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MODELING OF INFORMATION ARCHITECTURE AND INFORMATION SUPPORT OF TRANSPORTATION IN CONDITIONS OF UNCERTAINTY

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The article considers the content characteristics of the information architecture of transport logistics (IATL) as a means of orientation on websites using appropriate interfaces and dialog windows. The logistical and physical description of the information support of transport operations is given. The scheme of the IATL is proposed for complex transportations carried out in conditions of uncertainty of external environmental influences and risk. The IATL is built on a structural-functional organizational basis, which allows forming groups of information objects based on understanding of the ultimate needs, patterns of perception and features of transport logistics. A distinctive feature of the proposed scheme is the categorization of information architecture modules in a certain format and its adaptability to the external environment. The use of information in the proposed scheme highlights the following components: the presence of priorities in the application of input information and software and hardware, the location and ranking of auxiliary subsystems according to their importance in making decisions regarding transportation conditions, coordination of interactions, the presence of logical subordination relationships between the elements of the scheme, alternation and sequence of functional procedures, coordination of goals and interactions, timely transfer of information, development of methods for eliminating uncertainty. A logistic mathematical model of the information architecture of transport transportation is proposed, an information structure and a simulation model of management under uncertainty, which includes the relationships between goals, alternative means of achieving them and available resources. The use of basic theoretical principles and organizational and methodological provisions when creating blocks of information architecture provides the ability to adjust management decisions to increase the efficiency of transportation according to developed and agreed plans. The development of transport and logistics information architecture systems allows for a deeper understanding of the complex interactions of elements within the system, to assess the degree of influence of factors, and to identify bottlenecks. The scientific direction of this aspect includes methods of choice theory, expert systems, simulation modeling, Markov processes, dynamic programming, fuzzy logic game theory. All of them are related to multi-criteria assessments of the current situation and have elements of risk in achieving alternative options for managing transportation.

Keywords: *information architecture, transport logistics, transportation, structural diagrams, functional approach, uncertainty.*

Statement of the problem

The intensive process of relocation of production from Western Europe and the USA to the countries of Southeast Asia and the formation of a reverse flow of finished products in the context of growing consumption in developed countries have become the main incentive for the development of the world market of transport and logistics services.

Transport logistics is based on the integration of transport, supply, storage, and sales. Its task is to develop a route that allows cargo to be delivered from the sender to the recipient in a short time with minimal costs. In the process of logistics development, the problems of optimizing the volume of deliveries, routes, placement, warehouse sizes, and monitoring of transport flows along the entire route are solved. To facilitate their solution, the appropriate information architecture is used.

Information architecture is a set of processes for organizing structured information to navigate through websites with the distribution of cognitive load and orientation through the appropriate interfaces and dialog boxes when it is necessary to convey the importance of various parts of the content to create a scenario. Information architecture denotes the fundamental organization of the target system, which describes the main components and modules with the principles of their operation and interrelation with each other, as well as various variations of development and evolution of events.

Information architecture is designed to support the parameters of transport flows, coordinating the actions of all transport links on an interactive map to ensure maximum use of resources by optimizing transport operations.

Transport logistics functions under dynamic changes in the external environment when the influence of the external environment is unpredictable, i.e. under conditions of uncertainty. Therefore, information support for technological operations of transport transportation under challenging conditions of their implementation becomes relevant. Uncertainty is a system-wide property associated with limited knowledge about the state of the external environment. Risk arises from uncertainty and is understood as the probability of a negative outcome of events.

The problem under consideration relates to decision-making on the organization of transportation when unforeseen situations arise on the route.

The lack of the necessary level of consistency and dynamism in the field of transportation is the rationale for the need to develop new theoretical principles and organizational and methodological provisions in creating information architecture blocks.

Analysis of the latest achievements on the identified problem

Among the topics of information architecture of transport logistics (IATL), it is worth noting the works of domestic scientists in the field of analytical methods for managing the development of innovations and transport flows in logistics [1-4].

The international logistics platform of information architecture distributes information across countries with complex businesses and various data sources. The architecture of the information service for the international multimodal corridor POL-Corridor is presented in [5]. In [6], a service-oriented architecture of distribution and exchange of data in a heterogeneous environment is analyzed and designed. Information architecture for solving the problems of filtering, aggregation and operational analysis of downstream flows is presented in [7, 8]. A conceptual service-oriented program of information architecture with the interception of digital events related to transportation and monitoring of logistics processes with the presentation of interfaces is described in [9]. A method of operational information management on a route in the form of graph nodes describing stops between destinations, edges describing distances between routes and correspondence of implementations along several routes is presented in [10]. A collision-free pathfinding for multiple agents based on neural structures is presented in [11]. A system architecture of intelligent transport logistics based on collecting and transmitting information for electronic coding in urban transport management is described in [12]. A functional model of the information architecture of the transport and logical platform is presented in [13]. Functional requirements for logistics distribution based on Internet of Things technologies are described in [14]. In [15], it is proposed to use the Node-RED programming tool for structured environments of the Internet of Things (I_0T) system, using the same technologies and communication protocols to form a logistics apparatus. The form of business logic, hierarchy of information and applications are defined. In [16, 17], an information architecture is proposed that allows integrating information carried in containers into the logistics chain through an open interface platform that supports interaction with ports around the world. Elements of building the information architecture of technical products and processes are described in [18-21].

Despite the obvious advantages of using information architecture, information on its applicability in transport logistics is very limited.

Purpose and task statement

The work aims to build a diagram of the information architecture and information support for multimodal transportation in conditions of uncertainty and risk.

Tasks of the work:

- formation of a logistic mathematical model of transportation,
- physical description of information support for transport operations,
- substantive characteristics of the IATL,
- construction of a diagram of the information architecture and information support for transport logistics.

Summary of the main material

The reasons for the emergence of uncertainty in transport logistics are presented in Fig. 1.

The causes of uncertainty in transport logistics include time-gap deliveries, traffic congestion, dynamic routing, and the gap between operational actions and practice.

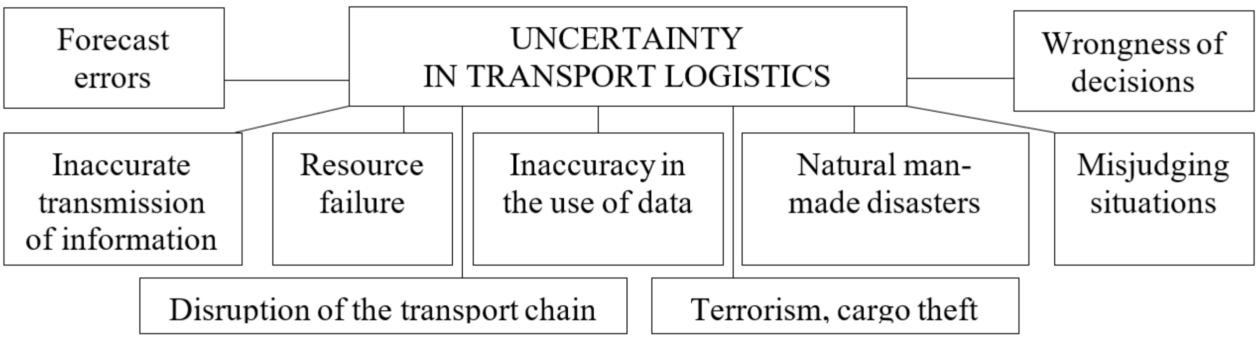

Fig. 1 – Causes of uncertainty in transport logistics

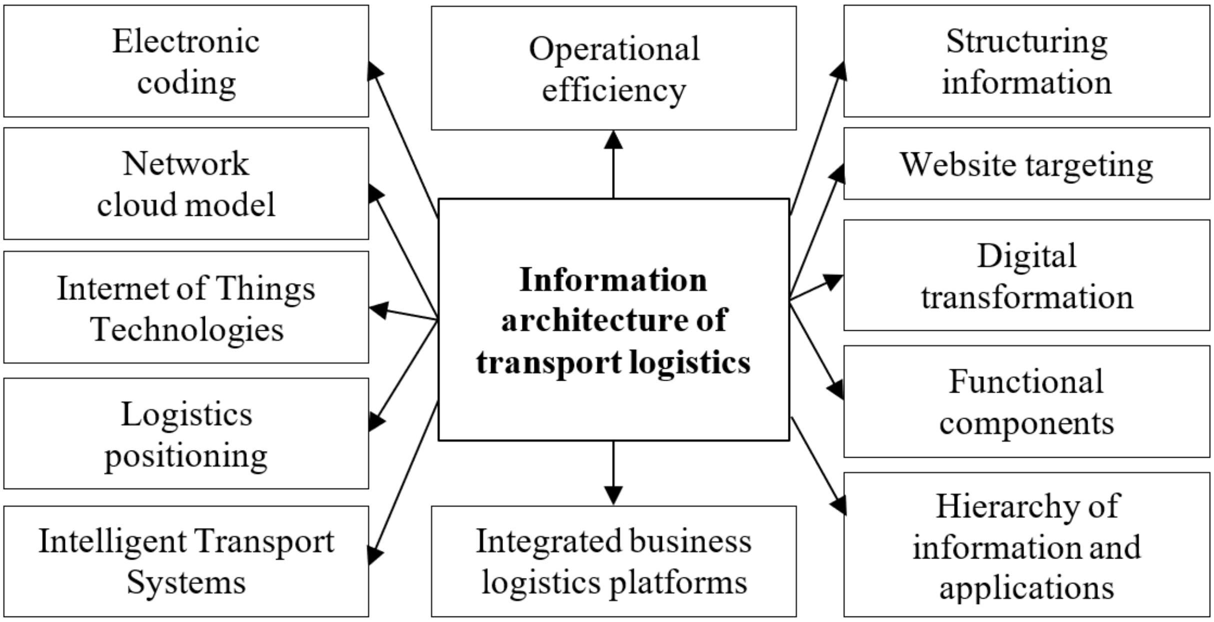

Fig. 2 – Implementation model of the IATL

Transport logistics is currently experiencing a turning point and changing operational purposes. The central place in international freight transport systems is provided by the constant reaction to disruptive events and volatility caused by a combination of various factors and the need to adapt to them. Geopolitical tensions and climatic factors are increasing, which are the basis for macroeconomic uncertainty and digitally enabled globalization models. As for maritime transport, which accounts for about 80% of the world's merchandise trade, it is necessary to solve the problems associated with low carbon emissions and the introduction of cleaner alternative fuels. By the end of 2023, global logistics, which is based on maritime transport, was threatened by events related to the war in Ukraine and events taking place in the Red Sea, Suez and Panama Canals.

Globalization and the development of cooperative relations between participants in the production processes lead to the fact that most freight transportation is carried out by different modes of transport. Today, the share of sea transport with the participation of river and rail transport accounts for up to 90% of the transportation. Rail transport, in interaction with road transport, carries out transportation of up to 35% of all cargo. Since the beginning of military actions in the territory of Ukraine, direct sea deliveries and air transportation have ceased. Today, most domestic cargo crosses the border using freight trains and cars, heading to the seaports of Hamburg, Romania and the Baltic countries, as well as to the airports of Poland in Katowice and Warsaw. The implementation model of the information architecture, compiled on the basis of the analysis and experience of using information technologies in transport logistics, is shown in Fig. 2.

The logical description includes products that define the boundaries between the system and its environment, between functional interfaces and the external system. The logistic mathematical model of transportation is a system of connections between goals, alternative means of achieving them and available resources.

The most acceptable apparatus for formalizing the description of transport management under conditions of uncertainty is the choice of options from a variety of alternatives $\{\chi\}$ [4]. Any alternative can be assigned to this set using the principle of choice *F*

$$\{\{\chi\}, F\} \to \chi^*,$$

where χ^* – selected alternative.

Gradation of solutions by the degree of formalization of transport management tasks:

- a set of alternatives $\{\chi\}$ is clearly defined and fixed, and the principle of choice is formalized;

- a set of alternatives $\{\chi\}$ is also strictly defined, but the principle of choosing F is not formalized and carries elements of experience, intuition, subjectivity;

- a set $\{\chi\}$ has no defined boundaries, can be supplemented and modified, and there is no formalization in the principle of choosing *F*, that is, we have a situation of decision-making under conditions of uncertainty.

Thus, for the values $\{\chi\}$ ta *F* does not have exact values and indications, but there is an assumption of effectiveness and going beyond the limits of formalization.

There is an initial set of alternatives $\left\{\chi^{(0)}\right\}$. This initial condition restricts the finite set of alternatives, making the problem statement more concrete.

Another constraint that narrows the task of decision making under uncertainty is that any alternative can be evaluated in terms of its inclusion in $\left\{\chi\right\}$. This is achieved using the principle of choice *F*.

This achieves the invariance of the mathematical description of the behavior of the elements of the information architecture, which gives it universality. Control alternatives are selected depending on the situation, the assessment of which requires diagnostics. The process of changing the state of the system over time is determined by the dynamics of the transport system, characterized by a multidimensional value *y,* which can take on a number of values at hierarchical levels $y \in Y$.

Having designated the process dynamics parameter as t, and the set of its values through T, we have $t \in T$, where $y = y(t)$. The process of transition of a system from a state with a time parameter value t_0 into state *S* with value $t > t_0$ we have

$$S_{t_0 t}(y(t_0)) = y(t), y \in Y, t \in T.$$

Having designated through the control action on the course of the process of transport transportation from the entire possible set of controls, we have

$$S^u_{t_0 t}(y(t,u)) = y(t,u), y \in Y, t \in T, u \in U.$$

Each individual management alternative can be assessed by a specific number or value of the corresponding criterion. Then the comparison of alternatives will be reduced to a comparison of the numbers corresponding to them. Let us denote by *x* some alternative from the set *X*, then for $x \in X$ a function can be given $q(x)$, called the objective function and having the property that if the alternative x_1 preferable to alternatives x_2, i.e. $x_1 > x_2$, that $q(x_1) > q(x_2)$.

If there are several ways to compare the obtained alternatives or criteria, the most suitable one for a given situation is selected. Phenomenologically, this means that there is a certain criterion in the hierarchies of which all other properties of the system can be applied by reducing information about them to a single generalized scale.

To formalize each alternative, it is necessary to use a set of their target functions f_1, $f_2, \dots f_m$, $m \geq 2$, defined on a set of possible solutions *X*. These objective functions form vector criteria $\vec{f}$. Each component of the vector criterion $\vec{f} = \left(\vec{f}_1, \vec{f}_2, \dots \vec{f}_m\right)$, as a rule, characterizes some goal. The desire to achieve this goal in mathematical terms is expressed in maximization or minimization of the function f_i on the set *X* [4].

Taken together, the initial structuring determines the a priori information *I* or information structure

$$I = \{S, \beta_0(S), X, [X_s \subset X, s \in S], Y, [Y_x \subseteq Y, x \in X], G, q^g(S|S \times Y), w^g(Y \times (S \times X)), g \in G\}$$

where S – set of states;

$\beta_0(S)$ – probability distribution over a set of states;

X – many situations;

$X_s \subset X$ – restrictions on the admissibility of diagnostic alternatives depending on the condition $s \subset S$;

Y – a multitude of control alternatives;

$Y_x \subseteq Y$ – restrictions on the admissibility of control alternatives depending on the situation $x \in X$;

G – many structural alternatives;

$q^g(S|S \times Y)$ – transition function from $S \times Y$ in S;

$w^g(Y \times (S \times X))$ – utility function representing a priori preferences over alternatives $y \in Y$ and structural alternatives $g \in G$.

This information structure allows us to create a simulation model for managing transport operations under conditions of uncertainty.

Mathematically, the problem of finding the best alternative x^* is written as

$$x^* = arg \max_{x \in X} q(x).$$

However, in practice, an alternative must be assessed not by one, but by several criteria at once, which differ qualitatively from each other. In this case, the search for the necessary management alternative leads to the reduction of a multi-objective problem to a single-objective one. This is achieved by introducing a scalar function of the vector argument $q_0(x)$:

$$q_0(x) = q_0\left(q_1(x), q_2(x) \dots q_p(x)\right) \dots$$

This function allows you to arrange alternatives by size q_0 and select the best one. The contribution of each criterion to the values q_0 estimated using additive or multiplicative components

$$q_0 = \sum_{i=1}^{p} \frac{\alpha_i q_i}{S_i},$$

$$1 - q_0 = \prod_{i=1}^{p} \left(1 - \frac{\beta_i q_i}{S_i}\right).$$

Here is the coefficient S_i introduced to reduce the right-hand side of the equations to a dimensionless form

The simulation model of control under uncertainty is reduced to finding the best alternative x^* in a multi-objective problem it comes down to maximizing the function $q_0(x)$:

$$x^* = arg \max_{x \in X} q_0\left(q_1(x), q_2(x), \dots, q_p(x)\right).$$

The construction of the IATL begins with its physical description, which defines its mission, the need for its creation, the formulation of goals, the presence of the existing infrastructure, and consideration of the current situation. The physical description defines the boundaries of the system and the components of the information technology system, the interaction of modules and interfaces with detailed specification. In practical use, the information architecture is a modeling scheme for transport systems with a vertical form of management and subordination in operational activities between elements and subsystems. With the priority arrangement of elements from the top to the bottlenecks in the lower part of the information architecture scheme of transport logistics, the subordination of elements from the center inward is ensured. The choice of the transportation scheme determines the interaction of their structural components. Cargo transportation can be performed either by one carrier from the moment of receiving the cargo until the moment of its delivery to the consumer, or by transferring it to other carriers at separate sections of the route, i.e. stage-by-stage logistics transportation is implemented. In this case, the divisions of the chain are responsible only for their section of work. The complexity of organizing stage-by-stage logistics transportation is that it is necessary to synchronize the actions for transportation by other transport. In the case of an integrated system, the use of sequences of different carriers, including modes of transport, information requests to the main element can come from any department. In this type of transportation, the cargo is assigned to one transport operator, who selects the route and method of delivery of the cargo, takes care of the necessary documents and cargo insurance. The sequence of operations depends on the essence of a specific task and goes to the information processing and transportation process management center. Such a system will be multi-level and hierarchical.

A multi-level hierarchical structure is characterized by a common corporate management system. Authority and responsibility for each decision are transferred to the level of the structure in which decisions are made that are within the competence of this level. Coherence in cargo transportation depends on the precise operation of the entire logistics system. The effectiveness of such a structure will be determined by the communication tools used, taking into account resource constraints and environmental influences. The advantages of a multi-level hierarchical structure of transportation are that it is organized by one company rather than several. In this scheme, information is aimed at providing each level of the information architecture with information about the processes taking place in the logistics system.

The multi-level hierarchical structure of transportation includes three levels:

- the main level, which is the network infrastructure for moving cargo until it is received by consumers
- the first level, which is the functional infrastructure of the route section along which the cargo is transported
- the second level, which is the business processes occurring at the workplace where logical operations are carried out

A similar architecture of a three-level logistics information system using the C# platform and an SQL database is described in [20]. The main problem of managing complex multi-level hierarchical structures is that all elements of such structures function simultaneously and in combination, so synchronization with another type of transport is allocated as a separate structural block.

The sequential division into parts of the route controlled by the center in a multi-level hierarchical system provides for the decomposition of information connectivity between the elements of transport logistics. There is a division of responsibility for the implementation of management operations.

It may happen that during the implementation of the planned activities and plans, the content of the problem under consideration may change, caused by complex interactions with the environment. To eliminate or mitigate negative factors, the information architecture must provide for the correction of management decisions. Information support requires constant monitoring of the transportation process, provision of the necessary information and coordination of the actions of all participants in the movement of cargo.

Information architecture includes conceptual tools that determine the integrity of the product, navigation, orientation priorities, decision points that determine the occurrence of the main scenario. The foundation of information architecture is information. When constructing a diagram of the IATL, information is used as a collective term for storing, transmitting, transforming and collating information about the processes of transportation. The quantitative representation of information is determined through the probability of a possible event and is expressed through the number of messages, operators and files in software.

When constructing a structural and functional diagram of information architecture, the principle of consistency must be observed, which allows for the unity and continuity of the transportation process and an open information space. architecture of transport logistics takes into account the interaction between the elements.

The organizational component of the structure of the information system that determine the order, internal structure and target orientation. It is the logical basis for constructing the information architecture. The functional purposes of the organizational component are determined by the optimization of the parameters of transportation.

Results and discussions

The IATL is built on a structural and functional organizational feature that allows for the formation of groups of information objects based on an understanding of the final needs, perception patterns, and features of transport logistics. The diagram of the structural and functional IATL, compiled on the basis of these provisions, is presented in Fig. 3.

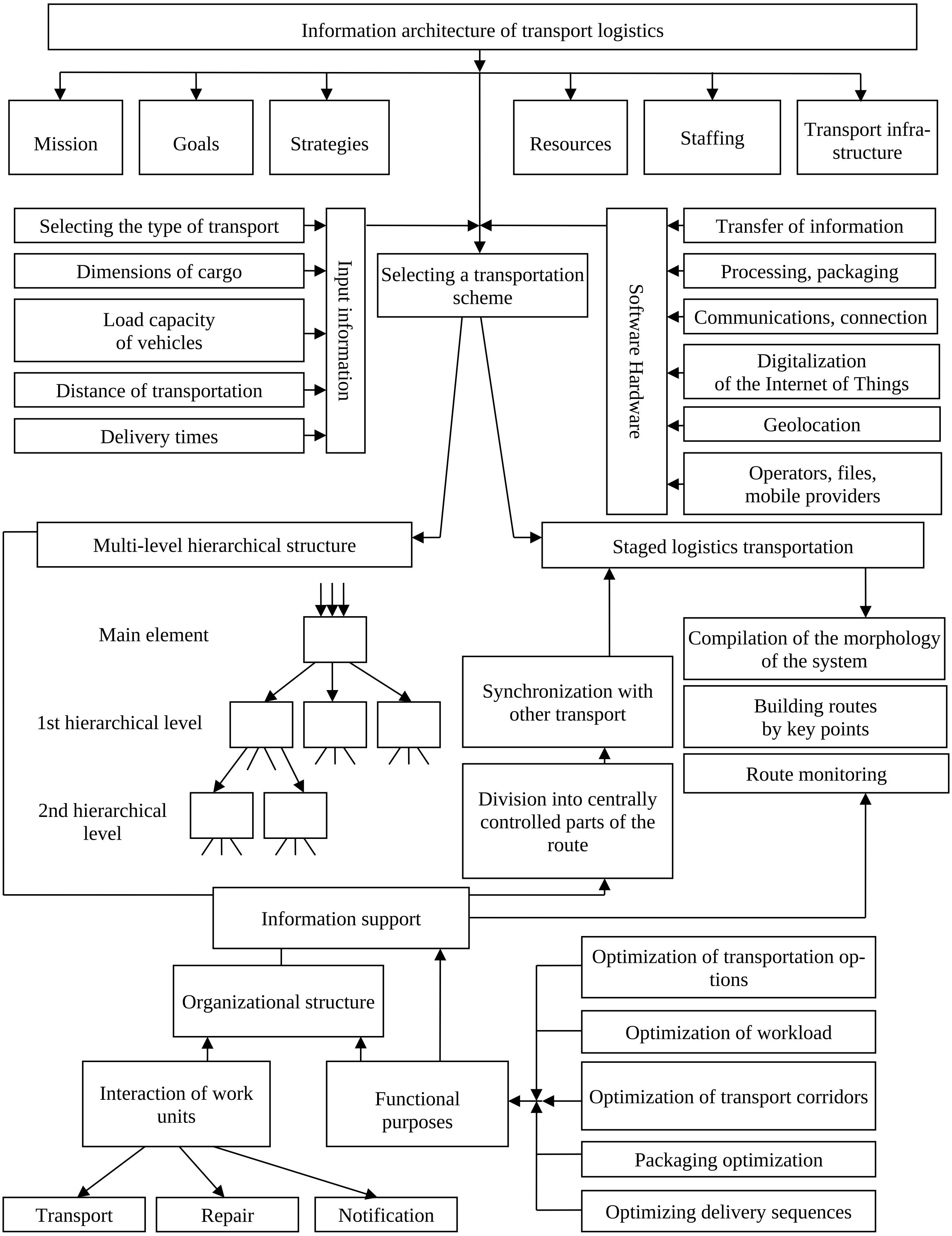

Fig. 3. Scheme of structural and functional IATL

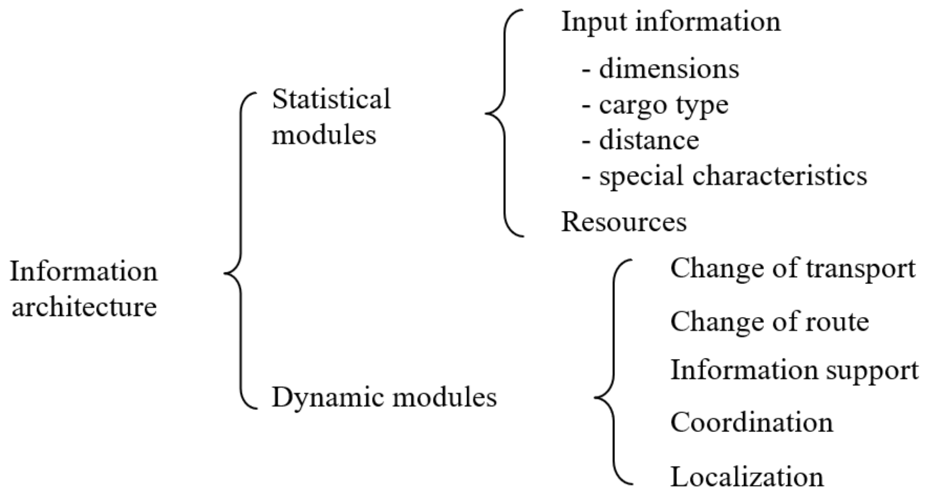

Fig. 4 – Categorization of modules of the information architecture in real time

The use of information in the proposed functional model highlights the following components:

- the presence of priorities in the application of input information and software and hardware.
- the location and ranking of supporting subsystems according to their importance in making decisions on transportation conditions
- coordination of interactions
- the presence of logical subordination relationships between the elements of the scheme
- alternation and sequence of functional procedures
- coordination of goals and interactions
- timely transfer of information
- development of uncertainty removal techniques.

Communication of information architecture modules, in a certain format, is shown in Fig. 4.

Information on identification and information support of the state of moving objects is used in software processors of service departments of links in the chain of transport transportation. The scheme of structural and functional IATL requires concentrated information for using knowledge and technologies of the subject area of transport transportation in conditions of uncertainty of the influence of the external environment.

Modern innovations in the field of multimodal transportation and information support are digitalization and automation of logistics processes, implementation of Internet of things technologies, implementation of computer technologies.

Logistics of sea transportation is a system of procedures aimed at their implementation and organization of cargo delivery by sea. Transport logistics focuses exclusively on the management of transportation and movement of goods. While general logistics covers a wider range. Including inventory management, production and distribution of goods.

An example of modeling the information architecture of sea transport logistics can be the organization of existing information on the current state of sea transport logistics by directions and current development trends in the context of large volumes of unstructured and poorly formalized information (Fig. 5). The purpose of such a structure is the introduction of information technologies into transport activities. When constructing the information architecture scheme, we tried to support the following principles: the content of websites should be located in the order of their subordination, the distribution of priorities is carried out by the levels of the logical hierarchy.

In the presented scheme, it is proposed to use spreadsheets, page templates, headings, satellite images, software and hardware solutions, electronic document management as tools for providing visual support. Information systems of port facilities, operational management of vessel arrival, transport, distribution centers of communication with other types of transport, digitalization of operations can be used as segmentation of the application of the maritime industry.

The information architecture of maritime transport logistics includes a combination of organization, labels, navigation and search implemented in the information system. Without information architecture, the content does not have a logical division and clear ways of their implementation. The presented scheme creates a visualization of page hierarchies, which can determine navigation and search structure. Grouping information by topics of interest using the proposed navigation, categorization and structuring blocks helps users navigate messages of different practical content more effectively.

Prospects for further research lie in the construction of information transport logistics schemes with detailed filling of the columns of the proposed structuring and classification of features.

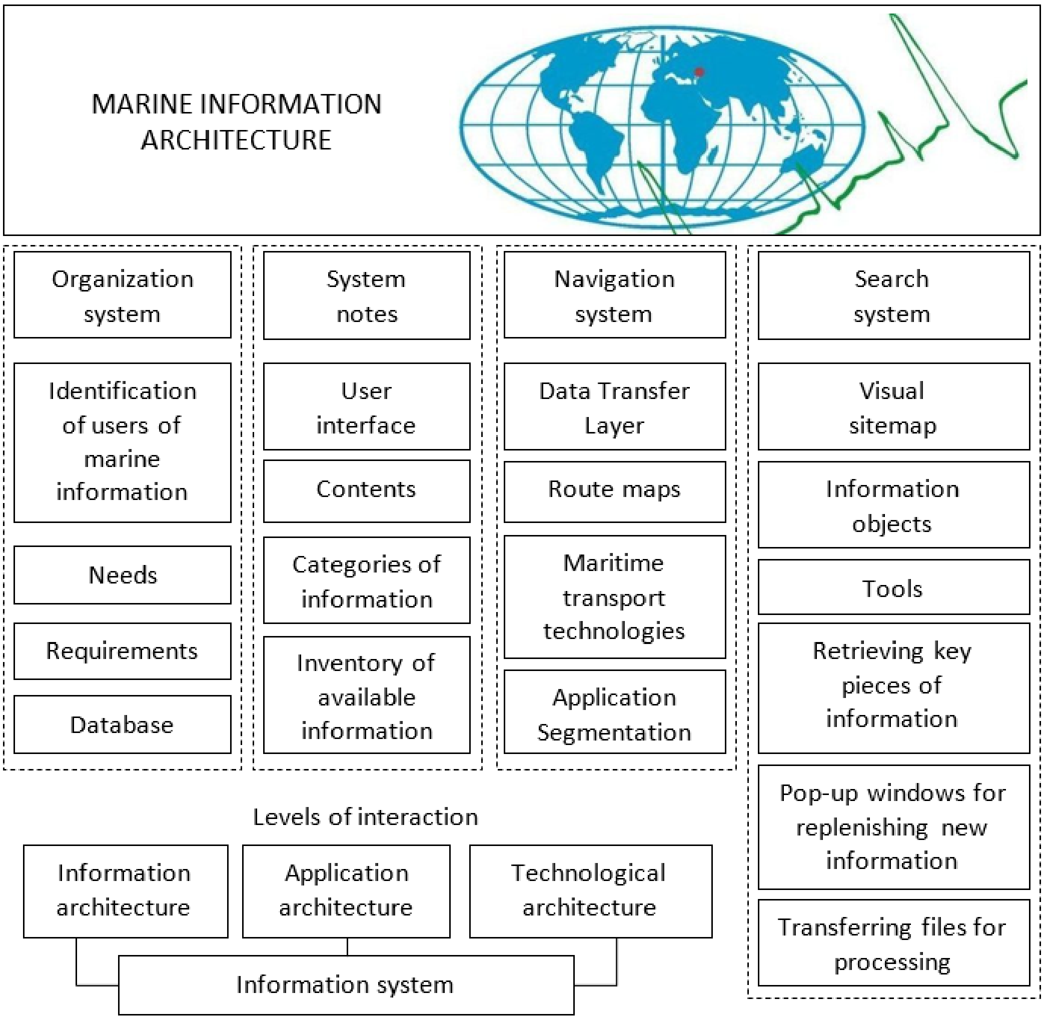

Fig. 5 – Visual representation of the information architecture of maritime transport logistics

Conclusions

1. The use of principles for constructing transport and logistics systems in information architecture provides the ability to adjust management decisions to improve the efficiency of transportation according to developed and agreed plans. The development of transport and logistics systems of information architecture allows for a deeper understanding of the complex interactions of elements within the system, an assessment of the degree of influence of factors, and the identification of bottlenecks.

2. The categorization of content in the proposed information architecture scheme, performed according to the structural and functional feature using element-by-element and resource approaches, allows for the improvement of scientific and methodological provisions for the processes of implementing transportation, the formation of a set of organizational measures, and the development of simulation models of transportation.

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МОДЕЛЮВАННЯ ІНФОРМАЦІЙНОЇ АРХІТЕКТУРИ ТА ІНФОРМАЦІЙНОГО ЗАБЕЗПЕЧЕННЯ ТРАНСПОРТНИХ ПЕРЕВЕЗЕНЬ В УМОВАХ НЕВИЗНАЧЕНОСТІ

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У статті розглянуто змістовні характеристики інформаційної архітектури транспортної логістики як засобу орієнтації на веб-сайтах з використанням відповідних інтерфейсів та діалогових вікон. Наведено логістичний та фізичний описи інформаційного забезпечення транспортних операцій. Запропоновано схему інформаційної архітектури транспортної логістики для складних перевезень, що здійснюються в умовах невизначеності зовнішніх впливів середовища та ризику. Інформаційна архітектура транспортної логістики побудована за структурно-функціональною організаційною ознакою, що дозволяє формувати групи інформаційних об'єктів на основі розуміння кінцевих потреб, закономірностей сприйняття та особливостей транспортної логістики. Відмінною особливістю запропонованої схеми є категоризація модулів інформаційної архітектури у певному форматі та її адаптивність до зовнішнього середовища. Використання інформації в запропонованій схемі виділяє наступні компоненти: наявність пріоритетів у застосуванні вхідної інформації та програмно-технічних засобів, розташування та ранжування допоміжних підсистем за їх важливістю у прийнятті рішень щодо умов транспортування, координація взаємодій, наявність зв'язків логічної підпорядкованості між елементами схеми, чергування та послідовність функціональних процедур, координація цілей і взаємодій, своєчасна передача інформації, розробка методик усунення невизначеності. Запропоновано логістичну математичну модель інформаційної архітектури транспортних перевезень, інформаційну структуру та імітаційну модель управління в умовах невизначеності, що включає взаємозв'язки між цілями, альтернативними засобами їх досягнення та наявними ресурсами. Використання основних теоретичних принципів та організаційно-методичних положень під час створення блоків інформаційної архітектури забезпечує можливість коригування управлінських рішень для підвищення ефективності перевезень за розробленими та узгодженими планами. Розробка транспортно-логістичних систем інформаційної архітектури дозволяє глибше зрозуміти складні взаємодії елементів усередині системи, оцінити ступінь впливу факторів, виявити вузькі місця. Науковий напрямок цього аспекту включає методи теорії вибору, експертних систем, імітаційного моделювання, марківських процесів, динамічного програмування, теорії ігор нечіткої логіки. Всі вони пов'язані з багатокритеріальними оцінками поточної ситуації та мають у досягненні альтернативних варіантів керування транспортними перевезеннями елементи ризику.

Ключові слова: *інформаційна архітектура, транспортна логістика, транспортування, структурні схеми, функціональний підхід, невизначеність.*

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