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INFORMATION TECHNOLOGY OF TRANSPORT INFRASTRUCTURE MONITORING BASED ON REMOTE SENSING DATA

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ABSTRACT

Context. In the light of current road network monitoring practices, this study aims to explore the capability of remote sensing technologies to solve the problems of increasing the objectivity of preliminary evaluations of the condition of the infrastructure as a whole. The object of the study was to process the monitoring of transport infrastructure (TI) to find ways to improve it in the implementation of development projects.

Objective. The goal of the work is to increase objectivity of decision-making on the evaluation, reconstruction, development of the transport network structure due to the visual presentation and disclosure of open data for monitoring the transport value.

Method. Existing approaches to TI monitoring and evaluating its condition are analyzed. The identified shortcomings, as well as the development of remote sensing technologies, open up prospects for the use of remote sensing data in the TI monitoring process. A set-theoretic model of the monitoring process information flows is proposed, the consistent refinement of the elements of which made it possible to develop information technology (IT). Formation of a set of input and output parameters of IT, the set of its operations, their representation with IDEFX-models set explains how a set of heterogeneous (graphic, text, digital, cartographic, etc.) data about TI elements coming from different sources are processed and presented to support decision-making on the survey of existing infrastructure and its improvement. The developed IT makes it possible to obtain complex indicators for analyzing the TI of a particular area, to solve the problems of inventorying objects, TI and its elements modeling, taking into account the physical and geographical location, which makes it possible to consider it as an auxiliary tool that complements existing methods of TI monitoring.

Results. The developed IT was studied in solving the problem of monitoring the TI section of the Kharkiv region using satellite imagery of medium (Sentinel–2) and high (SuperView-1) resolution and the results of laser survey of the road bridge across the river Mzha (as an element of infrastructure).

Conclusions. The conducted experiments confirmed the operability of the proposed information technology and showed expediency of its practical use in solving the problems of obtaining generalizing characteristics of the infrastructure, inventory of TI objects and their modeling. This opens up opportunities for substantiating project decisions for the reconstruction of the transport network and planning procedures for examining its condition. Prospects for further research may include: creating reference models of TI objects, expanding the table of decryption signs of road transport infrastructure objects, integrating remote data, survey results of TI sections and engineering surveys of objects to obtain evaluations of the condition of TI in general.

KEYWORDS: model of information flows of the process, IDEFX-models, mapping and 3D-modeling.

ABBREVIATIONS

IT is an information technology;

GIS is a geoinformation systems;

GPR is ground penetrating radar;

RMC are road-maintenance companies;

TI is a transport infrastructure.

NOMENCLATURE

φ is an update function;

ψ is an output function, that generates an output data;

A is a set of operations that implement the transport infrastructure monitoring process;

H is a population size, thousand people;

I_Pr is a model of information flows of the transport infrastructure monitoring process;

J_k are junctions, that define the interaction logic of IDEF3-model operations;

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$K(E)$ is an Engel coefficient;
$K(G)$ is a Goltz coefficient;
L is the length of roads in the given territory, km;
N is the number of settlements;
O is a set of output data the TI monitoring process;
r is the correlation coefficient;
S is the area of the territory, km^2;
V is a set of input data, incoming into an input of an IT in the TI monitoring process;
Z is a set of documents regulating the TI monitoring process.

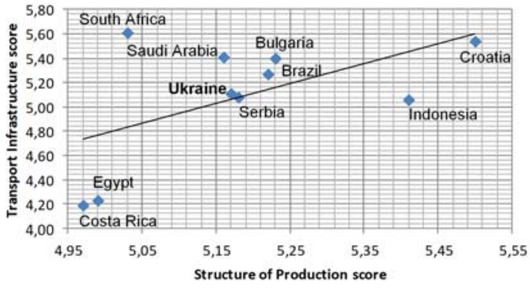
INTRODUCTION

The development of countries, the strengthening of international relations, the activation of globalization processes increases the importance of transport as a factor in economic and social development [1]. Thus, experts from the World Economic Forum note that for countries and economies are assigned to nascent archetypes, is a medium-pronounced dependence (with a correlation coefficient $r = 0.567$) between indicators of TI and the structure of production components, reflecting the complexity and scale of the country's current production base (Fig. 1a). A more pronounced relationship ($r = 0.637$) between indicators of TI and drivers of production, that position a country to capitalize on emerging technologies and opportunities in the future of production (Fig. 1b) [2]. Thus, transport and the transport sector have an impact on the location and efficiency of production, on the formation of local and national markets, and on the solution of socio-economic problems [1, 3].

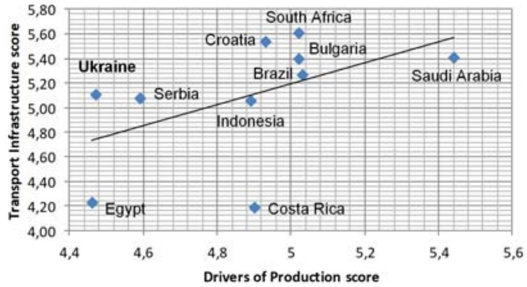
Determining the cost of production, on the one hand, TI turns out to be a measure of economic activity; on the other hand, it becomes its reflection, forcing the business to coordinate the development of its enterprises with the development plans of TI [2–4]. In this context, improving the efficiency of the existing TI becomes the main goal of government programs and development projects, and understanding the quantity, quality of roads and the entire infrastructure as a whole is necessary for making strategic decisions.

The object of study is the process of monitoring transport infrastructure in order to find ways to improve it when implementing development projects.

One of the most promising and powerful monitoring tools for TI is considered to be methods based on remote sensing of its elements, which traditionally focus on monitoring the condition of the road surface [5]. However, it is noted that TI is a broader concept that combines not only roads as elements of communication networks for all types of transport, but also the corresponding set of structures to meet the needs of the population and production in transportation [6]. Therefore, in order to increase the objectivity of TI evaluation in general, it is necessary to expand the use of remote zoning by implementing models and methods based on the analysis of spatially distributed data about its elements.



a



b

Figure 1 – The scatterplot (for the top 10 countries of the nascent archetypes) that illustrates dependence between transport infrastructure components and indicators: a – structure of production; b – drivers of production
(According to the results of the analysis of work [2])

The subject of study is the information technology for transport infrastructure monitoring, which uses remote sensing data to analyze it and find ways to improve it.

Increasingly, urban planners and transport engineers note that there is a need to create scientific and methodological support that combines spatial data with evaluations of TI to provide information support for its monitoring process while making decisions on ways to improve it. The growing number of vehicles, in particular, on highways, increases the need to step up efforts to implement IT of TI monitoring as a set of methods for searching, processing and presenting heterogeneous data in the implementation of development projects. Therefore, the known sampling methods [5–16], which, unfortunately, are focused on the remote evaluation of only the road surface, have excellent prospects for using the entire road infrastructure in IT for monitoring.

The purpose of the work is to increase the objectivity of the decisions made on the survey, reconstruction, development of the existing transport network through the representation and visualization of spatial data for monitoring of the TI.

1 PROBLEM STATEMENT

Assume there is a set of data $V = \{v_i\}, i = \overline{1, n}$, obtained during the TI monitoring process and incomed on the input of IT. Next, this data is transformed into a set $O = \{o_j\}, j = \overline{1, m}$ – a set of output data for analysis and

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search for ways to improve the TI. The rules for this transformation are set by the function

$$f : V \to O, \forall v_i \in V \; \exists o_j \in O : v_i = f(o_j) . \qquad (1)$$

It is necessary to define actions within the framework of information technology for TI monitoring, which implements the mapping $V \xrightarrow{f} O$ in expression (1).

2 THE LITERATURE REVIEW

Among economists, the generalizing Engel or Goltz coefficients are widely used as a tool for evaluating the condition of the transport component. These coefficients, based on statistical data, show the level of provision of the population with a transport network or the level of development of this network between settlements, taking into account the length of roads, the area of the analyzed territory, the population and the number of settlements. To calculate the level of provision of the population of the analyzed territory with the transport network, we use Engel's formula [6, 7]:

$$K(E) = \frac{L}{\sqrt{SH}} . \qquad (2)$$

and to calculate transport network development level – Goltz's formula [7]:

$$K(G) = \frac{L}{\sqrt{SN}} . \qquad (3)$$

These coefficients make it possible, with a certain reliability, to judge the level of development of transport networks in relation to their main users and to determine the main differences in development in the study areas. However, the coefficients useful for the system analysis of the transport component of the territories do not take into account the configuration of TI, the condition of the road surface, its objects, etc. [6, 7]. Therefore, more and more often, urban planners and transport engineers come to the need to create indicators for sustainable planning and making informed decisions that combine spatial data with evaluations of TI [8, 9].

The regulatory database for evaluating the condition of roads in Ukraine is regulated by a number of state, industry and departmental standards (for example, GOST 8747:2017, BC B.2.3-4-2007, BC B.2.3-218-534:2011, DBC H.1-218-530.2006 etc.). For employees of road maintenance organizations (RMC), the standards define the rules for expert-visual or visual-instrumental control of the road surface, all structures and elements of TI. However, due to the high operating costs of specialized inspection vehicles, conventional monitoring systems suffer from a limited amount of data collected from periodic inspections, which makes it impossible to fully evaluate the condition and form a clear plan for upgrading roads, structures and TI elements. This makes road survey work cumbersome and inefficient [6, 10]: some checks are redundant, and some lead to belated detection of problems. At the same time, visual methods are resource-intensive (in terms of human, time and financial resources), not promptly (do not allow you to clearly and quickly obtain data on the condition of TI, develop project documentation, etc.) and subjective (significantly depend on the experience and qualifications of employees exercising control roads) [10, 11].

It is precisely because of the outdated and poor functioning of TI monitoring systems that today RMC are reforming their observational methods and, supporting world trends, are moving to new competitive technologies that can detect and analyze the condition of TI in a short time and with high accuracy [11].

An analysis of the development of approaches to TI monitoring (A. Shtayat, et al. [11]) shows the presence of trends in the use of remote methods to solve the problems of evaluating its condition. The existing monitoring methods are conditionally divided into two groups: static methods – focused on the use of stationary sensors or instruments; dynamic methods – require certain actions to collect data on the condition of TI. At the same time, the growing appearance on the market of drones, video cameras, GPR, laser scanners, etc. as a constant and periodic source of information, contributes to monitor the condition of roads in real time (D. Gura, et al. [5]).

Static remote methods implement the ideas of non-destructive control to obtain accurate and valuable information about TI objects without direct physical contact with them. They have proven themselves well in the problems of determining local surface and structural deformations in linear transport networks (F. Tosti, et al. [12]). With low operating costs, non-contact information, and less labor required, these approaches enable early inspection of pavements, optimizing maintenance and repair practices, reducing maintenance costs, and extending pavement life (M. Rasol, et al. [13]). However, it is fair to say that the potential of these methods in TI monitoring systems is still not well understood, and they are not suitable for large-scale studies of surface deformation of the road network [5, 11, 12].

Even more theoretical are studies related to the use of dynamic methods for TI monitoring. The few studies in this area are focused on a dynamic monitoring system using portable equipment. For example, Khoudeir et al. [14] experimentally prove that, in comparison with other monitoring systems, the use of digital images of the road surface can increase the efficiency of its evaluation and operational safety. In addition, digital images can be used to evaluate any type of pavement, as well as unpaved roads. For example, Amarasiri S., et al. [15] based on the evaluation of the change in the brightness level of the image of TI objects, conclusions are drawn about the potential possibility of monitoring the degradation of the macrotexture of the road surface. Evaluating the prospects of dynamic monitoring methods, many experts consider them the most effective and recommend them, in particular, for information systems for evaluating the condition of concrete pavement [11]. We also note that in the case

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of using spatial data, an important point is the ability to track the dynamics of TI development, highlighting common features and main geographical patterns [8, 16].

Thus, regardless of the aspects of the monitoring problem considered, the TI literature review results confirm the following. The effectiveness of TI status evaluation is reduced due to the large size of the geographical areas that need to be controlled, the limited amount of human and financial resources available for RMC [10, 11, 17]. At the same time, studies of the possibility of using remote methods confirm the reduction of socio-economic costs due to such unique advantages [10, 17]:

– a large amount of data increases the accuracy of predicting the condition of TI;

– the cumulative measurement of the current condition of the object increases the accuracy of the inspection, contributes to the early detection of problems and reduces the number of visits of the TI facilities with an inspection;

– reducing the time of road maintenance work while complying with RMC policies based on continuous monitoring of the TI condition.

Therefore, in order to increase the objectivity of monitoring results based on the analysis of independent heterogeneous data obtained by different methods from different sources, it is necessary to implement IT that combines visual control of the TI condition with remote sensing data. Implementing the concept of non-destructive control to obtain accurate and timely information about the condition of TI, such technologies [11, 12, 17]:

– allow you to create lists of works for maintenance, renovation and / or reconstruction of TI facilities, reducing the total cost of maintenance;

– help RMC prioritize finding ways to improve TI by formulating plans and investment strategies for development projects;

– make it possible to track the dynamics, establish common features and patterns of TI development, etc.

3 MATERIALS AND METHODS

Today, the legislation of Ukraine in the field of evaluating the condition of roads is in the process of formation, only some operations of the TI monitoring process are regulated at the level of industry standards (for example, [18, 19]). Traditionally, the standards prescribe to collect data (the initial elements of the set $V = \{v_i\}$) by expert-visual and visual-instrumental methods, the choice of which is determined by road-maintenance priorities, available resources and geographical limitations [17]. The global practice of RMC "transfer of responsibility" embedded in the regulatory framework can significantly reduce the objectivity of the obtained evaluations of the TI condition [6, 15], causes delays in problems detection [17], increases overall maintenance costs [20], reduce road safety and quality of TI [12]. In order to eliminate the possible listed problems, it is proposed to expand the set V by adding data obtained by remote sensing methods.

When monitoring the TI, an idea is formed about the actual condition of the road surface and infrastructure elements to find ways to improve it, i.e., in accordance with expression (1), the resulting elements of the set V must be transformed by IT into a set $O = \{o_j\}$ for evaluating the TI condition.

At the same time, like any information process, the TI monitoring process under consideration requires algorithmizing and formalization to eliminate chaos, determination of a clear sequence of operations, ease of control over their implementation, etc., as well as for systematizing the data, requirements, norms and rules in one document arising from the provisions of various regulatory documents [21].

To determine the procedure for actions that implement the mapping $V \xrightarrow{f} O$, using the author's methodology for studying information processes, we will conceptually present the process of TI monitoring as a set-theoretic model of its information flows [21–23]

$$I\_\mathrm{Pr} = (V, O, A, \psi, Z, \varphi) . \tag{4}$$

Based on the requirements of the standards [18, 19] and taking into account global trends [5, 17], we will form the set V of the model (4) from the following elements: v_1 – satellite imagery of the TI study area; v_2 – survey results of the TI section; v_3 – results of engineering surveys of the TI section objects; v_4 – base map. At the output of the process, a set O is formed, which combines the following elements: o_1 – TI section objects database; o_2 – the list of objects of problematic TI section; o_3 – TI section condition evaluations. It is possible by implementing the operations defined by the set A: a_1 – to define the objects of the TI section; a_2 – to check the condition of the TI section objects; a_3 – to form TI section condition evaluations. To normalize the internal content of information flows during TI monitoring, documents that specify the requirements for TI objects, the rules for their definition, control and operation are used. This means that the set Z (a set of documents regulating the process) will combine the elements: z_1 – table of decryption signs of objects; z_2 – requirements of the Building Code; z_3 – TI section objects evaluation requirements. Also, in model (4) ψ means the output function, which uniquely determines the rules for the formation of elements of the set O; φ – update function, the execution of which is necessary to clarify the input data of the process in accordance with the requirements of the elements of the set Z.

TI monitoring is carried out discretely in time, which means that the inputs and outputs will change depending on the requirements of the regulatory documents, the initial data at the input and the set of operations that implement the process:

$$\begin{cases} V(t) = \varphi(V(t-1), Z(t)); \\ O(t) = \psi(V(t), A(t)), \end{cases} \tag{5}$$

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that is, the input of the process at the present $V(t)$ depends on the input at the previous moment of time and the set of documents regulating the process, $Z(t)$; the output of the process $O(t)$ is determined by the set $V(t)$ and the operations $A(t)$ performed in the present.

The output function – displaying the view:

$$\psi : A \times V \to O, \tag{6}$$

which depends on the complexity of the process, can be presented in tabular, graph and graphical view [21–23].

Defining the mapping (6) in the model (4), we present the function ψ in graph form (Fig. 2) in accordance with the rules formed in [22].

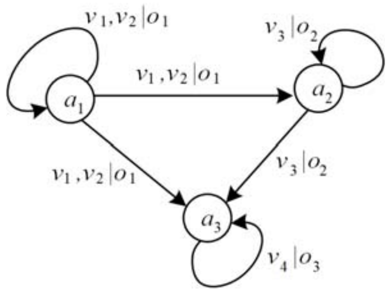

Figure 2 – Output function graph view (6)

Output function graph view (6) – it is a directed graph representation (Fig. 2), whose vertices correspond to the operations of the set $A = \{a_g\}, g = 1,...,3$, and edges – possible transitions from one operation of the process to another. Each edge has a weight – specifying an element of the set $V = \{v_i\}, i = 1,...,4$, on which there is a transition from the execution of one operation a_g to another, and an element of the set $O = \{o_j\}, j = 1,...,3$ as a result a_g, necessary to perform subsequent operations [22]. For example, at time *t*, the arrival of the operation at the input a_3 element v_4 allows to form an output element o_3. But at the same time, an output o_1 is needed, resulting from an operation a_1 by combining an input data v_1 and v_2, as well as the exit o_2, as a result of operation a_2.

For clarity and to facilitate the perception of data and operations of the *I_Pr* process, while maintaining the rigor and formality of the presentation, we depict the graph (Fig. 2) in the form of an IDEF0-model (Fig. 3) [22, 23]. Based on the provisions of the functional modeling methodology, IDEF0-model determines the structure of IT monitoring of the TI.

In the IDEF0-model, GIS is considered as a means of performing a set of operations A, and spatial analysis (or GIS analysis) of TI monitoring tasks solved with its help contains a set of methods and tools for combining geospatial data with the arguments of decision makers [3, 17, 23].

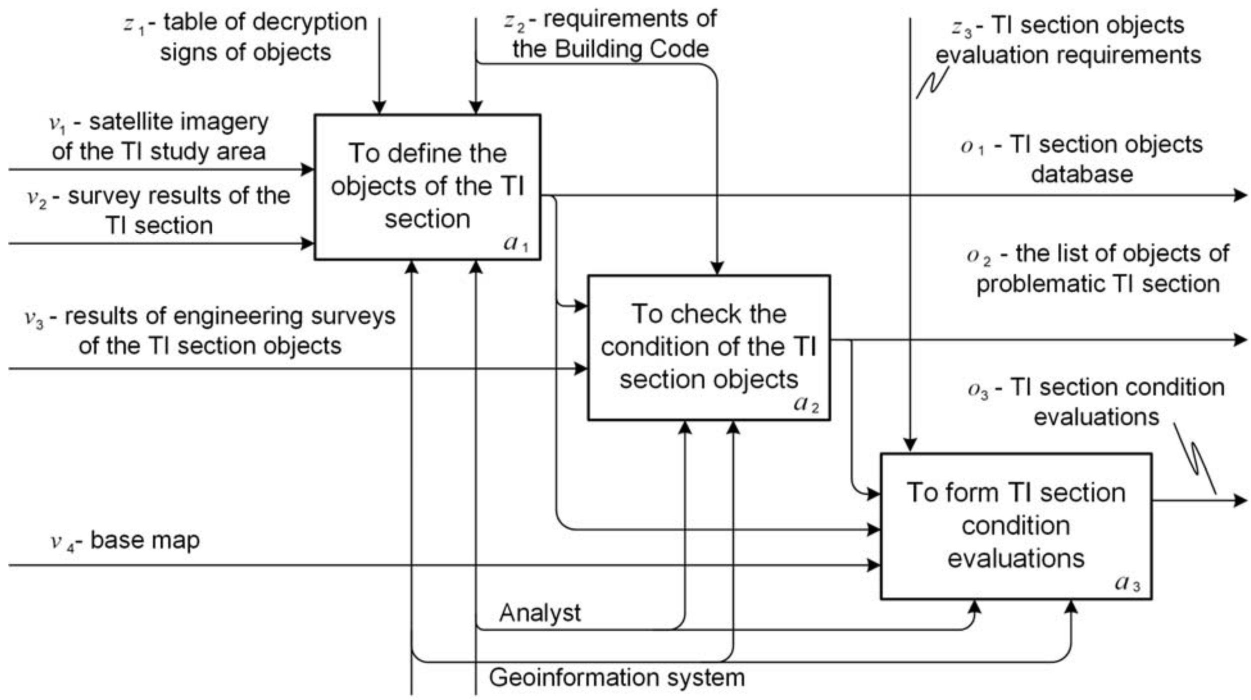

Figure 3 – IDEF0-model as a structure of information technology of transport infrastructure monitoring, that explains graphical view of function ψ realizations

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Executing the update function – displaying the view [21–23]:

$$\varphi : V \times Z \to V \qquad (7)$$

is necessary to refine the input data in accordance with the requirements of the documents of the set Z.

The simplest approach to the definition of function (7) is enumeration, when the expert associates each element of the set V with an implementation of the view:

$$v_i = \varphi(v_i, z_l) \;\; \forall v_i \in V \;,\; i = \overline{1,4} \;\; \forall z_l \in Z \;,\; l = \overline{1,3} \,. \qquad (8)$$

Taking into account the dynamic nature of the TI monitoring process, based on the first expression of the system (5), experts need to discretely form a set of implementations (8) in time. On the other hand, in the context of digitalization of TI monitoring and its information support, the expert approach to the formation of implementations (8) contradicts the principles of standard procedures, adherence to uniform approaches and data processing technologies, formed, for example, in [5, 12, 15]. Dynamic nature of the function φ can be explained by using the IDEF3 methodology. It has been chosen due to the following reasons [21, 24]:

– IDEF3 reveals the implementation logic of set A operations, representing their dynamic sequence in the form of a scenario that is implemented by IT in a finite time in accordance with the first expression of the system (5);

– IDEF3 is an extension of the IDEF0 standard, which is used to represent the function of outputs ψ;

– IDEF3 provides a tool for creating a set of graphical models that reveal the mechanism for generating realization (8) of the update function φ of the process, while providing simplicity, clarity and ease of perception of the dynamic character of information flows;

– IDEF3 as a part of a structural analysis, has certain semantics for describing information processes, which facilitates their full understanding by developers and end users.

All of the above, on the one hand, makes it possible to take into account the dynamic nature of the TI monitoring process and, in particular, the update function φ according to (5), on the other hand, reveals the mechanism for obtaining realizations (8) in the form of a final sequence of process operations. A graphical representation of the implementations of the function φ based on the IDEF3 methodology, which explains the TI monitoring mechanism in accordance with the expressions of system (5), is shown in Fig. 4. The resulting IDEF3-model reveals the IT monitoring structure of TI for decision-making when looking for ways to improve it [24].

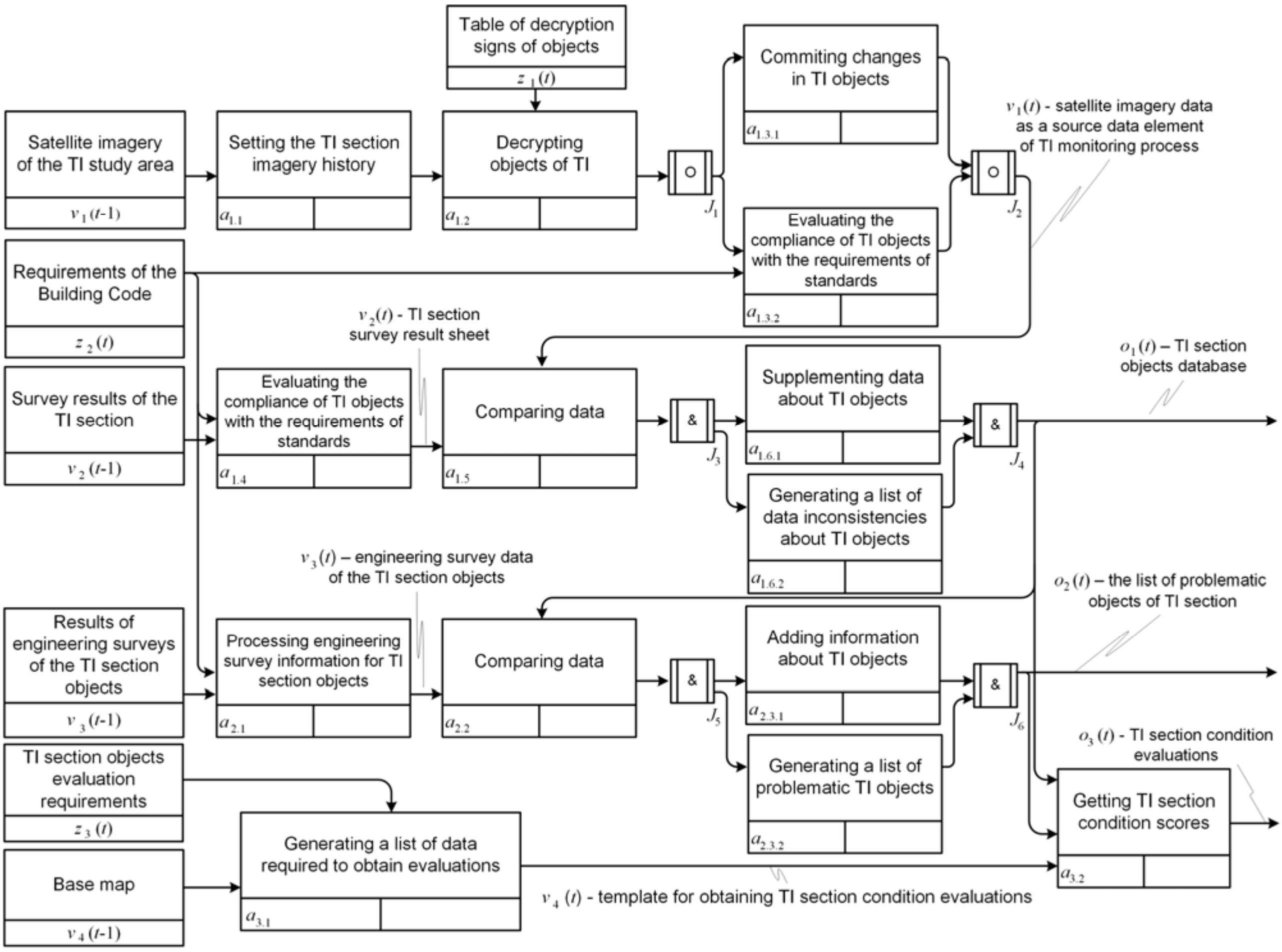

Figure 4 – IDEF3-model, that explains graphical view of function φ realizations

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The sequence of actions on Fig. 4 is formed by summarizing the results of works [5, 12, 15, 17] and the recommendations of current standards [18, 19]. At the same time, the operations of the set $A=\{a_g\}, g=1,...,3$ are refined and revealed as the function $f:V \to O$ is implemented. This is explained by the corresponding identifiers of the unit of work of IDEF3-model (for example, the identifier $a_{3.1}$ denotes the first sub-operation of the operation a_3, etc.). Also here, a temporary designation of the elements of the sets V and Z is additionally introduced to explain the dynamics of their change (which is not typical for the IDEF3 methodology).

The IDEF3-model uses typical definitions of industry standards [18, 19], for example, the TI section survey results sheet, etc. This is a document that organizes the results of a survey of a road surface by a visual or visual-instrumental method in order to determine its technical condition. Thus, the output o_1, obtained from the junction J_4, is a multidimensional database that combines in a single description heterogeneous information about static (TI object name, coordinates, geometric and operational characteristics, etc.) and dynamic (a snapshot of the object, the area of damage to the coverage on the date of the survey, the strength of concrete relative to the norms, etc.) characteristics of the objects obtained during TI monitoring. The algorithm for the formation of such a database on the example of another object of study is considered in the work of the authors [23]. The same data are input to operations a_2 and a_3, where, in one case, they are considered as the basis for the formation of evaluations of the condition of the TI site, in the other, these data are refined by comparison with the results of engineering surveys of TI objects.

Thereby, the consistent refinement of the conceptual model of information flows of the TI monitoring process makes it possible to form the structure of IT and present it as a set of IDEFX-models that explain how a set of heterogeneous (graphic, text, digital, cartographic, etc.) data about TI elements obtained from different sources are processed and presented to support decision-making on ways to improve it.

4 EXPERIMENTS

The possibility of using the proposed IT for TI monitoring is considered on the example of the Kharkiv district of the Kharkiv region near the villages of Rokytne, Pavlivka, Vatutine, Vilkhuvatka, Ordivka, Krynychky with a total population of 3602 people (Fig. 5).

The purpose of the experiment was to evaluate the possibility of using remote data in TI monitoring to solve the following problems:

– obtaining generalizing coefficients for the analysis of TI of a separate area for choosing directions for the strategic development of territories;

– inventorying the TI objects;

– modeling the TI and its elements;

Figure 5 – Study area (TI section) on the Sentinel-2 imagery

– researching the TI properties to substantiate design decisions during the reconstruction, development of the existing transport network;

– planning a procedure for surveying the condition of highways and other TI facilities.

The following were used as initial data:

– satellite images of the study area from Sentinel–2 and SuperView-1;

– table of decryption signs of TI objects;

– results of laser survey with a Leica RTC 360 scanner;

– results of tachometric survey in the SK-63 coordinate system using the Leica FlexLine TS03 device.

The implementation of proposed IT is possible by using the ArcGIS software suite by Esri. When validating the evaluations, they were compared for compliance with the results obtained from the statistics department of the Kharkiv region, which made it possible to conduct an experiment to study the effectiveness of IT in real conditions and on real objects.

As a result of the experiment, conclusions were drawn about the possibility of using remote data as auxiliary tools that complement the existing expert-visual and visual-instrumental methods for TI monitoring.

5 RESULTS

An analysis of a snapshot of the road infrastructure in the study area (Fig. 5) showed that it covers an area of S=61.25 km^2, the total length of roads of various types is L=17.8 km. Using formulas (2), (3), we find generalizing coefficients $K(E) \approx 0.038$ and $K(G) \approx 0.93$. To validate the obtained data, using statistical data, for the Kharkiv region we will obtain S=31418 km^2, L=9672.8 km, H=2633834 people, N=1755; hence the values of the coefficients for Kharkiv region are $K(E) \approx 0.034$ and $K(G) \approx 1.3$.

Fig. 6 shows the result of solving the problem of inventorying objects and TI cartographic modeling of the

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study area: all TI objects were found and plotted on a cartographic base to fix spatial data, systematize and visualize the information received about the road transport infrastructure.

Artificial structures, and primarily bridges, are the most complex and expensive structures in the transport infrastructure [25]. The cartographic model (Fig. 6) shows several bridges that have been identified in the study area. Further, among the bridges presented in Fig. 6, a bridge over the river Mzha, located on the territory of the Rokytne village, which is on the local road that connects the M-18 and M-29 highways, was selected for analysis.

Traditionally, evaluation of the condition of bridges is based on visual inspections and surveys using geotechnical field instruments and geodetic equipment. Naturally, the results of such engineering surveys significantly depend on subjective factors, including the level of training of specialists [17, 25]. However, laser scanning technology is increasingly attracting the attention of inspectors and researchers in the field of bridge management, allowing to obtain detailed bridge geometry. Being a kind of remote methods, laser scanning of objects increases the reliability of the survey results by increasing the sample of measurements, and improves the quality of project documentation [5, 25].

The results of laser survey of the bridge obtained as initial data made it possible to build an information 3D-model of bridge structures (Fig. 7) with an accuracy of 1 mm. Its integration into a 3D relief model improves the perception of TI objects as natural elements located in real conditions of the natural environment of the study area.

6 DISCUSSION

The results of the experiment confirmed that, based on remote data, it is easy to find the generalizing Engel and Goltz coefficients for analyzing the transport component of the area. In the context of the ongoing administrative-territorial reform in Ukraine, when statistical data on the region may not be available, remote data becomes the only means of obtaining the necessary information. Note that the found values of the coefficients for the study area are comparable with the statistical values for the region. At the same time, the level of provision of the population with motor transport routes slightly exceeds (by 12.7%) the statistical data for the Kharkiv region, and attention should be paid to the development of the road network between villages: compared to the region, this indicator is lower by 28.7%.

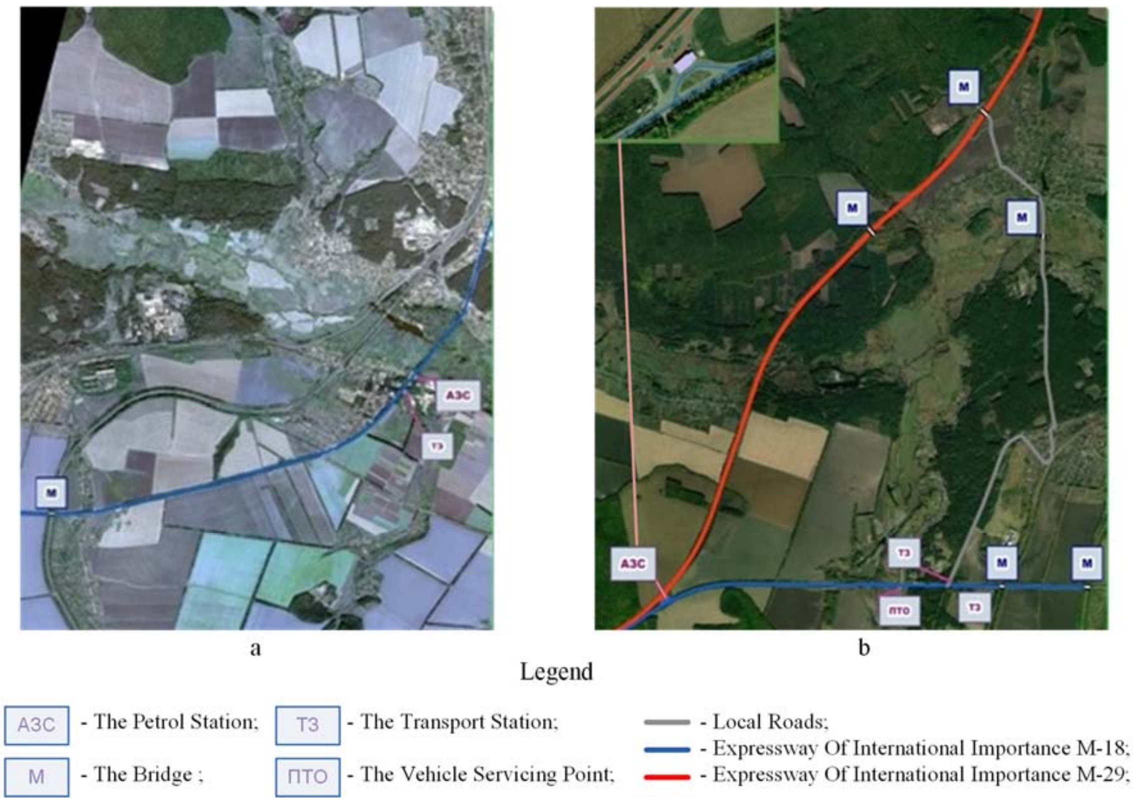

Figure 6 – An example of solving the problem of object inventory and TI cartographic modeling based on:
a – satellite images from SuperView-1; b – satellite images from Sentinel–2

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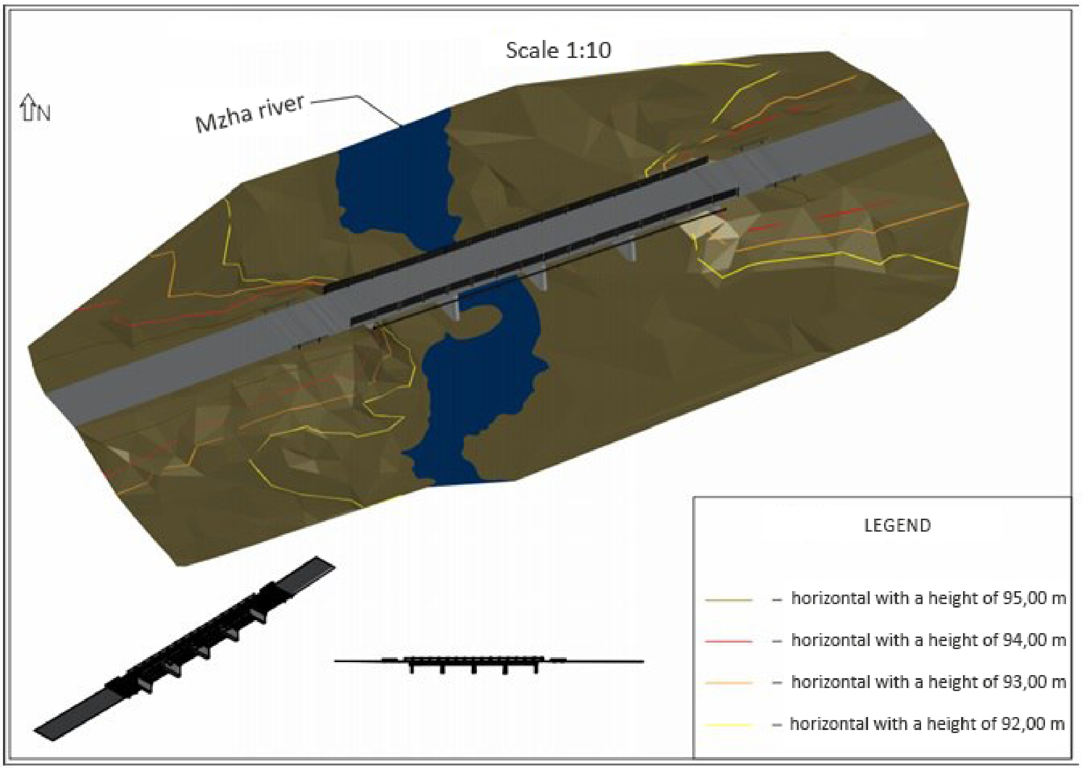

Figure 7 – An example of solving the problem of 3D-modeling of TI objects based on the results of laser scanning

The results of solving the problem of inventory of objects and cartographic modeling of the TI of the study area (Fig. 6) showed that the graphical interpretation of different types of objects and the possibility of combining different images on the model improves the visual perception of the condition of the TI section. At the same time, the high resolution of images does not affect the speed of their processing by ArcGIS.

Analyzing the image from the SuperView-1 satellite (Fig. 6a), we note that its resolution (0.5 m per pixel) makes it possible to apply the results of a visual inspection of the highways concrete pavement condition to the model using the gradation provided by the Building Code B.2.3-218-534:2011. This significantly expands the scope of the developed IT and in the future creates an opportunity for substantiating design solutions for the reconstruction of the transport network and planning procedures for examining its condition, which is also confirmed by the conclusions obtained in [17]. However, due to the lack of results of a real survey of TI in the study area, the scope of this study is limited only to evaluate the possibility of using the developed IT in solving such problems. It should be noted that the low-resolution, free images from the Sentinel–2 satellite (Fig. 6b) do not allow solving such problems. But the resulting cartographic models will help RMC to identify vulnerabilities in the investigated road infrastructure, facilitate decision-making when planning procedures for examining the condition of TI objects, etc.

Interesting prospects are opened by the integrated use of remote data and the results of engineering surveys of TI objects, collected using modern geodetic equipment. The 3D-model of the bridge built based on the results of laser scanning makes it possible not only to obtain accurate design documentation, but also makes it possible to conduct a comprehensive analysis of the bridge, taking into account the physical and geographical location and predict its behavior without fieldwork. However, the lack of a reference model makes it difficult to solve the problem of evaluating the condition of the bridge: research is primarily focused on its representation as a whole, it lacks a clear linkage of changes to specific characteristics, which means that it is difficult to understand what data should be used as a reference for the condition evaluating for a certain period of time.

CONCLUSIONS

The actual problem of developing scientific and methodological support of information support for the process of monitoring the transport infrastructure in order to find ways to improve it in the implementation of development projects has been solved.

The scientific novelty of the obtained results is that the methodology for researching information processes has been further developed by adapting it to solve TI monitoring problems by refining the set-theoretic model of information flows process. Based on the requirements of current standards, taking into account global trends, a set of input and output parameters of the model, as well as a set of process operations, are formed. As a result of the consistent refinement of this model, for the first time, an information technology for monitoring the transport infrastructure was proposed, including a set of IDEFX-models

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that explain how a set of heterogeneous (graphic, text, digital, cartographic, etc.) data about TI elements upcoming from different sources are processed and presented to support decision-making process on the survey and improvement of the existing infrastructure.

The practical significance of the obtained results is that the representation of the IT structure based on the IDEF functional modeling standard makes it easy to move to the creation of information monitoring systems for TI based on remote data. The conducted experiment on studying the capabilities of the proposed IT showed its effectiveness in solving the classical problems of complex analysis of TI based on generalizing coefficients, and also outlined the range of tasks where it can be used as an addition to the existing expert visual and visual-instrumental methods of TI monitoring. The results of the experiment make it possible to recommend the developed IT for use in practice, as well as to determine the effective conditions for its application.

Prospects for further research are the combining of remote data, survey results of TI sections and engineering surveys of objects on these sections to form evaluations of the TI condition. On the other hand, the direction associated with the refinement and expansion of the table of decryption signs for road transport infrastructure objects, as well as obtaining reference models of TI objects for monitoring the road surface and infrastructure as a whole, becomes interesting.

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ МОНИТОРИНГУ ТРАСПОРТНОЇ ІНФРАСТРУКТУРИ НА ОСНОВІ ДАНИХ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ

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АНОТАЦІЯ

Актуальність. На тлі існуючої практики моніторингу автодорожньої мережі це дослідження спрямоване на вивчення можливостей технологій дистанційного зондування для вирішення завдань підвищення об'єктивності одержаних оцінок стану транспортної інфраструктури в цілому. Об'єктом дослідження являється процес моніторингу транспортної інфраструктури для пошуку шляхів її вдосконалення при реалізації проєктів розвитку. Мета роботи – шляхом наочного подання та візуалізації просторових даних моніторингу транспортної інфраструктури підвищити об'єктивність рішень, що приймаються, відносно планів обстеження, реконструкції та розвитку існуючої транспортної мережі.

Метод. Проаналізовано існуючі підходи до моніторингу транспортної інфраструктури (ТІ) та оцінювання її стану. Виділені недоліки, а також тенденції розвитку технологій дистанційного зондування відкривають перспективи з використання дистанційних даних у процесі моніторингу ТІ. Запропоновано теоретико-множинну модель інформаційних потоків процесу моніторингу, послідовне уточнення елементів якої дало змогу запропонувати інформаційну технологію (ІТ). Формування множин вхідних і вихідних параметрів ІТ, множини її операцій, подання їх у нотації IDEFX-моделей пояснює як сукупність різнорідних (графічних, текстових, цифрових, картографічних тощо) даних про елементи ТІ, які надходять з різних джерел, обробляються та надаються для підтримки прийняття рішень щодо обстеження існуючої інфраструктури та її вдосконалення. Розроблена ІТ дає змогу отримати комплексні показники для аналізу ТІ окремого району, вирішувати завдання інвентаризації об'єктів інфраструктури, картографічного моделювання ТІ та її елементів з урахуванням фізико-географічного розташування, що дає змогу розглядати її як допоміжний засіб, що доповнює існуючі методи моніторингу ТІ.

Результати. Розроблена ІТ досліджена при вирішенні завдань моніторингу ТІ ділянки Харківського району з використанням супутникових знімків середньої (Sentinel–2) і високої (SuperView-1) роздільної здатності та результатів лазерної зйомки дорожнього мосту через р. Мжу (як елементу інфраструктури).

Висновки. Проведені експерименти підтверджують працездатність запропонованої ІТ і дають змогу рекомендувати її для використання на практиці при вирішенні завдань з отримання узагальнюючих характеристик інфраструктури, інвентаризації об'єктів ТІ та їх моделювання. Це відкриває можливості щодо обґрунтування проєктних рішень реконструкції транспортної мережі та планування процедур обстеження її стану. Перспективи подальших досліджень можуть полягати: у створенні еталонних моделей об'єктів ТІ, розширенні таблиці дешифрувальних ознак об'єктів дорожньо-транспортної інфраструктури, комплексуванні дистанційних даних, результатів обстеження ділянок ТІ й інженерних вишукувань об'єктів для отримання оцінок стану ТІ в цілому.

КЛЮЧОВІ СЛОВА: модель інформаційних потоків процесу, IDEFX-моделі, картографічне та 3D-моделювання.

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