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УДК 517.51

ПЕРІОДИЧНІ ФУНКЦІЇ ЗІ ЗМІННИМ ПЕРІОДОМ – ОСНОВНІ ПОНЯТТЯ ТА ДЕЯКІ РЕЗУЛЬТАТИ ЇХ ДОСЛІДЖЕННЯ

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Резюме. *Одним із важливих прикладних напрямків математики є дослідження реальних сигналів. За своїми властивостями сигнали бувають досить різноманітними, відповідно різними є і методи їх дослідження. Серед цього різноманіття значну долю складають періодичні сигнали, але при цьому період, через який їх значення повторюються, вже не є постійним, а певним чином змінюється. Яскравим прикладом таких сигналів є електрокардіограми, отримані під час чи після дії на організм людини певного збудника спокою, наприклад, фізичного навантаження. На інтервалах часу, протягом яких пульс приходить у «норму», період електрокардіограми змінюється. Подібною до електрокардіограми буде поведінка спірограми, теж отриманої після дії навантаження чи іншого збудника психофізичного стану людини. Приклади аналогічних сигналів можна також навести із багатьох технічних систем. Аналіз літературних джерел показує, що для такого роду сигналів будь якої теорії та аналітичних методів їх дослідження до недавніх пір не існувало. Вказується, що перші дослідження сигналів зі змінним періодом започатковані в роботах автора цієї статті. Наведено деякі з основних результатів цих досліджень. Найперше, визначено клас періодичних функцій зі змінним періодом* $T(x)$. *Розглянуто деякі властивості змінного періоду, а також введено змінний період* $T^{-}(x)$ *для випадку, коли аргумент функції спадає. Наведено приклади аналітичного задавання таких функцій у вигляді тригонометричних функцій зі змінним періодом* $\sin x^{\alpha}, \cos x^{\alpha}$, $tgx^{\alpha}, ctgx^{\alpha}$ $\alpha > 1, \alpha \neq 1$, *та записано їх змінні періоди. Показано, що періоди тригонометричних функції* $\sin x, \cos x$, $tgx, ctgx$ *є частинним випадком змінних періодів для функцій* $\sin x^{\alpha}, \cos x^{\alpha}$, $tgx^{\alpha}, ctgx^{\alpha}$ *при* $\alpha = 1$, *а, отже, і функції* $\sin x, \cos x$, $tgx, ctgx$ *є частинним випадком функцій* $\sin x^{\alpha}, \cos x^{\alpha}$, $tgx^{\alpha}, ctgx^{\alpha}$. *Наявність функцій* $\sin x^{\alpha}, \cos x^{\alpha}$ *наштовхує на питання щодо їх використання як базових функцій для отримання тригонометричної системи функцій зі змінним періодом, і у випадку її ортогональності розглянути питання побудови рядів Фур'є функцій зі змінним періодом. До поставленого завдання запланованого звернутися в наступних публікаціях.*

Ключові слова: *періодичні функції зі змінним періодом, змінний період, тригонометричні функції зі змінним періодом, ряди Фур'є функцій зі змінним періодом.*

https://doi.org/10.33108/visnyk_tntu2024.01.046 *Отримано 03.01.2024*

Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2024, № 1 (113) https://doi.org/10.33108/visnyk_tntu2024.01
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 629.123.066

ENTROPY MODEL FOR DETERMINING THE NECESSARY INFORMATION IN THE DIAGNOSTICS OF MARITIME TRANSPORTAT

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Summary. *The main problem of diagnostics and management of traffic flows under conditions of uncertainty of the impact of the external environment is to obtain the required amount of high-quality information, since in the case of its small values the accuracy of forecasts decreases, and in the case of its redundancy the possibility of its use is hampered. The information-entropy model, which is the substantiation of diagnostics and the required amount of input information in the context of environmental fluctuations is presented in this paper. On the example of studying maritime transportation under conditions of variable conjuncture, the consequences of pandemic and military interventions and other manifestations of environmental impact, the entropy of different values of a priori and a posteriori information is estimated. The main factors of the merchant marine fleet development are the volume of international shipping, the annual growth rate of the merchant fleet, the average age of the fleet, and tariff rates in container transportation. The main trends in the modern development of the world's maritime fleet are identified. The algorithm for determining the required amount of information with regard to uncertainty is constructed. The experimental verification is carried out taking into account the dynamics of the main indicators of the world merchant fleet. It is shown that entropy is a quantitative measure of input information for managing and diagnosing transport processes under conditions of uncertainty.*
Key words: *transportation processes, uncertainty, sea transportation, information support, entropy, diagnostics.*

https://doi.org/10.33108/visnyk_tntu2024.01.058 *Received 16.01.2024*

Statement of the problem. The globalization of the world economy requires the development of communications, long-distance transportation, reduction of trade barriers between countries, growth of international relations and competition. The development of transportation processes makes it possible to compensate the location of enterprises not by national basis, but in countries with regions having low production costs. Technological changes are taking place everywhere and are reflected in the development of modern transport logistics. The transformation of commodity flows into transportation flows is the required operation of transportation processes.

There are several options for transportation modeling:
- vehicle routing at the set levels;
- generation of models with discrete choice of system states;
- hybrid structure of cargo flows and transport network matrices.

The general labor intensity of the proposed models is complex procedure for collecting the necessary data, their qualitative and quantitative composition, homogeneity and informativeness. The result of solving transportation problem under conditions of uncertainty is the search for certain routes and the need for information support.

The complication of the conditions for transport processes functioning, the emergence of new ideas, priorities and resource restrictions make the investgation of theoretical and practical problems of management under conditions of uncertainty important. One of the main problems in this area is obtaining the necessary amount of input information to predict possible situations when parameters and processes are changed by environmental impact. The total amount of information required for analytical substantiation of management decisions requires quantitative assessment.

Analysis of available researches and publications. There are no general recommendations for creating models for justifying the amount of information for making management decisions under conditions of uncertainty, so any steps in order to solve this problem are extremely useful [1–3]. Assessment of the state of maritime transportation in the world, its dynamic changes and diagnostics is necessary element in the transport industry development. The variety of economic indicators does not allow us to determine unambiguously the development trends and diagnostics, since in addition to quantitative assessments of indicators characterized by different measurement scales, there is qualitative diversity of them. To predict possible situations of maritime transportation development under conditions of uncertainty, it is impossible to use any extrapolations and trends due to stochastic changes in the external environment. It is necessary to create single indicator that takes into account the state of the industry as a whole. Quantitative assessment of the real state of maritime transport industry is the starting point for diagnosing and forecasting changes in the state of transportation under conditions of uncertainty caused by dynamic changes in the environment. Since there is no generalizing indicator characterizing this state, it is natural to manifest synectics, i.e., borrowing knowledge and scientific achievements taken from other areas of scientific knowledge. For this purpose it is proposed to consider the value of entropy as the measure for assessment the state of the transportation process. Entropy is the degree of uncertainty and incompleteness of knowledge about particular state of the object. In physics, entropy characterizes spatial and energy interactions that manifest themselves as the measure of probability of the system being in this state [4, 5]. In sociology, entropy is the deterioration of self-organization [6]. In computer science, entropy is the measure of uncertainty of random events. Entropy can be used to decipher the coded text by analyzing the probability of characters appearing in the text [7, 8]. In the management of economic system development, the concept of entropy refers to the system being in this state [9].

In the field of transportation modeling, the concept of entropy is used to provide theoretical basis for estimating the most probable traffic flow matrices. The maximum entropy probability distribution is associated with the greatest uncertainty due to the use of incomplete and poor quality information about the objective function.

The objective of the paper is to create the model of the required amount of information for making managerial decisions regarding the diagnosis of maritime transportation development.

Materials and methods. 2021 Maritime Transport Review declares that maritime transport survived in the conditions disrupted by the pandemic [10]. In 2020, transportation volumes decreased, but not as sharply as it was expectedexpected, and by the end of the year they began to grow, laying the foundation for the transformation of global supply chains and the emergence of new models of maritime transportation.

In 2021, there was the revival of maritime transport, but in 2022, working conditions became more difficult due to risks and uncertainties. After 3.8% decline in 2020 caused by pandemic and accumulated problems of the global logistics network, the volume of sea transportation increased by 3.2% to 11 billion tons. The growth was due to the increased demand for container cargo. Gas and dry bulk shipments increased, while crude oil shipments decreased. The volumes of international sea transportation are presented in Fig. 1.

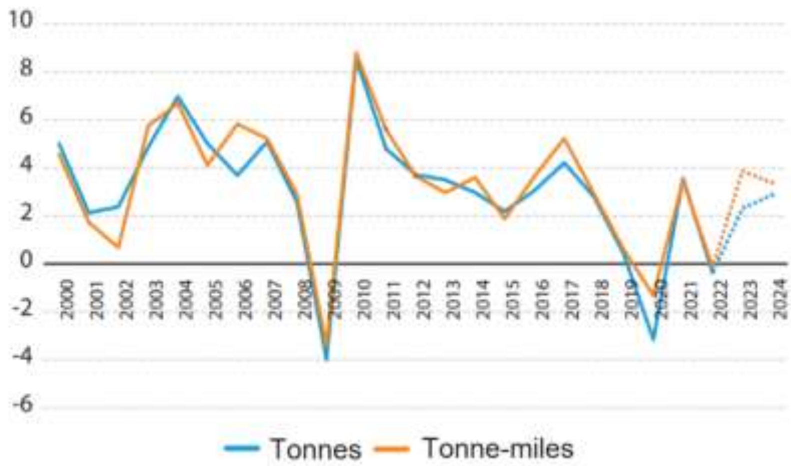

Figure 1. Dynamics of international sea transportation volumes

For many years, the fastest growing segment has been container transportation, which accelerated by 1.9% in 2023. The schedule of port calls varies due to the overall workload and changes in service. The most problematic ports were those in the US, Europe, and China. The uncertainty is caused by the macroeconomic environment and the weakening of Chinese economy, accelerated inflation, and rising consumer costs. In Ukraine, all Black Sea ports have been closed since the beginning of military operations.

At the same time, it should be noted that the increase in transportation is constrained by the low growth rate of the fleet. In 2022, the global merchant fleet grew by three percent compared to 2020 (Table 1).

Table 1

World fleet by main types of vessels

Types of vessels	**2020**	**2022**	**Changes in percentage**
Oil tankers	601 342 29.03%	619 148 29.00%	2.96%
Container carriers	274 973 13.27%	281 784 13.20%	2.48%
Other types of vessels	238 705 11.52%	243 922 11.43%	2.19%
Offshore platform supply vessels	84 049 4.06%	84 094 3.94%	0.05%
Liquefied gas vessels	73 685 3.56%	77 455 3.63%	5.12%
Tankers for chemical products	47 480 2.29%	48 858 2.29%	2.90%
Other vessels with no data	25 500 1.23%	25 407 1.19%	–0.36%
Ferries and passenger vessels	7 992 0.39%	8 109 0.38%	1.46%
Vessels for general cargo	76 893 3.71%	76 754 3.60%	–0.18%
Total, all countries of the world	**2 071 638**	**2 134 640**	**3.04%**

Annual growth rates of the merchant fleet are shown in Fig. 2.

Figure 2. Annual growth rate of the merchant fleet

The highest growth rates, driven by the demand for maritime transportation, were observed in the liquefied natural gas carriers sector, followed by the container and bulk carriers sectors.

Since 2011, the aging of the fleet has been observed. The average age of ships in 2022 is 21.9 years. The youngest vessels are bulk carriers with the average age of 11.1 years, container carriers with the average age of 13.7 years, oil tankers with the average age of 19.7 years [11].

This is caused by the fact that currently it is difficult to determine the ways of technological development and which types of fuel will prove to be the most efficient in the future, as well as how regulatory requirements and and prices for carbon emissions will change. Therefore, there is a tendency to use older vessels in the context of high current tariffs and freight nets with with focus on the operation of older vessels. The dynamics of the average age of the merchant fleet is shown in Figure 3.

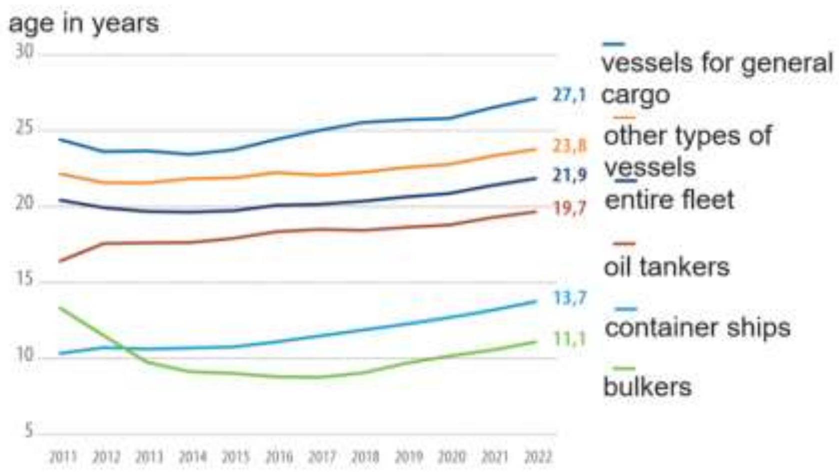

Figure 3. Average age of the merchant fleet

If the current situation in in the field of international maritime transportation continues, global consumer prices could rise by 15% in 2024. Tariff rates in container transportation have reached their maximum.

The study of the dynamic system entropy is used as the research method in this paper.

The entropy of the state of the transport fleet H is the generalized parameter that characterizes its position in time.

$$H = \frac{I}{n} = -\sum_{i=1}^{m} P_i \log_2 P_i$$

where P_i is the probability of the production system being in this state; I is volumetric information; N is number of analyzed indicators.

To define unambiguously the unit of measurement, it is necessary to specify the number of states of the dynamic system m and the base of the logarithm. The smallest possible number of states of the dynamic system that characterize its efficiency can be evaluated by the symbols «suitable» and «unsuitable», «yes» or «no» equal to two. Such code with the base of two is considered to be dual, since it corresponds to the state of receiving information or its absence, i.e. $m = 2$. Therefore, it is reasonable to use the number two as the base of the logarithm. Thus, the entropy of equally probable states remains the unit of uncertainty. This unit is called the bit. Turning to information assessment, the unit of information can be considered as the amount of information containing messages that reduce the uncertainty of knowledge by half. The equality of these two investigations of notification units affects their general nature and is manifested in the removal of uncertainty of input information or its sufficiency. Entropy is a real and non-negative value, since for any value of P_i it varies from 0 to 1. Entropy H is related to the probability of systems by the ratio.

$$H = k \ln W \,,$$

where k is Boltzmann constant.

The entropy of dynamic transport system is the logarithmic measure of the information source inversion and characterizes the average degree of uncertainty in assessing the state of this information source.

The entropy of diagnostics of dynamic transportation is mathematical expectation of the logarithm of the probability of the transport system being in state m. Based on the law of larger numbers, with large number of states of maritime transportation, the arithmetic value of these states of the same value generally acquires stable value. This makes it possible to identify general patterns of self-organization of the functioning of dynamic transport system under conditions of external disturbances caused by fluctuations in the external environment. In this way, the principles of feedback between maritime transportation and the information system are used. With small number of observations, this value is considered to be random. It stabilizes as the number of observations increases and approaches the mathematical expectation. In this formulation, entropy is the mathematical proof of the state of the transportation system by partial observation of quantitative information.

Statistical analysis of the properties of information sources is to determine its probability $P(a)$ as the ratio of the number of accepted results $N(a)$ to the total number of possible results N.

$$P(a) = \frac{N(a)}{N}$$

The mathematical expectation is one of the most important concepts in mathematical statistics and probability theory that characterizes the distribution of random variables. It can be used in risk assessment and is used to develop game theory strategies. Mathematical expectation $M[X]$ is the sum of all probability values of random variables x_i, divided by the probability of these values p_i. The mean value of discrete random variable is equal to:

$$M[X] = \frac{x_1 p_1 + x_2 p_2 + \ldots + x_n p_n}{p_1 + p_2 + \ldots + p_n} = \frac{\sum_{i=1}^{n} x_i p_i}{\sum_{i=1}^{n} p_i}$$

The uncertainty of the state of maritime transportation, forecasting and diagnostics of the development depends on the number of probabilistic states and the probability distribution of these states. The degree of uncertainty of these states of maritime transportation of means or sources of information depends not only on the number of probabilistic states but also on the probability of these states. The entropy of the source with two states u1 and u2 when changing the ratio of their probabilities P(u1) = P and P(u2) = 1 – P is determined from the following equation.

$$H(u) = -\left[P \log_2 P + (1-P)\log_2 P\right]$$

It is not the absolute value of entropy that is of practical interest, but its changes. As the entropy decreases, the input information increases, and finally, as the entropy increases, it decreases. The change in entropy is the fundamental criterion for the efficiency of transportation processes.

A priori and a posteriori information are interrelated concepts of information discourse, meaning knowledge of previous experience and knowledge gained by the system from the experience of its use.

The information structure of the a priori data required to calculate the a priori entropy of maritime transport under uncertainty should include the information contained in the a priori information on international traffic volumes, annual fleet growth rates, traffic, and diagnostic alternatives.

Entropy and the amount of information are interrelated. The necessary amount of information for the diagnosis of international maritime transportation and its information support can be found by determining the difference between a priori and a posteriori entropy. This thesis is the basis of the proposed model for quantifying the input information of international transport development under conditions of uncertainty.

For events x_1, x_2, …, x_n which have equal probability state $1/n$, the values of the a priori entropy are equal:

$$H_0 = -n \times \frac{1}{n}\log_2\frac{1}{n} = -\log_2 1 + \log_2 n$$

taking into account that

$$P_1 = \frac{N(x_1)}{N}, \quad P_2 = \frac{N(x_2)}{N}, \quad \dots , \quad P_n = \frac{N(x_n)}{N}.$$

a posterior entropy formula is as follows:

$$H_1 = -\left[\begin{array}{l} P_1\left(\log_2 N(x_1) - \log_2 N\right) + P_2\left(\log_2 N(x_2) - \log_2 N\right) + \dots \\ \qquad \dots + P_n\left(\log_2 N(x_n) - \log_2 N\right) \end{array} \right]$$

The calculation of the a priori distribution of the state of the external environment is carried out by processing statistical material or by analytical methods based on probabilistic representations.

A posteriori information about the state of maritime transportation is the residual uncertainty of the availability of values after obtaining additional information. The entropy of the summary of statistical independent sources of information on the state of maritime transportation H is equal to the sum of these entropies.

$$H = \sum_{i=1}^{n} H_i$$

Establishing the probability of the appearance of the quantitative values of the analyzed indicators is one of the stages of the methodology of information support of transport processes, since the number of sea transportations depends on the amount of information provided.

Presentation of the main investigation material. An important point on the way to the implementation of the concept of sustainable development of the naval fleet is the formation of the system for measuring indices and indicators of transport processes. The main requirements for the measurement system are its completeness and adequacy.

All economic indicators have different order of numbers and different dimensions. In order to make them dimensionless and reduce the number of analyzed bits, it is necessary either to normalize them by dividing them by some common indicator or calculate their relative changes.

In order to defuse tense situations in the existing system of maritime transportation, the change in proportions in the structure and the formation of new connections between the components that make up this system are needed. The structure availability is the most important attribute of the transport system. Special indicators or indices are used for quantitative characteristics in the structure. The structure of the system is the statistical category that has quantitative characteristic and shows the significance of the selected index at a certain point in time.

The system of base indices is the series of consistent representations of the same phenomenon with the constant comparison base. From this point of view, the system of basic indices characterizes the changes that occur in the investigated phenomenon during the investigated period of time.

Calculations of the a priori H_0 and a posteriori H_1 entropy and the amount of information I at different values of the probability of occurrence of the analyzed events caused by the states of the environment that affect the functioning of maritime transport were performed while analyzing three above mentioned indicators of the development of the maritime transport fleet: the volume of international maritime transportation x_1, the annual growth rate of the merchant fleet x_2, the average age of the merchant fleet x_3.

These sources of information given in [10] are considered to be statistically independent.

The data to be analyzed for diagnostics of the maritime transportation dynamics should have the following features:

- properties of the global transportation system remain unchanged during the diagnostic interval under consideration, i.e., no new equipment capacities or new transportation technologies are introduced;
- the qualification level and competence of the staff is not improved;
- the following indicators are independent on the previous ones, so they truly reflect the actual state and composition of the research object;
- the presented indices are consistent, but not dependent.

Under conditions of equal probability manifestation of the corresponding indicators of the dynamic personnel of transport transportation x_1, x_2, x_3 characterizing the general state of the maritime transport industry and the absence of any restrictions, the source of maritime transport efficiency should be as informative as possible.

The input information of the dynamics of the maritime transport fleet indices is presented in Table 2.

Table 2

Input information on the dynamics of the maritime fleet characteristics

Index	2015	2016	2017	2018	2019	2020	2021	2022
Index of the international shipping volumes	1.008	1.117	1.211	1.003	0.961	2.957	0.601	0.921
Index of annual growth rates of the transport	1.009	1.003	0.801	0.602	0.920	1.311	1.106	0.751
Merchant fleet average age index	1.007	1.012	1.06	1.082	1.087	1.092	1.102	1.104

The calculations are based on the data presented in Table 1 and Fig. 1–3. 2015 is chosen as the permanent basis for comparison, in relation to which the percentage of growth or decline of this index is calculated.

In case of $P_1 = P_2 = P_3$ and i = 1,2,3 the a priori entropy is equal to

$$H_0 = -\left[\frac{1}{3}\left(\log_2 1 - \log_2 3\right) + \frac{1}{3}\left(\log_2 1 - \log_2 3\right) + \frac{1}{3}\left(\log_2 1 - \log_2 3\right)\right] =$$

$$= -\left[\log_2 1 - \log_2 3\right] = -\left[0 - 1.58496\right] = 1.58496\ [bit]$$

For values $P_1 = 0.7$, $P_2 = 0.2$, $P_3 = 0.1$ and i = 1, 2, 3 which characterize the possible degree of influence of the external environment on the activities of the merchant marine, represented by indicators x_1, x_2, x_3, the posterior entropy is equal to

$$H_1 = -\left[\frac{7}{10}(\log_2 7 - \log_2 10) + \frac{1}{5}(\log_2 1 - \log_2 5) + \frac{1}{10}(\log_2 1 - \log_2 10)\right] =$$
$$= -[(-0.360206) + (-0.464386) + (-0.332193)] = 1.156785\ [bit]$$

The difference of these values characterizes the change in entropy

$$\Delta H = H_0 - H_1 = 1.58496 - 1.156785 = 0.428175\ \ [bit]$$

In order to determine the minimum number of dynamic variables that uniquely describe the observed process of the merchant marine fleet functioning, the practical use of the proposed model is based on the expansion of the data in Table 1, the result of such expansion is presented in Table 3.

Table 3

The input information of the dynamics of the maritime fleet indices has been expanded

Index	2015	2016	2017	2018	2019	2020	2021	2022
Index of international shipping volumes	1.008	1.117	1.211	1.003	0.961	2.957	0.601	0.921
Index of annual growth rates of the transport fleet	1.009	1.003	0.801	0.602	0.920	1.311	1.106	0.751
Index of the average age of merchant fleet	1.007	1.012	1.06	1.082	1.087	1.092	1.102	1.104
Index of tariff rates in container transportation	1.005	0.951	0.921	1.015	1.114	0.949	1.096	1.049

After assigning the corresponding probability of indices x_1, x_2, x_3, x_4 through P_1, P_2, P_3, P_4 we will obtain the a priori entropy of the state of sea transportation

$$H_0 = -\left[\begin{array}{l}\frac{1}{4}(\log_2 1 - \log_2 4) + \frac{1}{4}(\log_2 1 - \log_2 4) + \\ \qquad + \frac{1}{4}(\log_2 1 - \log_2 4) + \frac{1}{4}(\log_2 1 - \log_2 4)\end{array}\right] =$$
$$= -[\log_2 1 - \log_2 4] = 2\ [bit]$$

The a posteriori entropy of the state of transport transfers of the entity's activities for values $P_1 = 0.4$, $P_2 = 0.3$, $P_3 = 0.2$, $P_4 = 0.1$, which characterizes the possible degree of the external environment influence, is determined on the basis of expert opinion and is equal to:

$$H_1 = -\left[\begin{array}{l}\frac{2}{5}(\log_2 2 - \log_2 5) + \frac{1}{5}(\log_2 1 - \log_2 5) + \\ \qquad \frac{3}{10}(\log_2 3 - \log_2 10) + \frac{1}{10}(\log_2 1 - \log_2 10)\end{array}\right] =$$
$$= -\left[\begin{array}{l}\frac{2}{5}(1 - 2.322) + \frac{1}{5}(0 - 2.322) + \\ \qquad \frac{3}{10}(1.585 - 3.322) + \frac{1}{10}(0 - 3.322)\end{array}\right] = 1.9138\ [bit]$$

The difference between these values characterizes the variation of entropy:

$$\Delta H = H_0 - H_1 = 2 - 1.9138 = 0.0862 \quad \text{[bit]}$$

The degree of uncertainty elimination is the amount of missing information, $I = \Delta H$ (Fig. 4).

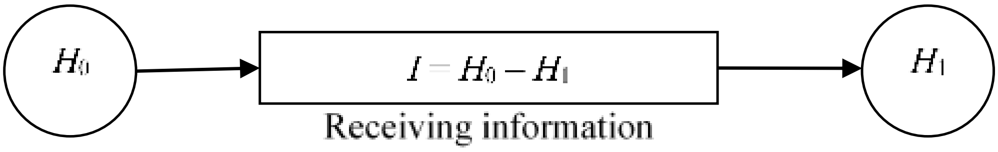

Figure 4. Eliminating uncertainty due to the information support of management system

The objective function of transportation can be expressed by the entropy of uncertainties in the state of traffic flows in the dynamics of their functioning and probabilistic representations. In order to develop freight transportation models, the maximum entropy method can be applied, considering the task of evaluating all flows on the route as a whole without detailed consideration of its individual sections. Maximum entropy assumes that in the absence of data on freight traffic on the transportation network, all flows are considered the flows are considered to be equally probable.

The algorithm for finding the amount of necessary information in managing the development of transportation under conditions of uncertainty of the external environment impact is shown in Fig. 5.

The representativeness of information is associated with the accuracy of its selection and formation for adequate display of the properties of the transportation dynamics.

It is evident from the above mentioned that the amount of information characterizing the state of transportation is proportional to the number of considered indices and depends on the probability of their occurrence in the total implementation.

In order to implement the proposed methods, it is necessary to perform functional analysis of the operational procedures for managing transportations under conditions of uncertainty, which will formalize the management processes of the main decision support operations: assessment of the required amount of information, processing of the information situation, selection of the optimization criterion, and performing calculations in accordance with the proposed calculation methods.

As it follows from the results of the above mentioned investigations, the amount of information clarifying the state of the transport industry at the time of its use is proportional to the number of considered indices and depends on the probability of their general implementation of the transport industry state. $I = -n\sum Pi\log_2 P_i$, where n is the number of analyzed indexes of the transport industry activity.

The amount of required information I depends on the total number of indices reflecting the structure of the transportation industry n and the number of states of each index m.

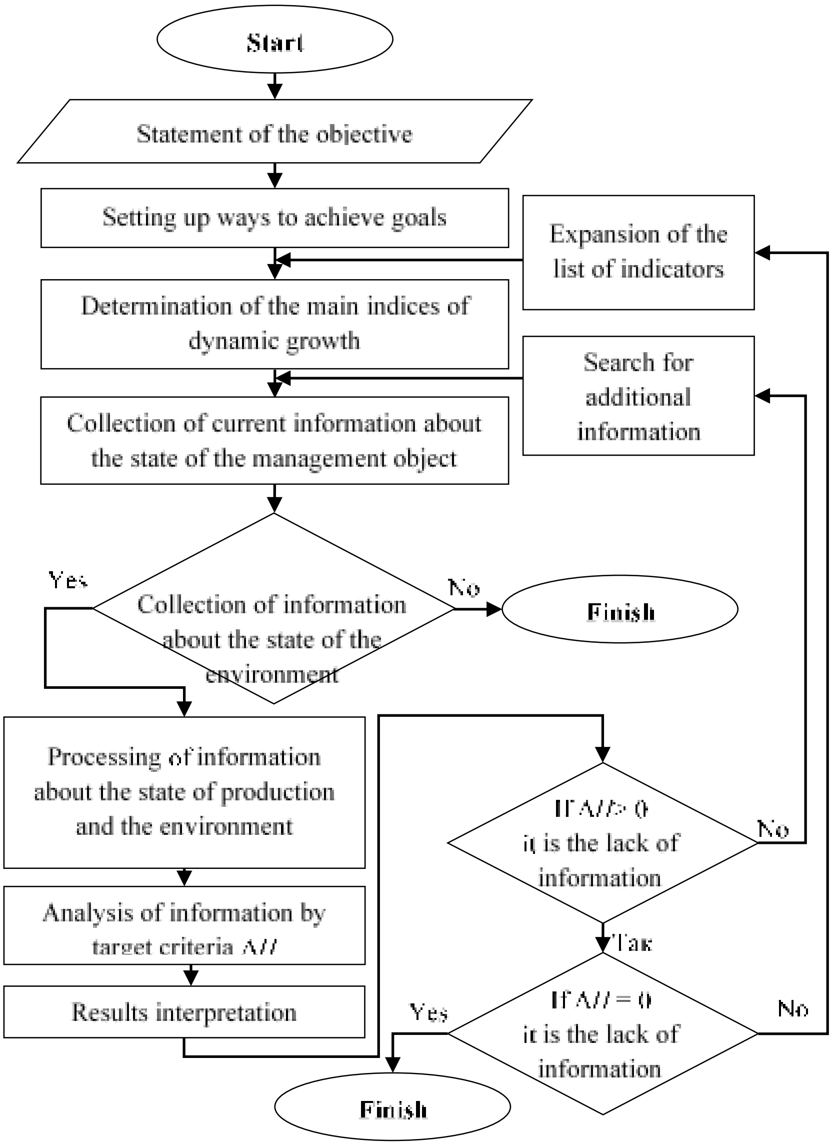

Figure 5. Algorithm for determining the required amount of information for making adequate management decisions

Any stable system $I = -n\log_2 m$ tends to reach the state of equilibrium in its activity. Non-equilibrium processes in the isolated system are accompanied by the increase in entropy. Stationary states correspond to the minimum entropy. Entropy increases under the influence of external conditions and due to the intrusion of the equilibrium state of the transport industry dynamics, if such intrusion does not occur, entropy reaches the absolute minimum. If the state of transportation cannot be recognized as efficient, then entropy can be characterized by its state as the difference between a priori and a posteriori information.

Conclusions. The proposed information-entropy model of quantitative assessment of the necessary input information and the algorithm for its implementation makes it possible to improve the basic principles and rules of the organization of information provision of the process of dynamics of the main structure-forming indices. Calculations of a priori and a posteriori information and the value of entropy are able to regulate the process of accumulating the necessary amount of information when making basic decisions regarding the improvement of the transport industry.

In order to implement the proposed methodology, it is necessary to carry out functional analysis of the operational procedures of transport management in conditions of uncertainty, which makes it possible to form the processes of managing the development of transport and to focus on the main operations of supporting the adoption of management decisions regarding the development of the information support field, the assessment of the necessary volume of current information, its processing, selection of optimization criteria, making calculations and assessments using appropriate methods.

The entropy of maritime transport in the context of its dynamic changes due to the influence of the external environment is given as asymptotic increase in uncertainty. Obtaining information is the process of identifying uncertainties in the state of the investigated object at the given moment of time.

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УДК 629.123.066

ЕНРОПІЙНА МОДЕЛЬ ВИЗНАЧЕННЯ НЕОБХІДНОЇ ІНФОРМАЦІЇ ПРИ ДІАГНОСТУВАННІ МОРСЬКИХ ТРАНСПОРТНИХ ПЕРЕВЕЗЕНЬ

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Резюме. *Основною проблемою діагностики та управління транспортними потоками за умов невизначеності впливу зовнішнього оточення є отримання необхідного обсягу якісної інформації, оскільки в разі її малих значень зменшується точність прогнозів, а в разі її надмірності утруднюється можливість її використання. Представлено інформаційно-ентропійну модель, яка є обґрунтуванням діагностики та необхідної кількості вхідної інформації в умовах флуктуації зовнішнього середовища. Запропонована інформаційно-ентропійна модель кількісного оцінювання необхідної вхідної інформації та алгоритм її реалізації дає змогу вдосконалити основні принципи та правила організації інформаційного забезпечення процесу динаміки основних структуроутворюючих індексів. Розрахунки апріорної та апостеріорної інформації та величини ентропії здатні регулювати процес накопичення необхідної кількості інформації при ухваленні основних рішень щодо вдосконалення транспортної галузі. На прикладі вивчення морських транспортних перевезень в умовах змінної кон'юнктури, наслідків пандемії та воєнних втручань й інших проявів впливу довкілля оцінено ентропії різних значень апріорної та апостеріорної інформації. Як основні чинники розвитку торговельного морського флоту обрано обсяги міжнародних морських перевезень, річні темпи зростання торговельного флоту, середній вік флоту, ставки тарифів у контейнерних перевезеннях. Для реалізації запропонованої методики здійснено функціональний аналіз операційних процедур управління транспортними перевезеннями в умовах невизначеності, що дало змогу формувати процеси управління розвитком транспортних перевезень та акцентовано увагу на основних операціях підтримання ухвалення управлінських рішень щодо розвитку галузі інформаційного супроводу, оцінювання необхідного обсягу поточної інформації, її опрацюванні, виборі критеріїв оптимізації, здійсненні розрахунків та оцінок відповідними методами. Крім того, визначено основні тенденції сучасного розвитку світового морського флоту. Побудовано алгоритм визначення необхідної кількості інформації з урахуванням невизначеності. Експериментальна верифікація виконана з урахуванням розгляду динаміки основних показників світового торгового флоту. Показано, що ентропія є кількісним заходом вхідної інформації для керування та діагностики транспортними процесами в умовах невизначеності.*

Ключові слова: *транспортні процеси, невизначеність, морські перевезення, інформаційна підтримка, ентропія, діагностика.*

https://doi.org/10.33108/visnyk_tntu2024.01.058 *Отримано 16.01.2024*