I. Gritsk³, M. Bulgakov³

¹Rzeszow University of Technology, Department of Engineering of Technical Systems, al. Powstancow Warszawy 8, Rzeszow, 35959, Poland
²National Transport University, Faculty of Automotive and Mechanical Engineering, Omelianovycha-Pavlenka str. 1, Kyiv, 01010, Ukraine
³Kherson State Maritime Academy, Department of Ship Power Plants Operation, Ushakova avenue 20, Kherson, 73000, Ukraine

msmieszk@prz.edu.pl

Abstract. The article describes the information system for remote monitoring and control of vehicle technical condition and motion modes with the use of modern telematics technologies. There are 17 morphological features in the system, which determine the level of telematic support of the main functional elements of the system to obtain information about vehicle technical condition and motion modes in the appropriate infrastructural conditions. The information model of the system for monitoring of parameters of vehicle technical condition, motion modes and infrastructural characteristics was built. This model is implemented in the information and software complex for remote monitoring of vehicle operational efficiency. The results of experimental studies of freight vehicle operational efficiency on a given route with use of the developed information and software complex are presented. The results show significant influence of the vehicle technical speed and average coolant temperature of its engine on operational efficiency indicators such as fuel consumption, carbon dioxide, nitrogen oxides and particulate matter emissions on the route characterized by different road height profiles.

Keywords: vehicle, information system, monitoring, model, vehicle operational efficiency

1. Introduction

Positive changes in the composition and structure of world transport at the beginning of the 21st century are accompanied by a number of negative consequences, the scale and significance of which give grounds to assess them as strategic challenges of a national, regional and even continental dimension. These include: an unacceptable level of loss of life; growing consumption of non-renewable energy sources and negative impact on the environment; constantly growing delays of people and goods on all types of transport, associated with both objective shortcomings in terms of the infrastructure capacity, and with a low level of logistics management of traffic flows [1].

The world transport community has found a promising solution in the creation of modern transport systems, in which means of communication, management and control are directly built into vehicles and infrastructure facilities, and management capabilities (decision-making) based on information...
 received in real time are available not only to transport operators, but also to all users of means of transport [2-3]. In recent years, the phrase "intelligent transport systems" and the corresponding abbreviation "ITS" (Intelligent transportation system) have become an integral part of the strategic and programmatic documents of the developed countries of the world [1 - 5].

Improving the operational efficiency of wheeled vehicles (WV) based on intelligent information technologies is an important scientific and technical problem, the relevance of which is growing every year [3, 6-10]. In this subject area, research is carried out by individual scientists and organizations from different countries with significant results in solving a wide range of individual aspects of the problem [3, 5, 6, 11 - 14].

Today, it is important to develop scientific methods and engineering assessment methodology for the operational efficiency of WV with modern power plants with intelligent control of the technical condition and modes of WV movement in the given conditions of the infrastructure environment. This is possible only on the basis of up-to-date information from the internal system for diagnosing the technical condition and modes of movement of the WV, as well as information from the external infrastructure environment about real operating conditions (road, transport, meteorological, etc.).

To monitor and evaluate vehicle performance under operating conditions, the authors have developed an information system for remote monitoring of WV parameters and infrastructure, which determine the level of safety, productivity, energy efficiency and environmental friendliness of the WV in specified conditions.

The article describes the main approaches to the construction and information support of the "Wheeled Vehicle - Infrastructure" system (WV – I system) and the features of its application for assessing the speed, fuel consumption and harmful emissions of the vehicles, which determine its operational efficiency on a given route.

2. The structure of the information system for remote monitoring of the vehicle operational efficiency

The information WV – I system is a satellite monitoring and control system, which is a specialized software and hardware complex for remote monitoring of the parameters of a power plant technical condition, control of engine and transmission operating modes, the processes of interaction of a vehicle with road infrastructure and the processes of implementing a given law movement in the appropriate conditions of the infrastructure environment [6]. The creation of the vehicle-infrastructure system is based on the idea of combining into a complex all the necessary tasks that today can be put forward for similar transport systems, as well as combining actions aimed at solving these problems (Fig. 1).

The article shows a system with options for implementing 17 morphological features that determine the level of information support for the main functional elements of the vehicle-infrastructure system to obtain information about the technical condition of the vehicle and motion modes in the corresponding infrastructure conditions (Fig. 1). The aggregate combination of exactly the indicated 17 variants of morphological signs (information channels) is considered as a variant of the constructed information model of the system for monitoring the parameters of the vehicle technical condition, the operator's operating modes and infrastructure characteristics.

The developed system provides continuous remote monitoring and control of vehicles at low operating costs through the use of modern information telematic technologies. The application and implementation of the system is a qualitatively new level of efficiency management for wheeled vehicles under operating conditions.

The WV - I system is an information hardware and software complex based on an information platform for remote monitoring by means of ITS in the implementation of various morphological structures of the system, built on the "client-server" technology using Web-technologies. The components of this system are: server; general and special software for the server and onboard equipment; GIS server; basic specialized software of the dispatcher's (operator's) workplace, etc. [3, 4, 8, 10, 12 - 15].

To assess the effectiveness of the functioning of the WV - I system, taking into account changes in the variants of morphological features of its elements, a new methodology has been developed that is able
to assess possible morphological structures of the information support of the system and its elements, form optimal structures of the system and manage individual characteristics of functional elements to achieve maximum performance of vehicles with minimal unit energy costs and emissions in the given conditions of the infrastructure environment.

Figure 1. The main components of the information support for the WV – I system

The main functions of the WV-I system can be roughly divided into the following groups: monitoring functions (continuous receipt of information, both from the vehicle and from the infrastructure), functions for managing technical condition parameters and modes of vehicle movement and functions for storing information and interacting with external information systems. Monitoring functions by the tasks of the WV-I system fully correspond to the already known monitoring systems developed at KhNAHU, NTU and KhSMA, RUT [10 - 13, 15]. The control functions of the WV-I system, in addition to the already known functions [10 - 13, 15], provide for the solution of additional tasks, including the following:

- increasing the efficiency of the system in terms of ensuring the main functional processes by combining individual variants of all morphological features of both functional elements, which ensures the formation of a new morphological structure of the information support of the system under study;
- obtaining new structures of information support of the system by changing one of the options for the implementation of any feature of both functional elements, thereby achieving a new functioning of the system;
- formation on electronic maps of the area of the corresponding geo-zones to correct the movement of the vehicle;
- control and analysis of technical and technological parameters of the vehicle condition for certain periods of time, and so on.

Physical architecture includes software, information technology hardware, peripheral equipment. The physical architecture defines the basic requirements for the operation, interaction and placement of the element base of the system. The remote monitoring information system includes a set of stationary and mobile means for collecting and transmitting information [3, 5, 8, 9, 12].

The collection system is a data exchange network that can use all means of data transmission. Stationary infrastructure posts perform communication functions and the simplest control functions. These functions provide the receipt of control, measuring and technological information from the on-board systems, control of the time of vehicle movement at specified points, collection of information about communications and structures, data transfer to the WV-I system [10 - 13].

The situational and operational control center in the basic version of the system is a workstation of the vehicle monitoring network, which is built on the basis of an information and computing system using the basic (standard) and developed software [10, 15].

The basic principle of information exchange between the elements of the information structure of the vehicle and the transport infrastructure in the process of monitoring the parameters of the technical condition is that the vehicle in it is not only an object of control and management, but also a source of constantly updated information about the technical condition, management and its operation conditions [10, 12 - 15].

3. Formation of the subject area for remote monitoring of the vehicle operational efficiency

Data flow diagrams (DFD) [10-12] were used to form the subject area for remote monitoring of the vehicle operational efficiency using the developed information system. A data flow diagram developed by the authors, which is the uppermost descriptive level of information support for the WV-I system based on remote monitoring by means of ITS. The sources of primary information in the WV-I system are "Participants in the management of transport means", "System management processes: to ensure monitoring and ensure the specified law of movement of the vehicles", "Databases, system software", "The level of information support of the system" are "External entities" [10-12, 15]. The functional tasks of the information system include identification, monitoring of parameters, diagnostics of the technical condition, assessment of the vehicle movement modes and so on.

In general, the WV-I system can be considered as complex in terms of vehicle monitoring and control, which depends on technical and organizational factors. At its different levels, it is necessary to combine in the aggregate the tasks (processes) [10, 15]: informational (monitoring, analysis, forecasting, diagnostics, comparison of components), \( F_0 \); functional (conversion of the initial energy into mechanical, transfer of mechanical energy to the wheels of the vehicle; converting the rotational motion of the wheels into the translational movement of the vehicle, changing the modes and directions of movement in accordance with the given law of motion as a result of the interaction of the vehicle with the transport infrastructure), \( F_0 \).

On the basis of the provisions of Def Stan 00-60 [11] and system approaches in works [10-15], the functional of the system was formed to ensure its operability, as a combination of components: collection of information about the parameters of the vehicle and power plant in operation (PSV) processing of the information received on the parameters of the state of the vehicle and power plant (OIV) forecasting based on the information received about the parameters of the state of the CTS and power plant (PPV); collection and information decoding on the automation level of the vehicle and power plant; identification of the vehicle and operators (IV); collection and decoding of information on external factors and conditions operation (ZFUEV); diagnosing the technical condition and malfunctions of the vehicle and power plant (DV); control the parameters of the technical condition of the vehicle and power plant (thermal state, etc.) (UPSV); control the mode of operation of the vehicle transmission (URTV); control the intensity of changes in the processes of converting the rotational
motion of the wheels in forward motion of the vehicle (IPUV) to control the given law of movement of the vehicle (UZRV).

All of the listed components of the WV - I system in terms of information support (PSV, OIV, PPV, IV, ZFUEV, DV) and in terms of functional support (UPSV, URTV, IPUV, UZRV) are complex functions of organizing the process of vehicle operation and interaction of WV - I system elements, depending on the levels of morphological features implementation, and their totality is some functional characterizing "supportability", that is, "suitability for maintenance" or, in other words, a set of system properties that determine the convenience of its operation, that is suitability of the system to ensure the main processes of operation and control of the vehicle [10 - 15]:

\[ S = F (F_{i1} (PSV, OIV, PPV, IV, ZFUEV, DV...); F_{i2} (UPSV, URTV, IPUV, UZRV...)) \]  

(1)

In the simplest case, the functional \( S \) can be expressed by the "weighted" algebraic sum of the quantities included in it, for example:

\[ S = k_{\Sigma i} \cdot F = F (k_{\Sigma i1} \cdot F_{i1}; k_{\Sigma i2} \cdot F_{i2}) \]  

(2)

where: \( k_{\Sigma i} \) are weight coefficients that act as normalizing factors that bring all quantities in relation to the same order.

The larger the \( S \) value, the higher the level of system suitability for providing support in the performance of the assigned tasks.

The analysis of the terms and, accordingly, the concepts and components of the functional \( S (1) \), indicates their "temporary" nature. Here, absolutely all components are time parameters [10-15].

In the structure of the WV - I system, it is necessary to form the components of the parameter \( S \), as well as the methods and means of its development and assessment in the structure of modern ITS [10, 12, 15].

The most effective and customary way of creating operational standards for ensuring the efficiency of vehicle operation is the formation of an information system for monitoring the operational efficiency of the vehicle [10, 12, 15].

Thanks to the use of the appropriate dependencies in the WV - I system, it is possible to create a single centralized storage of information distributed in space in the form of information system databases, support a multi-user environment for obtaining information (editing) in situational and operational control centers, the ability to access remote users, systematize information using models and algorithms of functional processes and its visual display in a single complex.

For the formation of information support for the operation and control of the vehicle in the WV - I system at the appropriate time, the available sources of information were collected in terms of the coordinates of the vehicle on the ground in real time, models of highways, models of road infrastructure facilities, the results of vehicle tracking, etc. Sources of information to ensure the functioning of the information system WV - I are presented in the literature [10, 12, 15].

The main options for information on the actual parameters of the technical state and the vehicle's movement mode in the WV-I system are shown in the article as the construction of functions in the processes of managing the technical condition and vehicle movement modes at the appropriate time and are described by dependence (3).

where \( F_{\Sigma e, y, V - H} \) is an information about the parameters of the technical condition and mode of vehicle movement at the corresponding time;

\( \vec{H} \) is a vector of the control body for the technical condition and modes of vehicle movement (coordinate of the originator of the control body, etc.) in the corresponding time period \( t \);

\( t \) is the current time of the monitoring process of the technical condition and modes of vehicle's movement;

\( \Delta t \) is the time interval between periods in monitoring processes.
\( \vec{X}_i(t) \) for \( i = 1, ..., m \) are characteristics of the process of monitoring parameters that are measured and are included in the list of retrospective influencing factors;

\( n \) is the number of intervals (set number of measurements) in the previous monitoring periods;

\( m \) is the number of measured parameters of the technical condition and modes of vehicle’s movement;

\[
F_{\sum e.y. \Sigma V - \text{II}} \left( H_i, t, \Delta t, \vec{X}_i(t), \vec{X}_i(t - \Delta t), ..., \right) \Rightarrow S_{\sum e.y. \Sigma V - \text{II}} (t) \]

\[
\Omega^m_i \left( e_{\sum e.y. \Sigma V - \text{II}}, r \right)^j = \Omega^m_i \left( e_{\sum e.y. \Sigma V - \text{II}}, r \right)
\]

\[
S_{\sum e.y. \Sigma V - \text{II}} (t) = \]

\[
F_{\sum e.y. \Sigma V - \text{II}} \left( e_{\sum e.y. \Sigma V - \text{II}}, \right)
\]

\( DTC_{s_i} K_{t_i} \) are results of determination (monitoring) of technical condition codes (diagnostic trouble codes which are named DTCs) during monitoring periods;

\( S_{\sum e.y. \Sigma V - \text{II}} (t) \) is the monitoring system at the appropriate moment in time (in the case under consideration, the system shows a reflection of the properties of monitoring subobjects) in the case under consideration, the system shows the subobjects’ properties of the technical condition and modes of movement at the corresponding moment of time and their ratios \( r \) for \( m \) and along \( J \) in \( l \);

\( m_i \) is the number of means to ensure the receipt of information (observation means) at the appropriate time;

\( l \) is connections between the means of observation, maintenance and control and subobjects of the infrastructure environment of the vehicle;

\( \Omega \) is the operator for displaying the morphological structure of the information support of the WV - I system (according to the options for implementing the system under study);

\( F_{\sum e.y. \Sigma V - \text{II}} \) providing information about the technical condition and modes of movement of the vehicle;
$S_{e,y.V} - I_i(t)_i$ - providing information on the technical condition and modes of vehicle movement based on server solutions in the WV - I system;

$S_{e,y.VV dt} - I_i(t)_i$ - providing information about the technical condition and modes of movement of the vehicle of a local source (information) in the WV - I system;

$S_{e,y.Ne} - I_{ii}(t)_i$ - providing information about the technical condition and modes of movement of the vehicle network databases;

$e_{e,y.ΣV} - I_{ii}$ is a set of sub-objects for determining information about the technical condition and modes of vehicle's movement

$e_{e,y.ΣV} - I_{ii}.PSV$ - collecting information about the parameters of the vehicle and power plant (PSV) state

$e_{e,y.ΣV} - I_{ii}.OIV$ - processing of the obtained information about the parameters of the vehicle and power plant state (OIV)

$e_{e,y.ΣV} - I_{ii}.PPV$ - forecasting the vehicle condition and power plant (PPV) based on the received information about the parameters

$e_{e,y.ΣV} - I_{ii}.IV$ - collection and decoding of information about the level of automation of the vehicle and power plant, identification of the vehicle and operators (IV)

$e_{e,y.ΣV} - I_{ii}.ZFUEV$ - collection and decoding of information about external factors and operating conditions of the vehicle (ZFUEV)

$e_{e,y.ΣV} - I_{ii}.DV$ - diagnostics of the technical condition and malfunctions of the vehicle and power plant (DV)

$e_{e,y.ΣV} - I_{ii}.UPSV$ - management of technical condition parameters of the vehicle and power plant (thermal condition, etc.) (UPSV)

$e_{e,y.ΣV} - I_{ii}.URTV$ - control of the transmission operation mode of the vehicle (URTV)

$e_{e,y.ΣV} - I_{ii}.IPUV$ - control of the changes in the processes of converting the movement of the wheels and the translational movement of the vehicle (IPUV)

$e_{e,y.ΣV} - I_{ii}.UZRV$ - control of the given law of movement (UZRV)

$r$ is a lot of relations between the main sub-objects in determining the technical condition and modes of movement of the vehicle;

$J$ is the task of monitoring the technical condition and modes of movement of the vehicle

4. Model of the subject area of ensuring the operational efficiency of vehicles as part of the information system

The $M_i$ domain model of the system for monitoring the parameters of the technical condition of the wheeled vehicle (as part of the road train), the operator and the recorders is presented in the form of the following set of components, namely, the parameters of the technical condition of the engine and the vehicle; working hours of the driver $M_{ti}$; additional parameters of the state of the vehicle, trailer (road train), environmental indicators $M_{tr1}$, heat treatment system $M_{tr2}$, and the physical condition of the driver $M_{F}$ [10, 12, 13, 15]. Dependencies are presented in general:
\[
M_a = \begin{pmatrix}
M_V \\
M_{tg} \\
M_{tr1} \\
M_{tr2} \\
M_F
\end{pmatrix} = \begin{pmatrix}
\{O_V, V_{V_{in}}, V_{V_{out}}, F_V, H_V, P_V, R_V, \} \\
\{O_{tg}, V_{tg_{in}}, V_{tg_{out}}, F_{tg}, H_{tg}, P_{tg}, R_{tg}, \} \\
\{O_{tr1}, V_{tr1_{in}}, V_{tr1_{out}}, F_{tr1}, H_{tr1}, P_{tr1}, R_{tr1}, \} \\
\{O_{tr2}, V_{tr2_{in}}, V_{tr2_{out}}, F_{tr2}, H_{tr2}, P_{tr2}, R_{tr2}, \} \\
\{O_F, V_{F_{in}}, V_{F_{out}}, F_F, H_F, P_F, R_F, \}
\end{pmatrix},
\]

where for the components of the domain model, respectively: \(O_i\) - sets of automation objects; \(V_{in}\) is sets of input information elements; \(V_{out}\) is sets of outgoing information elements; \(F_i\) is the set of functions performed by the monitoring system; \(N_o\) is set of data processing tasks; \(P_i\) is set of users (number and composition of personnel); \(R\) is the set of relationships between the components of the subject area of the monitoring system [10, 12, 13, 15].

For the functional of the domain model (4), the corresponding dependencies are written down, which are indicated in the sources [10, 12, 13, 15]. To adapt the developed system to the requirements of the infrastructure and (or) the requirements for modern vehicles, all functions, data processing tasks can be either reduced or increased in volume [10, 12, 15].

5. Some results of the implementation of the vehicles' remote monitoring system

To study and manage the operational efficiency of vehicles in the processes of using the remote monitoring system, a combined approach was used, which included a combination of information about the technical condition from the vehicle control unit (controller), with information on operating conditions from other sources and the results of calculations of operational efficiency. All this is based on the provisions indicated in the study.

As a result of the experimental implementation of the system, a reliable fixation of the change in the parameters of the technical condition of the vehicle was obtained, taking into account the change in operating conditions in interaction with the infrastructure environment for an individual vehicle. Experimental research object was Mercedes-Benz Actros 1845 LS (Fig. 2a). For carrying out of studies WV was equipped by intelligent software complex (ISC) based on Ruptela FM-Tco4 HCV / HCV 3G connected to OBD and smart-tachograph of WV, GPS geoposition system and external server for collection and processing of data using 3G network (Fig. 2b). Technical parameters of WV and ISC are presented in Tables 1 and 2.

![Figure 2](image_url)

**Figure 2.** Experimental research object and means: a – Mercedes-Benz Actros 1845 LS; b – ISC based on Ruptela FM-Tco4 HCV / HCV 3G

**Table 1.** Technical parameters of Mercedes-Benz Actros 1845 LS

| Parameter                          | Value     |
|-----------------------------------|-----------|
| Maximum weight, kg                | 18000     |
| Minimum weight, kg                | 8277      |
| Wheel formula                      | 4x2       |
| Engine displacement, l            | 12.809    |
| Engine specification and cylinders arrangement | 6FT 13.2/15.6 inline |
Compression ratio | 17.3
---|---
Engine power, kW / rotation speed, rpm | 330 / 1800
Engine torque, Nm / rotation speed, rpm | 2200 / 1100
Fuel supply system | Common Rail
Exhaust gases cleaning system | Exhaust gases recirculation, nitrogen oxides selective catalytic reduction with AdBlue injection, diesel particulate matters filter
Number of transmission ratios | 12
Environmental class | Euro-6

| Parameter | Measuring limits and accuracy |
|---|---|
| Time | (0…24) h, ±1 s |
| Geographical coordinates | (-90…90)°lat., ±1·10⁻⁵°; (-180…180)°long., ±1·10⁻⁵° |
| WV speed | (0…255) km/h, ±1 km/h |
| Distance | (0…10⁹) m, ±1 m |
| Coolant temperature | (-40…215)°C, ±1 °C |
| Volumetric fuel consumption per hour | (0…3212.75) l/h, ±0.05 l/h |
| Crankshaft rotation speed | (0…16384) rpm, ±0.1 rpm |
| Driver condition | (0…3) |

The research route is presented on Fig. 3. For operational efficiency analysis the route with general length about 1300 km was divided on 12 sections. To analyze the impact of road conditions on the WV efficiency the height profile is also determined for the route.

![Figure 3. Research route](image)

The results of the study of WV operational efficiency on the route are shown in Fig. 4. As can be seen from the presented results, different sections of the route are characterized by different technical speeds (Fig. 4a), which is the main indicator of WV transport productivity. Also, the engine technical condition is determined by the different average coolant temperature (Fig. 4b). The technical speed and technical condition of WV have a decisive influence on other operational efficiency indicators. In particular, the specific indicators of fuel consumption (Fig. 4c) and CO₂ emissions (Fig. 4d), NOₓ (Fig. 4e)
4e), and PM (Fig. 4f) per unit of transport work were analyzed. Minimum fuel consumption and harmful emissions occur in sections 2, 3, 10 and 11. In these sections the highest technical speed values are achieved, the engine coolant temperature is at the optimal level, and the road height profile is characterized by minimal differences (Fig. 3). Reducing the technical speed and coolant temperature in sections 1, 4, 9 and 12 leads to increasing of fuel consumption and emissions.
Figure 4. Research results of WV operational efficiency on the route: a – technical speed; b – coolant temperature; c – specific fuel consumption; d – $\text{CO}_2$ specific emissions; e – NO$_x$ specific emissions; f – PM specific emissions

The highest fuel consumption and emissions are obtained in section 8, which is characterized by significant differences in road heights (Fig. 3). It also leads to a decrease in technical speed. Thus, the obtained results indicate a significant impact of operating conditions and WV technical condition on its productivity, fuel consumption and emissions.

6. Conclusions

The paper considered the features of building an information system for remote monitoring and control of the technical condition and motion modes to study of wheeled vehicle operational efficiency. The expediency of using morphological features that determine the level of information support of the system about the technical condition and motion modes of the vehicle in appropriate conditions has been substantiated. The results of building an information model of the system are presented. The developed system provides continuous remote monitoring and control of vehicle performance based on information about the technical condition from the vehicle control unit, information about operating conditions from other sources and the results of calculations of operational efficiency. With the help of the developed information system, the performance of the truck was monitored on a given route, which was characterized by different values of the height of the road profile. The research results are presented in the form of changes in technical speed, engine coolant temperature, specific fuel consumption and emissions on the route. The results of the study show a significant effect of the technical speed of a vehicle and the average temperature of its engine coolant on such indicators of operational efficiency as fuel consumption, emissions of carbon dioxide, nitrogen oxides and particulate matter in certain sections of the route. Further research will be aimed at studying and substantiating information support for the system for maintaining the optimal temperature of the engine coolant to reduce fuel consumption and vehicle emissions under operating conditions.

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