

Information Approach to Evaluating Effectiveness of the Marine Surface Monitoring System Functioning

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Abstract: *The article shows that the main purpose of the Border Guard Agency's marine surface monitoring system is the information support of the decision making. To achieve this purpose such tasks were performed: provided rationale for the indicators of the marine surface monitoring system effectiveness; developed the analytical models for determining indicators of reliability, completeness, operational efficiency processed by the marine surface monitoring system; developed an analytical model of the integral indicator of evaluating the efficiency of the marine surface monitoring system functioning; investigated the results of applying the information approach to evaluating the effectiveness of the marine surface monitoring system in different circumstances. The choice of system effectiveness indicators has been justified. It is stated that the composition of indicators of reliability, completeness and operational efficiency corresponds to the properties of the information resource of the marine surface monitoring system. A formal description of these indicators has been made and an integral indicator of the effective functioning of the marine surface monitoring system has been formed. The obtained value of the integral effectiveness indicator allowed to compare the results of modeling with the standard value of the effectiveness indicator and justified the managerial solution on the use of operational resources at the maritime border area.*

Keywords: *reliability; completeness; operational efficiency; marine surface monitoring system; effectiveness; indicator.*

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Introduction

The protection of the national interests of the state depends to a large extent on the effectiveness of the of the Border Guard Agency's activity. Under the current conditions, the quality of border protection tasks performance depends on the degree of information support for management decision-making systems. At the present stage of state development, national security entities are making extensive use of information and telecommunication systems to promptly process information.

The state border is monitored by the Border Guard Agency's bodies in various ways: organizational, operational, technical, etc. At the same time, certain sectors of the border can be kept under control only by technical means. These sectors include: marine or river sectors, airspace. Border protecting units have been actively using the technical means to monitor border sectors. The above mentioned technical means provide information about the presence (or absence) of unauthorized objects in the controlled border sector. It should be noted that the choice of such means is in most cases based on their value and does not take into account the value of the information provided by such a system.

In order to effectively carry out border protection tasks, Border Guard Agency's units have to be fully informed about the stance in the area of their responsibility. Moreover, the information should relate to the tactics of the units' action, in other words be "valuable" to them. On this basis, the issue of assessing the effectiveness of marine surface monitoring system functioning in respect of the informational aspect is urgent. The results of the study should show the effect of introducing new or upgraded existing elements of the marine surface monitoring system on the state border, taking into account different tactics of the units.

Literary Data Analysis and Problem Statement

The issue of evaluating the effectiveness of any system is top-of-the-agenda (Avital, Mathiassen & Schultze, 2017; Eroshkin et al., 2017; Koivisto & Hamari, 2019). Currently, there is a large number of works, which have explored different systems. Some authors (Al Rababah, 2019) analyze the components of the information and telecommunication system without its mathematical modeling. Other authors (Chao et al., 2017; Mancosu et al., 2016; Xu, Shen & Wang, 2014) propose to evaluate only some particular nodes of the information system without taking into account the cross-impact of other elements. One of the promising approaches is to consider

the probabilistic nature of the functioning of a complex system (Petukhov & Yakunin, 2006; Strelbitsky & Katerynychuk, 2019). However, the vast majority of authors do not take into account the particularities of employing complex technical systems, in particular, by the Border Guard Agency. Some researchers have investigated the issues of evaluating the effectiveness of functioning of the marine surface monitoring system (Mazur & Borovyk, 2018; Mkrtchyan & Varotsos, 2018). In their work, they give grounds to the methodological basis of evaluating the effectiveness of functioning of a unified marine surface monitoring system in the maritime area for the purposes of border security. This article reflects the dependence of the effectiveness of the system under study on the properties of its constituent elements, in which different subjects of monitoring of the marine surface environment act. For each element, the formalization of the determinants' influence on the result has been made. However, the macro-level of certain provisions of this approach does not allow its direct application.

The basis for the operation of the marine surface monitoring system is information obtained from various sources in the area of responsibility of the system about the presumable violator. Therefore, information aspects should be primarily reflected in the evaluating procedure of the effective functioning of the marine surface monitoring system.

The Purpose and Objectives of the Research

To justify the approaches to assessing the effectiveness of the marine surface monitoring system functioning, it is first necessary to determine its purpose. In the information aspect, the most important task of the system is the early detection of violators within the area of responsibility and their identification. Particularly, detection fact, identification degree and timing should be considered for the violators' detention. Various actors of the system such as technical observation posts, patrol ships, etc. solve these tasks. It should be noted that the above entities have their specific technical and functional characteristics; therefore, they can be attributed to certain types of information sources.

Thus, the **purpose** of the article is to develop an information approach to assessing the effectiveness of marine surface monitoring system functioning.

To achieve this goal, it is necessary to solve the following problems:

- to provide rationale for the indicators of the marine surface monitoring system effectiveness;

- to develop the analytical models for determining indicators of reliability, completeness, operational efficiency processed by the marine surface monitoring system;
- to develop an analytical model of the integral indicator of evaluating the efficiency of the marine surface monitoring system functioning;
- to investigate the results of applying the information approach to evaluating the effectiveness of the marine surface monitoring system in different circumstances.

RESULTS

Substantiation of the Indicators of the Marine Surface Monitoring System Effectiveness

The marine surface monitoring system is a complex organizational and technical system consisting of subjects and objects of the system (personnel and organizational and technical systems) and system elements, which provide information acquisition, processing and transmission). To summarize the study in the information aspect the term "subjects and objects of the system" will be replaced by the concept of "data resource". In what follows, we assume that the number of any elements of the system, which provide information is m . Let us determine that the number of equipment of the i -th type of data resource is equal n_i . In the general case, the value n_i for different i is various. We will also consider that the number of infringing objects within the area of responsibility of the marine surface monitoring system in the studied period of time is equal to l .

Against this background, it can be concluded that the assessment of data resource can be done on the basis of analysis of such indicators as reliability, completeness and operational efficiency. Reliability allows us to assess the reasonableness of the infringing object's presence in the area of the coverage of the marine surface monitoring system. Completeness should provide an opportunity to assess the level of identification of the infringing object, and operational efficiency – to assess good timing of the infringing object detection (Lakshminarayana & Rajasekaran, 2017; Mazur, 2017).

To evaluate the effectiveness of the marine surface monitoring system functioning, it is necessary to construct indicators that will meet the basic requirements (DeLone & McLean, 2016; Harasymchuk & Kostiv, 2011), namely: demonstrability (relevance to the goal), criticality (sensitivity to change), complexity (no involvement of other system characteristics),

stochasticity (taking into account the conditional ambiguity of system functioning), simplicity (accessibility of perception and analysis).

The indicator of reliability allows us to assess the level of reasonableness of the infringing object's presence and to decide on the expediency of operational forces and resources reaction to the infringing object in the area of responsibility of the marine surface monitoring system.

The indicator of completeness permits making decisions about the composition of the forces and resources that are appropriate to involve the response to the infringing object's presence in the area of responsibility of the marine surface monitoring system.

The indicator of operational efficiency ensures evaluation of the timeliness of the offending object detection and to decide on time parameters concerning the use of operational forces and resources upon the offending object's presence in the area of coverage of the marine surface monitoring system.

Thus, in the aggregate, these indicators make it possible to evaluate the effectiveness of the marine surface monitoring system functioning in terms of information, as well as to exert managerial influences related to information processing.

Analytical Model for Determining Information Reliability

Each infringing object is characterized by many parameters. For various objects, this number may be different. However, in practical terms, it is important to draw attention to certain parameters for exerting managerial influences. These can be, for example, the size of an object, its course, speed, etc.

Generally speaking, we assume that the number of object parameters is equal S . In what follows, we call these parameters information elements.

When operating a marine surface monitoring system, data resource should ensure information acquisition concerning each information element of the offending object. In this case, the reliability of certain information elements may be different.

It is obvious that the importance of single information elements is different. We will assume that in the study this importance is different but constant within one element for different objects of detection.

Let us introduce the notation. Suppose b_{ikjr} is a message about the k -th information element formed by the j -th equipment of the i -th type with respect to the r -th offender. The value b_{ikjr} is Boolean or logical data

type, that is $b_{ikjr} = \{0,1\}$. The value $b_{ikjr} = 1$ corresponds to the presence of the message, and the value $b_{ikjr} = 0$ corresponds to its absence.

And let r_{ikj} be the number of messages about the k -th information element, which is formed by the j -th equipment of the i -th type in the investigated period of time within the area of responsibility.

Taking the notation into consideration, it is clear that

$$r_{ijk} = \sum_{\forall r \in I} b_{ikjr}, \quad (1)$$

where $i, j, k = \text{const}$.

Let us denote a number of messages concerning k -th information element by r_{ijk}^{true} , which was formed by the j -th equipment of the i -th type in the investigated period of time within the area of coverage; their validity was confirmed. Thus, $r_{ijk}^{\text{true}} \leq r_{ijk}$.

Taking into account the entered notation and the physical sense of the marine surface monitoring system functioning, the data reliability of certain data resources about some information elements can be evaluated by

$$d_{ijk} = \frac{r_{ijk}^{\text{true}}}{r_{ijk}}. \quad (2)$$

In expression (2), d_{ikj} is the validity of the data concerning the k -th information element of the offending object provided by the j -th equipment of the resource of the i -th type. The reliability of d_{ikj} can be calculated by formula (2), regardless of r .

Since each data resource generates data concerning all information elements of the infringing object, the reliability of the data with respect to the infringing object in general, which is provided by the j -th equipment of the resource of i -th type, can be calculated by the formula

$$d_{ij} = \frac{\sum_{\forall k \in S} d_{ijk}}{S}. \quad (3)$$

This value can be interpreted as the reliability of the data of certain data resources concerning situation coverage within the area of responsibility. Taking into account (1) and (2), expression (3) can be represented as

$$d_{ij} = \frac{\sum_{\forall k \in S} \frac{r_{ijk}^{true}}{r_{ijk}}}{S}. \quad (4)$$

Since the reliability of different data resources may be different, and the reliability of information processed by the marine surface monitoring system is its potential (ability), then the reliability of information can be evaluated as

$$D = \max_{i,j} d_{ij}. \quad (5)$$

This theory is formulated with consideration of (4)

$$D = \max_{i,j} \frac{\sum_{\forall k \in S} \frac{r_{ijk}^{true}}{r_{ijk}}}{S}. \quad (6)$$

It should be noted that in some cases, information about certain information elements is sufficient to form control impacts. For this reason, to evaluate the reliability of the data generated by the marine surface monitoring system with respect to the k -th information element for the r -th offender, we can use the following formula

$$D_{kr} = \max_{i,j} d_{ijk} = \max_{i,j} \frac{r_{ijk}^{true}}{r_{ijk}} = \max_{i,j} \frac{r_{ijk}^{true}}{\sum_{\forall r \in L} b_{ijk r}}. \quad (7)$$

Analytical Model for Determining Information Completeness

The number of information elements about a detection object, concerning which a data resource can provide information, determine its completeness. The completeness of the information, in its turn, determines the ability to identify the infringing object.

Let us introduce the notation. Suppose V_k is the importance of the k -th information element, as long as $\sum_{\forall k \in S} V_k = 1$. As it has been already mentioned above, the values V_k are different depending on k . Therefore, these values play an important role in identifying the infringing object.

Since the importance of V_k within the research is different for each other, but constant within one element for different objects of detection, we can assume that $V_{kr} = \text{const}$, $\forall r \in I$, where V_k is the importance of the k -th information element for the r -th infringing object.

And let p_{ijr} be the completeness of the information about the r -th infringing object provided by the j -th equipment of the i -th type. Considering this, the completeness of p_{ijr} can be calculated with the following formula

$$p_{ijr} = \frac{\sum_{\forall k \in S} b_{ijk} V_k}{S}. \quad (8)$$

Since there may be more than one infringing object within the area of responsibility during the investigated period of time, it is important to be able to assess the completeness of the information concerning all such objects.

For this assessment, we propose to use the value p_{ij} , which is completeness of information concerning all infringing objects within the area of responsibility and the investigated period of time provided by the j -th equipment of the i -th type. In other words, p_{ij} is the complete coverage of the situation within the area of responsibility by means of j -th equipment of the i -th type.

Having regard to the additive property of completeness of information it is easy to conclude that

$$p_{ij} = \sum_{\forall r \in I} p_{ijr}. \quad (9)$$

Therefore, the completeness of information processed by the marine surface monitoring system within the area of responsibility (by all means) is equal to

$$P = \sum_{\forall i \in m} \sum_{\forall j \in n_i} p_{ij} . \quad (10)$$

Taking into account (8) and (9), expression (10) can be represented as

$$P = \sum_{\forall i \in m} \sum_{\forall j \in n_i} \sum_{\forall r \in l} \frac{\sum_{\forall k \in S} b_{ijk} V_k}{S} . \quad (11)$$

Analytical Model of Determining Operational Efficiency

Let us introduce the notation. Suppose t_{ijk} is the time of data formation on the k -the information element in relation to the r -the infringing object of the j -the equipment of the i -the type, and t_{ijk}^{fix} is the time of relevant data processing by the authorized body or a moment of the formation of the managerial influence concerning the k -the information element of r -the infringing object, determined by the j -the equipment of the i -the type.

Suppose T_{ijk} is also time period of data processing (from the detected moment to the response ready moment) concerning the k -th element of the r -th infringing object by the j -th equipment of the i -th type.

We will assume that managerial influences occur when all data about the information elements are available.

For assessing the operational efficiency processed by the marine surface monitoring system, the value T_{ijk} - the period of the data processing regarding the k -th element of the r -th infringing object, is crucial. Taking into account the physical content of information processing and constructing managerial influences, the latter can be presented in the following expression

$$T_{ij} = \min_{i,j} T_{ijk} . \quad (12)$$

Taking into account that

$$T_{ijkr} = t_{ijkt}^{fix} - t_{ijkr} , \quad (13)$$

the value T_{kr} will be equal to

$$T_{kr} = \min_{i,j} (t_{ijkt}^{fix} - t_{ijkr}) . \quad (14)$$

In this case, the time taken to make a decision (performing managerial influences) concerning all information elements of the r -th infringing object will be equal to

$$T_r = \max_k T_{kr} . \quad (15)$$

With allowances made for (13)

$$T_r = \max_k \min_{i,j} (t_{ijkt}^{fix} - t_{ijkr}) \quad (16)$$

In turn, the time taken to make a decision (performing managerial influences) respecting all information elements of at least one infringing object can be calculated by the formula

$$T = \min_r \max_k \min_{i,j} (t_{ijkt}^{fix} - t_{ijkr}) \quad (17)$$

The value T can be interpreted as the time of "postponing the decision" or "delaying the managerial influence".

Awareness about the value T makes it possible to assess the operational efficiency processed by the marine surface monitoring system. It can be interpreted as the possibility of just-in-time data acquisition from the operation of the marine surface monitoring system to respond timely to the actions of the infringing object. Considering the approach given in (Mazur, 2018), the operational efficiency can be evaluated by the formula

$$O = 1 - e^{-\frac{T_1}{T_2}} , \quad (18)$$

where T_1 is the actual time required for counteracting the infringing object, T_2 is the decision-postponing time with the reaction time towards decision-making.

Since according to the definition

$$T_2 = T_1 + \tilde{t}, \quad (19)$$

where $\tilde{t}$ is the reaction time for decision-making, then with allowances made for (17)

$$O = 1 - e^{-\frac{T_1}{\tilde{t} \times \min_{i,j} (t_{ijk}^{fix} - t_{ijk})}} \quad (20)$$

Analytical Model of the Integral Indicator of Effective Functioning of the Marine Surface Monitoring System

The validity of the indicators of reliability, completeness and operational efficiency allows applying them for the evaluation of certain aspects of functioning the marine surface monitoring system. However, it is natural to evaluate the effectiveness of the marine surface monitoring system with some integral indicator. Provided there is a vector

$$\vec{E} = \langle D, P, O \rangle, \quad (21)$$

and having considered a measurement set of some components of this vector, a generalized indicator of effective functioning of the marine surface monitoring system may have the following look

$$E = |\vec{E}| = \sqrt{D^2 + P^2 + O^2}. \quad (22)$$

This approach can be applied upon the condition of the equal value of some partial indicators (components of vector (21)). However, certain indicators may have different value in the formation of managerial influences. Because of this, the application of formula (22) is limited in this case.

In this case, we propose to use a different approach. Suppose K_d , K_p , K_o are coefficients of indicators' importance (moreover $K_d + K_p + K_o = 1$).

In this case, a generalized indicator of the effectiveness of the marine surface monitoring system can be presented in the form

$$E = K_d D + K_p P + K_o O. \quad (23)$$

Therefore, formulas (22), (23) is the result of the conducted research and determine the content of the evaluating procedure of the effectiveness of the marine surface monitoring system in the information aspect.

Discussion of the Results of Applying the Information Approach to Assessing the Effectiveness of the Marine Surface Monitoring System in Different Environmental Conditions

In general, the structure of the marine surface monitoring system is not constant. Depending on the time of year, time of day, and border security model, the number of data resources varies. In view of this, it is also necessary to take into account the technical modernization of the system itself, the replacement of old elements with new ones. The above factors will determine the ultimate value of the effective functioning of the marine surface monitoring system.

The evaluating procedure of the effectiveness of the marine surface monitoring system in different environmental conditions involves the application of specific values of the data resources characteristics (Yang et al., 2019). As a general matter, these values are unknown, in particular in case of using them by the Border Guard Agency. In order to find out the numerical values of the parameters of the model of the marine surface monitoring system functioning and the main characteristics of data resources, expert evaluation method was applied.

Normally, the methodology structure of the expert evaluation of the parameters of the model of the marine surface monitoring system functioning is a step-by-step process:

1. Determining the parameter list of the model of the system functioning and establishing the survey table.
2. Developing the evaluation scale of parameter values of the model of the marine surface monitoring system functioning for each data resource.
3. Composing the working group of experts.

4. Experts' evaluation of the parameters given in the tables according to the proposed scale.
5. Processing survey results.

To construct a diagram of the evaluating procedure of the functioning effectiveness of the marine surface monitoring system, we apply a system-and-concept related approach that puts forward such requirements:

1. Theoretical:

- a) completeness, that is, sufficiency for solving the problem of evaluating the effectiveness of the marine surface monitoring system functioning;
- b) conflict-free demand, i.e. interconnection and logical connection of all components.

2. Applied:

- a) uniformity, that is, the ability to meet the need of solving the evaluation problem;
- b) taking into account the basic provisions of modern and future-oriented concepts of development and use of such system type;
- c) possibility of realization in response to the modern development of the border guard agency, science and technology;
- d) long-term benefits, that is, adequacy not only for the present, but also for the up-coming needs and conditions of functioning of the marine surface monitoring system.

As a result of the analysis of the initial data and the purpose of the marine surface monitoring system, its components are determined, the system effectiveness indicators are substantiated and analytically described and, in view of this, a generalized structure of the methodology is built.

The evaluating procedure of the effectiveness of marine surface monitoring system functioning (Fig. 1) is relatively divided into three stages.

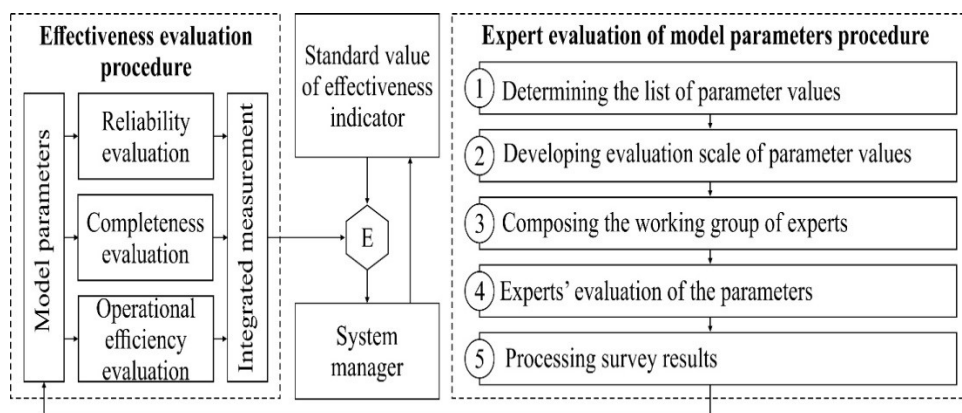


Fig. 1. Structural Diagram of the Evaluating Procedure of the Effectiveness of Marine Surface Monitoring System Functioning

At the first stage, a pattern is developed to evaluate the performance of the marine surface monitoring system, which specifies the systemically significant parameters and analytically describes their structure.

At the second stage, expert evaluation of the model parameters is carried out according to the pattern, which was developed at the first stage of the methodology. The input data for peer review is model parameters that have to be determined by experts. At the same time, the formation of a quantitative and qualitative composition of the expert group is performed by the system manager. The result of expert evaluation of model parameters is their specific value.

The third stage evaluates the effectiveness of the marine surface monitoring system functioning based on the parameters that were determined at the second stage of the methodology. The result is an integrated measurement of effectiveness, the value of which is compared to the standard value of the effectiveness indicator. By comparison, the system manager decides on the deployment of the marine surface monitoring system.

The application of the proposed procedure was carried out in the area of responsibility of the Regional Marine Guard Directorate. According to the results of the expert evaluation, a list of significant parameters of the model of the marine surface monitoring system functioning was obtained (Table 1). Parameters, in which the standard value of the information element is less than 0.01, were rejected as negligible.

Table 1. Standartization of values and selection of influential parameters in the model of the marine surface monitoring system functioning

№	Information element name (parameter)	Information element (parameter) value limitation	Parameter choice
1	Bearing	0,25525526	+
2	Distance	0,26226226	+
3	Course	0,18118118	+
4	Speed	0,18218218	+
5	Fix	0,08908909	+
6	Class of ship	0,00600601	–
7	Tonnage	0,003003	–
8	Belonging	0,00500501	–
9	Crew-member number	0,00500501	–
10	Cargo type	0,00900901	–
11	Ship's name	0,002002	–

The result of the second stage procedure is to determine the experts' numerical values of the coefficients of importance. Their values are shown in table 2.

Table 2. Summarized results of expert evaluation of determining the coefficients of importance of effectiveness indicators (K_d, K_p, K_o)

Parameter	Weighted average	Standard value	$\tilde{\epsilon}$	ϵ
K_d	3,08	0,308	0,54	0,23
K_p	2,31	0,231	0,46	0,20
K_o	4,61	0,461	0,49	0,21

The above values of the coefficients of importance allowed us to determine the numerical values of the effectiveness indicator of the marine surface monitoring system. Comparison of the obtained values under a different system structure and in different environmental conditions contributed to the improvement of the organizational and technical

functioning of the system. Better effect was achieved by streamlining information-sharing procedures, including the delay-time reduction of information flow, namely:

- simplification of the algorithm of actions of information flow in certain links, which will help to reduce time indicators for collecting (extracting) and processing of situation data. Under these conditions, the loss of time will be reduced to 8%;
- improving the coordinate actions of the system elements, which will increase the efficiency of data acquisition, processing and evaluation, mutual exchange as well as information entry in the database;
- time-efficient decision-making by officials;
- detailing timing, content and order of receiving (transmitting) information, which will increase the speed of obtaining the necessary data for their processing; as a result, the value and relevance of its purpose, place and time is preserved;
- complete and time-efficient formation of reports of the situation data in accordance with real time, without information distortion, which substantiates its value and relevance;
- reduction of record management and increase of efficient processing of proposals for decision-making;
- improvement of information and analytical products.

Under such conditions, the Border Security Body will be the main tool for evaluating the situation and information, forecasting its development and making management decisions in line with its area of activity and competence.

Conclusions

The information approach that has been developed to evaluate the effectiveness of the marine surface monitoring system is invariant to data resources. This circumstance will allow to take into account both technical and non-technical system data resources. Within the framework of the procedure, an analytical model for determining the components of the integral indicator of the effectiveness of the marine surface monitoring system functioning, in particular reliability, completeness and operational efficiency, has been proposed. The developed procedures of expert evaluation of the parameters of the analytical model will allow to determine the numerical values of importance for different variants of the system application. The obtained value of the integral effectiveness indicator will permit to compare the results of modeling with the standard value of the

effectiveness indicator and in turn to justify the managerial solution on the use of operational resources at the maritime border area.

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