The object of this study is the process of making a management decision based on the analysis of information from space surveillance systems.

Unlike the well-known ones, the method of making a management decision based on the analysis of information from space surveillance systems involves:

– segmentation of an optoelectronic image;

– determination and prediction of a priori probabilities of possible environmental states;

– an application for making a management decision of a combination of Bayes criteria and a minimum of variance.

Experimental studies have been carried out on making a management decision based on the analysis of information from space surveillance systems. To conduct experimental research on making a management decision based on the analysis of information from space surveillance systems, a model problem has been stated. As images from space surveillance systems, images obtained from the WorldView-2 spacecraft (USA) with a difference of four days were considered. The vegetation index was calculated, and the probabilities of degradation dynamics of plant segments were determined. It was established that the maximum value of the estimated functional is achieved when choosing a solution $\phi 1$, which is optimal according to the Bayesian criterion and the criterion of minimum variance.

The quality of management decision-making was assessed by the well-known and developed methods. To assess the quality of management decision-making, the concepts of objectivity of the decision-making method and the selectivity of the decision-making method by known and developed method were introduced. It has been established that both methods are objective, and the improved method is more selective (the gain is 2.6 times). This becomes possible through the use of information from space surveillance systems

Keywords: management decision, space surveillance system, image segmentation, state of the environment, forecasting

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THE DEVELOPMENT OF A MANAGEMENT DECISION-MAKING METHOD BASED ON THE ANALYSIS OF INFORMATION FROM SPACE OBSERVATION SYSTEMS

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1. Introduction

Geoinformation systems are used to make management decisions in various fields: management structures, municipal services, emergency services, forestry, business, in the interests of security and defense, building cities and towns, etc. [1, 2]. This leads to the presence of a large number of geographic information software products. On the basis of existing geographic information software products, thousands of different geographic information systems have been created. Such geographic information systems convert large amounts of diverse information. They make it possible to represent information on the ground and in time in a convenient form for further use, including for making management decisions.

Especially relevant is the use of geographic information systems in the interests of security, defense, and reintegration of the temporarily occupied territories [2]. The main source of geospatial data for such geographic information systems is information from space surveillance systems [3]. Such systems provide management bodies with operational, reliable, thorough, objective information, on the basis of which management decisions are made [4]. Therefore, research on the development of a method of making a management decision based on the analysis of information from space surveillance systems is relevant.

2. Literature review and problem statement

In [5], the methods of analysis of geospatial data are considered. Methods [5] involve a systematic analysis of geospatial data in order to find patterns in the data set. The search for such patterns is based on an analysis of the location of objects and topological relations between them. The advantage [5] is the theoretical substantial theoretical substantiation of the methods. The disadvantage [5] is the difficulty in implementing the analysis of geospatial data using these methods in practice.

In [6], three basic levels of input information and methods of information processing at these levels are proposed. The advantage [6] is the analysis of a large amount of heterogeneous information. The disadvantage [6] is the use of information from pickups and sensors, in addition to information from space surveillance systems.

Paper [7] proposed methods of visual analysis of information for decision-making, which is based on the algorithm C4.5. This method is combined with the analysis of the visualization map. The application of the method [7] makes it possible to identify spatial patterns for classifying information and making decisions. The disadvantage [7] is to conduct only visual analysis of information and not to use information from space surveillance systems.

In [8], the use of artificial neural networks in making a decision based on the results of information analysis is considered. The analysis of the properties of artificial neural networks in order to predict the concentration of pollutants in the air was conducted. Study [8] proposed using an extreme learning machine for training an artificial neural network. This ensures high generalization efficiency at an extremely high learning speed. Disadvantages [8] include the accumulation of errors and the inability to select parameters and the type of membership function.

Paper [9] presents a machine learning model for automatically identifying requests and providing information support services exchanged between members of the online community. This model is designed to process a large number of user messages in social networks. The disadvantages [9] are the lack of mechanisms for assessing the adequacy of the decisions made, and the great computational complexity.

In [10], the use of an artificial neural network to detect heart rhythm abnormalities and other heart diseases is presented. As a method of training an artificial neural network, an algorithm for the back propagation of an error is used. The disadvantages of this approach are its limited learning to only synaptic weights, without learning the type and parameters of the function.

In [11], the use of an artificial neural network to detect avalanches is presented. As a method of training an artificial neural network, as in [10], the algorithm for the back propagation of error is used. The disadvantages [11] are the limitation of learning to only synaptic weights, without learning the type and parameters of the function.

Study [12] presents the use of an artificial neural network to detect anomalies in home authorization systems. As a method of training an artificial Kohonen neural network, the "winner gets everything" algorithm is used. The disadvantages of this approach are the accumulation of errors in the learning process, the limitation of learning to only synaptic weights, without learning the type and parameters of the learning function.

In [13], the use of an artificial neural network to detect anomalies in the human encephalogram is presented. As a learning method, the method of fine-tuning network parameters is used. The disadvantages of this approach are the accumulation of errors in the learning process, the limitation of learning to only synaptic weights, without learning the type and parameters of the learning function.

In [14], the use of methods of artificial neural network and genetic algorithms is presented. A genetic algorithm is used as a training method. The disadvantages of this approach are its limited learning to only synaptic weights, without learning the type and parameters of the learning function.

In [15], the use of machine learning methods, namely an artificial neural network and a method of differential search, is presented. In the course of the study, a hybrid method of training an artificial neural network was developed, which is based on the use of an algorithm for back error propagation and differential search. The disadvantages of this approach are the accumulation of errors in the learning process and the limited learning of synaptic weights only.

In [16], the development of methods for training an artificial neural network using a combined approximation of the response surface, which provides the smallest errors in training and forecasting, was carried out. The disadvantage [16] is the accumulation of errors during training and the impossibility of changing the architecture of an artificial neural network.

Study [17] presents the use of an artificial neural network to assess the efficiency of the unit using the previous time series of its performance. SBM (Stochastic Block Model) and DEA (Data Envelopment Analysis) models are used to train the network. The disadvantages of this approach are limited in the choice of network architecture, learning only synaptic scales.

In [18], the use of an artificial neural network to assess geomechanical properties is given. As a training method, an algorithm for the back propagation of error is used. Improving the characteristics of the algorithm for the error back propagation is achieved by increasing the training sample. The disadvantages of this approach are its limited learning to only synaptic weights, without learning the type and parameters of the learning function.

Paper [19] shows the use of an artificial neural network to estimate the intensity of traffic. As a training method, an algorithm for the error back propagation is used. The disadvantages of this approach are its limited learning to only synaptic weights, without learning the type and parameters of the learning function.

In [20], the authors formulated the rules of association in transactional or relational databases, which can be used in the database of geospatial data. At the same time, in [20], spatial properties and predicates are considered. The disadvantage [20] is the need to carry out a large amount of calculations of various spatial predicates when deriving associative rules from large volumes of spatial data. Also, the disadvantage [20] is the need to find the rules of spatial association in order to filter out trivial rules.

In [21], measurements and algorithms for the intelligent analysis of spatial commonalities of the location of structures are proposed. The analysis of topology is closely related to the rules of associations, which makes it possible to establish rules for the behavior of objects relative to one another, as well as to identify similar rules in geospatial data using the functions of the neighborhood and overlay operations. The disadvantage [21] is the lack of methods for analyzing information from space surveillance systems.

Work [22] provides an operational approach to spatial analysis in the maritime industry to quantify and reflect related ecosystem services. The method [22] builds three-dimensional sea models by evaluation and mapping. The disadvantages [22] include the impossibility of flexible adjustment (adaptation) of evaluation models when adding (turning off) indicators and changing their parameters (compatibility and significance of indicators).

In [23], a method of data clustering using the Morishita diagram is proposed. The Morishita index is calculated for an area divided into equilateral cells of equal size. The Morishita index characterizes the probability that when choosing two random points they fall into the same cell. In [24], three types of characteristic values of the Morishita index are considered, combinations of which make it possible to judge the characteristics of the data. The disadvantage [23] is the failure to take into account data from space surveillance systems.

In [24], procedures and methods of analysis that are applied to big data. In [24], the methods of Data Mining, crowdsourcing, data consolidation and integration, etc. are considered. But the application of methods [24] to the analysis of information from space surveillance systems is not considered.

Making a management decision based on the analysis of information from space surveillance systems involves the processing of images from such systems. One of the most difficult and important stages of such processing is the decryption of images from space surveillance systems. Decryption is based on knowledge of the patterns of reproduction of the properties of objects of interest in images, features of their statistical characteristics (signatures), geometric shape, placement on the ground, etc. Procedurally, decryption involves identifying, classifying, and interpreting objects of interest and terrain. The most important step for making a management decision is the stage of segmenting images from space surveillance systems.

In [25], the authors proposed segmentation methods that take into account the statistical texture of the image. The disadvantage [25] is the impossibility of segmenting objects of interest masking as a background object.

Paper [26] proposed a method of segmentation based on Love's indicators. The method [26] makes it possible to highlight in the image a significant number of textural features. The disadvantage [26] is the need to take into account at the same time sixteen types of masks of objects in the image.

In [27], the method of segmentation based on the matrix of coincidences is considered. Coincidence matrices take into account statistical information regarding the brightness values of pixels in the image. The method [27] does not require significant memory. The disadvantages [27] are the obligatory presence of standards of image textures.

In [28], the method of automatic segmentation of k-averages is proposed. In this case, the classes in the image are refined. The advantage [28] is the reduction of the time of calculations. The disadvantage [28] is the uncertainty about the initial values of the clusters.

In [29], a method of segmentation based on a genetic algorithm is proposed. It was established that the method [29] works qualitatively under the conditions of segmentation of camouflage military equipment in the images. The disadvantage [29] is the failure to take into account the stage of making a management decision based on the analysis of images from space surveillance systems.

In [30], the method of segmentation based on C-averages is considered. The advantage [30] is that the method works in the absence of a priori information regarding the color of pixels in the image. The disadvantage [30] is the sensitivity of the method to noise, especially to additive noise.

Study [31] proposed a method of segmenting the image using the Voronoi mosaic. The advantage [31] is a clear selection of contours, even in conditions of minor noise. The disadvantage [31] is the low speed of the method.

Work [32] proposed a method of segmentation based on the calculation of the fractal dimension of the image. The disadvantage [32] is the need for a preliminary assessment of the fractality of the texture in the image.

In [33], a method of image segmentation based on the particle swarm algorithm is proposed. The advantage [33] is the qualitative work of the method for determining the optimal number of segments in the image. The disadvantage [33] is the high-quality work of the method only in the conditions of simple images from space surveillance systems.

Work [34] proposed a method of selecting military objects based on fuzzy systems of logical detection. The advantage [34] is the ability to work with uncertainty of the input data. The disadvantage [34] is the failure to take into account the adoption of management decisions based on the analysis of information from space surveillance systems.

In [35], a method of segmentation of tone aerospace images based on a conventional ant algorithm is proposed. The method [35] qualitatively conducts segmentation of lonely objects of interest. The disadvantage of the method [35] is the impossibility of segmenting masked objects in the image.

In [36], the methods of clustering (hierarchical and distribution) are considered. The disadvantages [36] are the impossibility of their application for making a management decision based on the results of image processing from space surveillance systems.

In [37], the method of image segmentation from space surveillance systems based on the Sine-Cosine algorithm is considered. The method [37] makes it possible to segment objects of interest under snow cover. The disadvantage [37] is the impossibility of its application for making a management decision based on the results of image processing from space surveillance systems.

Thus, when analyzing known methods of making management decisions, it was established that information from space surveillance systems is not taken into account. At the same time, regarding the use and analysis of information from space surveillance systems, only segmentation methods are used without further management decision.

Therefore, the development of a method for making a management decision based on the analysis of information from space surveillance systems is relevant.

3. The aim and objectives of the study

The aim of this study is to improve the method of making management decisions based on the analysis of information from space surveillance systems. This will provide an opportunity to improve the quality of management decision-making.

To accomplish the aim, the following tasks have been set:

– to determine the main stages of the method of making a management decision based on the analysis of information from space surveillance systems;

– to conduct experimental research on management decision-making based on the analysis of information from space surveillance systems;

– to conduct a comparative assessment of the quality of management decision-making by known and developed method based on the analysis of information from space surveillance systems.

4. The study materials and methods

The object of the study is the process of making a management decision based on the analysis of information from space surveillance systems.

The main hypothesis of the study was that the use of information from space surveillance systems will improve the quality of management decision-making.

During the study, the following research methods were used:

– in determining the main stages of the method of making a management decision based on the analysis of information from space surveillance systems:

a) methods of probability theory;

b) methods of the theory of mathematical statistics;

c) the mathematical apparatus of the theory of matrices;

d) methods of digital image processing;

e) iterative methods;

f) methods of system analysis;

– when conducting experimental research on making a management decision based on the analysis of information from space surveillance systems:

a) methods of system analysis;

b) methods of digital image processing;

– when conducting a comparative assessment of the quality of management decision-making by known and developed method based on the analysis of information from space surveillance systems:

a) methods of mathematical modeling;

b) analytical and empirical methods of comparative research;

c) methods of probability theory;

d) methods of the theory of mathematical statistics.

When validating the proposed solutions, analytical and empirical methods of comparative research were used.

When performing the study, mathematical support was used, which is included in the above research methods. A high-level programming language and an interactive environment for programming, numerical calculations, and visualization of MATLAB R2017b results was chosen as software.

When conducting the study, the following restrictions and assumptions were adopted:

– space systems of optoelectronic surveillance are adopted as space surveillance systems;

– the analysis of information from space surveillance systems is understood as the analysis of an optoelectronic image from a space surveillance system;

– the original image from the space system of optoelectronic observation is represented in the color space Red-Green-Blue (RGB);

– the image presents heterogeneous objects of interest;

– a priori information on the number and probabilistic characteristics of objects of interest is absent or has a limited volume;

– the size of objects of interest is taken much smaller than the size of the background objects;

– the effect of noise, rotation, and scaling on the original image is not taken into account.

5. Results of the study on devising a method of making a management decision

5. 1. The main stages of the management decision-making method based on the analysis of information from space surveillance systems

When defining the main stages of the method of making a management decision based on the analysis of information from space surveillance systems, we will use the results reported in [38].

Input data when making a management decision are possible states of the environment (possible situations) θ_i (i=1, ..., n), where n is the number of environmental states. Based on the determination of possible states of the environment, decisions are made ϕ_j (j=1, 2, ..., m), where m – the number of possible decisions made based on the determination of possible environmental conditions. Note that the elements of the set of states of the environment θ_i are mutually exclusive (there can be only one of the states of the medium at a time). Also, the elements of the set of solutions ϕ_j are also mutually exclusive (only one decision can be made at a time).

The input value in the development of a management decision-making method is also a type of evaluative functional $f_{ij}=f(\theta_i, \phi_\varphi)$, the value of which is calculated and corresponds to the i-th state of the environment when making the j-th decision.

So, in general, management decision-making can be formalized in the form of a matrix (1) [38]:

$$\begin{array}{lcccccc} \dfrac{\text{the set of solutions}}{\text{the state of environment}} & \varphi_1 & \varphi_2 & \dots & \varphi_k & \dots & \varphi_m \\ \theta_1 & f_{11} & f_{12} & \dots & f_{1k} & \dots & f_{1m} \\ \theta_2 & f_{21} & f_{22} & \dots & f_{2k} & \dots & f_{2m} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \theta_j & f_{j1} & f_{j2} & \dots & f_{jk} & \dots & f_{jm} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \theta_n & f_{n1} & f_{n2} & \dots & f_{nk} & \dots & f_{nm} \end{array}. \quad (1)$$

The main stages of the management decision-making method based on the analysis of information from space surveillance systems are shown in Fig. 1.

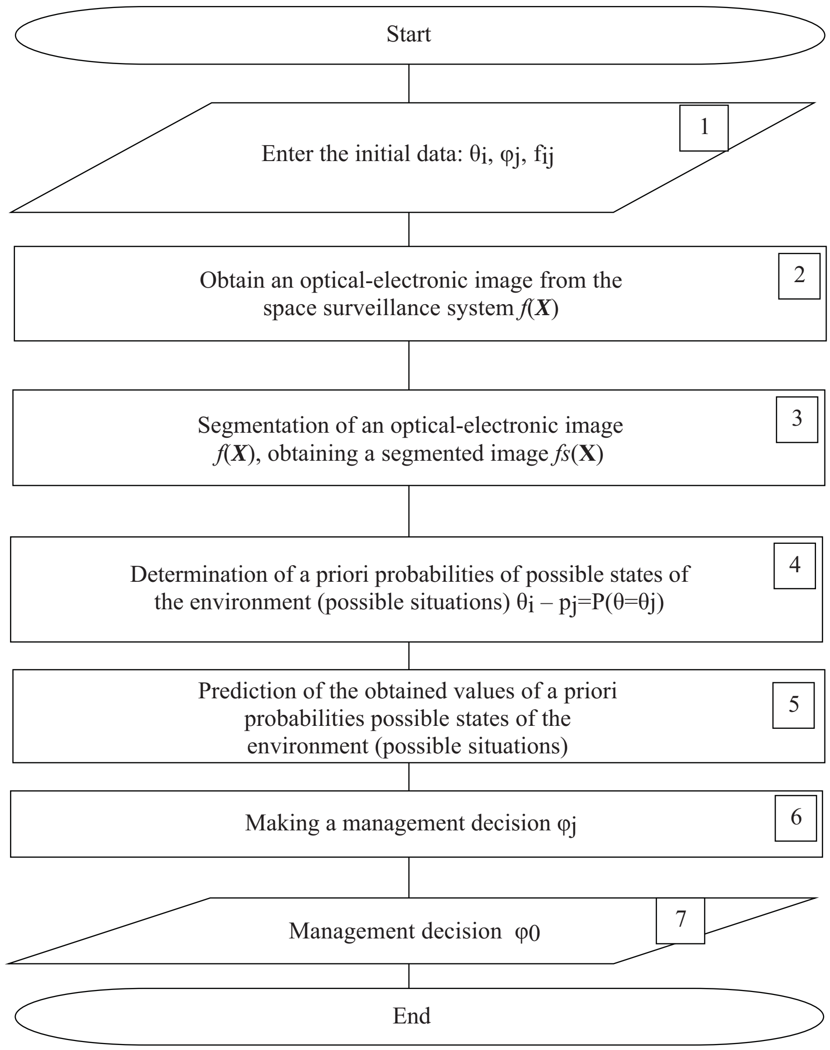

Fig. 1. The main stages of the management decision-making method based on the analysis of information from space surveillance systems

The method of making a management decision based on the analysis of information from space surveillance systems involves the following main steps:

1. Entering the original data: θ_i (i=1, ..., n); ϕ_j (j=1, 2, ..., m); f_{ij}=$f(\theta_i, \phi_j)$.

2. Obtaining an optoelectronic image from the space observation system $f(\boldsymbol{X})$, where $\boldsymbol{X}(x, y)$ is the coordinates of the pixels on the optoelectronic image, N is the number of pixels on the optoelectronic image.

3. Segmentation of optoelectronic image $f(\boldsymbol{X})$ (expression (2)) [39, 40]:

$$f(\mathbf{X}) \to fs(\mathbf{X}), \tag{2}$$

where $fs(\mathbf{X})$ is a segmented image.

We consider that segments B_i of the segmented image $fs(\mathbf{X})$ are determined by expression (3) [39, 40]:

$$\begin{cases} \bigcup_{i=1}^{K} B_i = B; \\ B_i \cap B_j = \varnothing, \text{ for } i \neq j; \ \forall i, j = \overline{1, K}; \\ LP(B_i) = 1; \ \forall i = \overline{1, K}; \\ LP(B_i \cap B_j) = 0, \text{ for } i \neq j; \ \forall i, j = \overline{1, K}, \end{cases} \tag{3}$$

where B: B={B_1, B_2,..., B_K} are segments of the segmented image $fs(\mathbf{X})$; K – number of segments, (i=1, 2,..., K); LP – predicate, which is determined by expression (4) [39, 40]:

$$LP(B_i) = \begin{cases} 1, & \text{if } f(x_1, y_1) = \ldots = f(x_m, y_m); \\ 0, & \text{others}, \end{cases} \tag{4}$$

where $(x_m, y_m) \epsilon B_i$; m=1, 2,..., M; M – the number of points of segment B_i.

The result of segmenting the image $f(x, y)$ is its division into segments.

4. Determination of a priori probabilities of possible states of the environment (possible situations) θ_i (i=1, ..., n), where n is the number of states of the medium – p_j=$P(\theta=\theta_j)$, $1 \leq j \leq n$.

A priori probabilities of possible environmental states are determined by expression (5):

$$p_j = \frac{1}{\sum_{j=1}^{K} \vartheta_j(\mathbf{X})} \sum_{(\mathbf{X} \in K_j)} \vartheta_j(\mathbf{X}), \tag{5}$$

where $\vartheta_k(\mathbf{X})$ is defined for each segment ($1 \leq k \leq K$) by expression (6):

$$\vartheta_k(\mathbf{X}) = \sum_{k'} S_k \delta_{kk'}, \quad (6)$$

S_k – index image that includes only pixels belonging to the segment k; $\delta_{kk'}$ is a Kronecker symbol.

5. Prediction of the obtained values of a priori probabilities of possible environmental states (possible situations).

To predict the values of a priori probabilities of possible environmental states, we will use an adaptive selective model. Such a model is built on the basis of an ensemble of integrated models of autoregression-moving average ARIMA (p, d, q). In this case, the order of the models p and q is different, d – the order of the difference between existing and predicted values [41, 42].

In general, the predicted value of the parameter at time t (denote it in general form X_t) is represented as (7) [41, 42]:

$$X_t = \hat{\mathbf{M}}(q)\hat{\mathbf{I}}(d)\hat{\mathbf{A}}(p)\hat{\mathbf{I}}^{-1}(d)\{X_{t-1}, X_{t-2}, ...\}, \quad (7)$$

where the operator $\hat{\mathbf{M}}(q)$ describes the model of the moving average and is given by expression (8):

$$X_t = \mu + \sum_{i=1}^{q}(b_i X_{t-i}) + \varepsilon_t, \quad (8)$$

where μ is the mathematical expectation X_t; q – model order; b_i – model coefficients; ε_t – white noise.

The operator $\hat{\mathbf{A}}(p)$ describes the autoregression model and is given by expression (9):

$$X_t = c + \sum_{i=1}^{p}(a_i X_{t-i}) + \varepsilon_t, \quad (9)$$

where c is some constant (without losing generality, one can assume that c=0); p – model order; a_i – coefficients of the model.

$\hat{\mathbf{I}}(d)$ is an integrating operator of order d, such that the operator inverse to it $\hat{\mathbf{I}}^{-1}(d)$ is an operator of the difference of the same order (expression (10)):

$$\hat{\mathbf{I}}^{-1}(d) = \Delta^d, \quad (10)$$

where Δ^d is defined by expression (11):

$$\aleph^{d}\aleph X_t \aleph c \quad \sum_{i=1}^{q}\left(a_i \quad {}^{d}X_{t-i}\right) \quad \sum_{i=1}^{q}\left(b_i X_{t-i}\right) \quad {}_t. \quad (11)$$

In [41–43] it is shown that the values of p, q, d should be chosen as follows: p=q=0; 1; 2, d=0; 1. So, we will use an ensemble of integrated autoregression-moving average models with the corresponding parameters p, q, d.

6. Management decision making ϕ_j=ϕ_0.

To make a management decision, it is necessary to choose a decision-making criterion. In the work, we will use a combination of known Bayesian criteria and a minimum of variance [44, 45]. To do this, we will calculate the value by expression (12):

$$K(\aleph_k, p) \aleph (1 \quad) B(\quad {}_k, p) \quad {}^{2}(\quad {}_k, p), \quad (12)$$

where $B(\varphi_k, p)$ is the evaluation functional according to the Bayes criterion (determined by expression (13)):

$$B(\varphi_k, p) = \sum_{j=1}^{n}(f_{jk} p_j), \quad (13)$$

$\sigma^2(\varphi_k, p)$ – evaluation functionality according to the criterion of minimum variance (determined by expression (14)):

$$\sigma^2(\varphi_k, p) = \sum_{j=1}^{n}\left(\left(f_{jk} - B(\varphi_k, p)\right)^2 p_j\right), \quad (14)$$

$$\lambda = \frac{\lambda_1 + \lambda_2}{2}, \quad (15)$$

where

$$\lambda_1 = \min_k \frac{\left(\sum_{j=1}^{n}(p_j f_{jk})\right)^2}{\sum_{j=1}^{n}(p_j f_{jk}^2)}, \quad (16)$$

$$\lambda_1 = \max_k \frac{\left(\sum_{j=1}^{n}(p_j f_{jk})\right)^2}{\sum_{j=1}^{n}(p_j f_{jk}^2)}. \quad (17)$$

The management decision ϕ_j=ϕ_{j0} is made at the maximum value of $K(\phi_k, p)$ (12):

$$K_0 = \arg\max_k\left(K(\varphi_k, p)\right). \quad (18)$$

Thus, unlike the well-known ones, the method of making a management decision based on the analysis of information from space surveillance systems involves:

– segmentation of optoelectronic image;

– determination and prediction of a priori probabilities of possible environmental states;

– application for making a management decision of a combination of Bayes criteria and a minimum of variance.

5. 2. Experimental research on management decision-making based on the analysis of information from space surveillance systems

To conduct experimental research on making a management decision based on the analysis of information from space surveillance systems, we will state the following model problem.

It is necessary, based on the results of the analysis of information from the space surveillance system, to make a decision on emergency response. Environmental conditions are characterized by the number of emergencies.

Possible environmental states are defined as follows:

– θ_1 – the average number of emergencies during the reporting period will be large (will increase significantly);

– θ_2 – the average number of emergencies during the reporting period will be moderately large (slightly increased);

– θ_3 – few emergencies will occur during the reporting period (their number will not change);

– θ_4 – during the reporting period there will be few emergencies (their number will decrease);

– θ_5 – there will be no emergencies.

Based on the definition of possible states of the environment, decisions are made ϕ_j:

– ϕ_1 – do not change the amount of resources;

– ϕ_2 – increase the number of resources by combining (variable composition);

– ϕ_3 – increase the number of resources;

– ϕ_4 – reduce the number of resources.

The evaluation functionalities f_{ij} are obtained from the results of a survey of experts and are given in the form of a matrix (19):

the set of solutions / the state of environment	φ_1	φ_2	φ_3	φ_4
θ_1	4	5	8	1
θ_2	6	6	7	2
θ_3	9	3	3	7
θ_4	4	2	1	8
θ_5	2	1	1	10

(19)

As images from space surveillance systems, we will consider images obtained from the WorldView-2 spacecraft (USA) [45] with a difference of four days. We will call these images "Fragment 1" and "Fragment 2". The original images ("Fragment 1" and "Fragment 2") are shown in Fig. 2, 3, respectively.

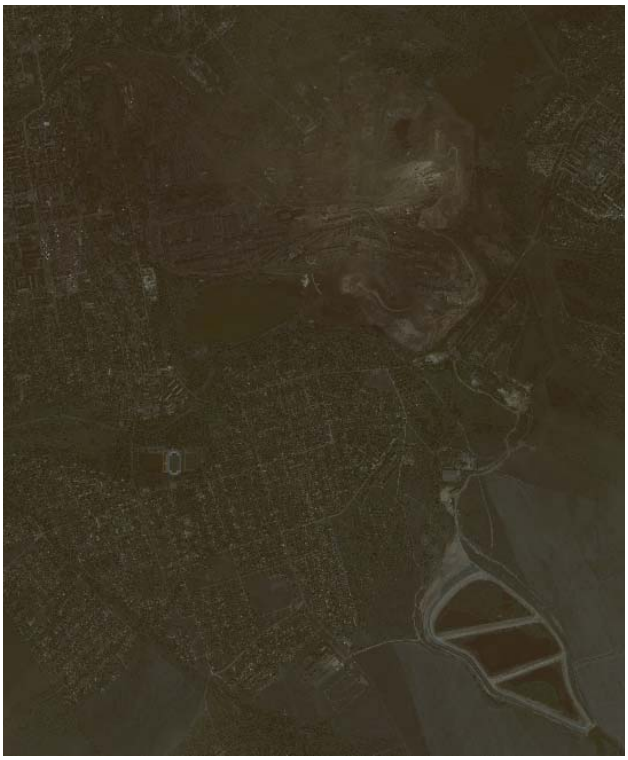

Fig. 2. Original "Fragment 1" image [45]

Fig. 3. Original "Fragment 2" image [45]

Image segmentation will be carried out using a convolutional U-Net-like deep learning network [46]. Segmentation will be carried out into 6 segments. List of segments: "Vegetation", "Trees", "Water", "Infrastructure", "Soil", "Other". The results of segmentation of the original images shown in Fig. 2, 3, are depicted in Fig. 4, 5, respectively.

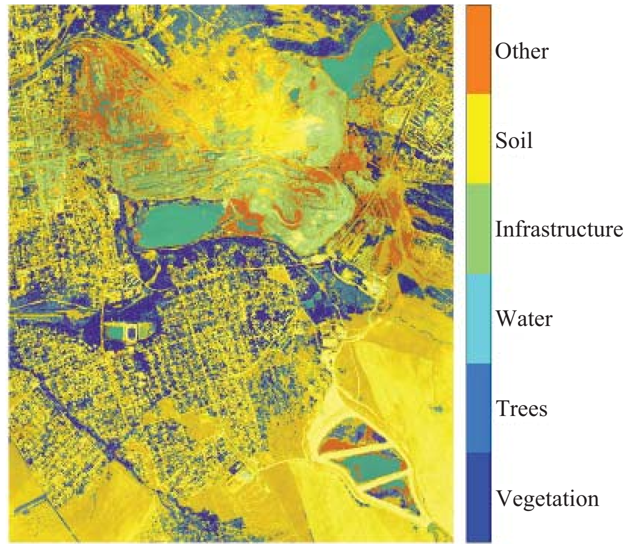

Fig. 4. The result of segmenting the original "Fragment 1" image

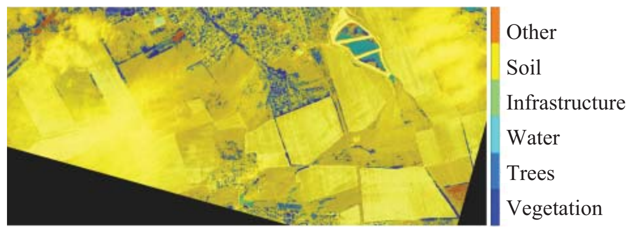

Fig. 5. The result of segmenting the original "Fragment 2" image

Let's define a common area for the original "Fragment 1" and "Fragment 2" images. This area is shown in Fig. 6 – from the original image "Fragment 1", Fig. 7 – from the original image "Fragment 2".

Fig. 6. Shared area from the original "Fragment 1" image

Fig. 7. Shared area from the original "Fragment 2" image

For further research, only plant segments in the images were considered. Their vegetation index was calculated, and the probabilities of degradation dynamics of these plant segments were determined.

Taking into account Fig. 6–9 show the vegetation indices of "Fragment 1" and "Fragment 2", respectively.

Fig. 8. Vegetation index of "Fragment 1"

Fig. 9. Vegetation index of "Fragment 2"

In Fig. 10, in order to determine the probability of degradation dynamics, the normalized difference in vegetation indices is given.

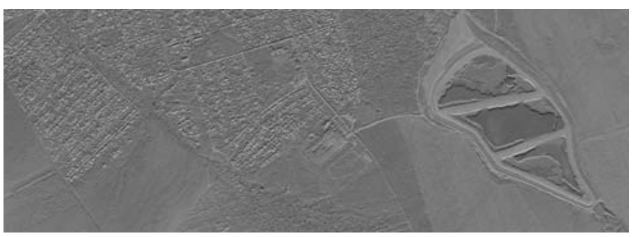

Fig. 10. Normalized difference between the vegetation indices "Fragment 1" and "Fragment 2"

The calculated probabilities of vegetation indices differences are shown in Fig. 11 and summarized in Table 1.

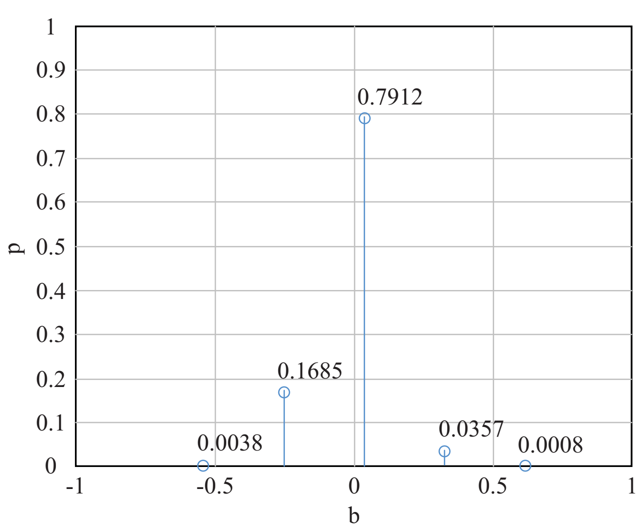

Fig. 11. Calculated probabilities of vegetation index differences

Having the probabilities of degradation dynamics, we calculate the values of λ_1 and λ_2 using expressions (16) and (17). We get λ_1=0.837; λ_2=0.87055. From expression (15), λ=0.9041.

So, calculating by expression (12) the estimated functionality, we have the values that are summarized in Table 2

Table 1

Calculated probabilities of degradation dynamics

Environmental states	p
θ_1	0.0038
θ_2	0.1685
θ_3	0.7912
θ_4	0.0357
θ_5	0.0008

Table 2

Results of calculation of estimated decision-making functionality

Evaluation functionality	ϕ_1	ϕ_2	ϕ_3	ϕ_4
$K(\phi_k, p)$	4.7570	–0.0549	–1.0490	0.3071

From the analysis of Table 2, we established that the maximal value of the estimated functional $K(\phi_k, p)$ is achieved when choosing a solution ϕ_1, which is optimal according to the Bayesian criterion and the criterion of minimum variance. That is, for a model problem, the most rational is the solution not to change the amount of resources.

5. 3. Assessment of the quality of management decision-making by known and developed methods

To compare the quality of management decision-making, we consider decision-making according to the criterion when the decision is made from the analysis of the most likely state of the environment. This criterion is called modal [38, 42, 43]. At the same time, they assume the existence of a single value j_0, which ensures the fulfillment of condition (20):

$$j_0 = \arg\max_j \left(p(\theta_j) \right). \qquad (20)$$

Then the governing body believes that the environment is in the state $\theta_{j=j0}$, and chooses the solution $\phi_{k=k0}$, for which

$$k_0 = \arg\max_k \left(f_{j_0 k} \right). \qquad (21)$$

To assess the quality of management decision-making by known and developed methods, we introduce the concept of objectivity of the decision-making method $Q^{obj}(\mathbf{C})$ and the selectivity of the decision-making method $Q^{sel}(\mathbf{C})$.

The selectivity of the decision-making method is understood as the coincidence of the best solution for this method with the statistical mode of decisions on all methods (expression (22)):

$$Q^{obj}(\mathbf{C}) = \left(\arg\min_{\varphi_k} \mathbf{C} = \underset{\{\mathbf{C}\}}{\mathrm{mode}} \left(\arg\min_{\varphi_k} \mathbf{C} \right) \right). \qquad (22)$$

The selectivity of the decision-making method is to be understood as the ratio of the differences in the values of the estimated functional $K^{\mathbf{C}}(\phi)$ for the two best solutions $\varphi_{k^{\cdot}}$ and $\varphi_{k^{\cdot\cdot}}$ to its standard deviation for all solutions for this method (expression (23)):

$$Q^{sel}(\mathbf{C}) = \frac{\left| K^{\mathbf{C}}\left(\varphi_{k^{\cdot}}\right) - K^{\mathbf{C}}\left(\varphi_{k^{\cdot\cdot}}\right) \right|}{std\left(K^{\mathbf{C}}(\varphi) \right)}. \qquad (23)$$

We calculate the relative frequencies of adoption of alternatives ϕ_k for each of the methods and find their statistical mode. Such data are given in Table 3.

Table 3

The results of calculating the objectivity of methods

Decision-making method	ϕ_1	ϕ_2	ϕ_3	ϕ_4	$Q^{obj}(\mathbf{C})$
Known	1	0	0	0	+
Improved	1	0	0	0	+
Selection frequency	2/2	0/2	0/2	0/2	+

From the analysis of Table 3, we found that both methods are objective.

Table 4 gives data on the calculations of the value of the selectivity of methods.

Table 4

Results of calculating the selectivity of methods

Decision-making method	The best solution $\phi_{k'}$	The second most optimal solution $\phi_{k''}$	Absolute difference	Standard deviation	$Q^{sel}(\mathbf{C})$
Known	9	7	2	3	0.6667
Improved	4.7570	0.3071	4.4499	2.5759	1.7275

From the analysis of Table 4, we found that the improved method is more selective (winning is 2.6 times). This becomes possible through the use of information from space surveillance systems.

6. Discussion of research results on the development of a management decision-making method

Unlike the well-known ones, the method of making a management decision based on the analysis of information from space surveillance systems involves:

– segmentation of optoelectronic image;

– determination and prediction of a priori probabilities of possible environmental states;

– application for making a management decision of a combination of Bayes criteria and a minimum of variance.

Experimental studies have been carried out on making a management decision based on the analysis of information from space surveillance systems. To conduct experimental research on making a management decision based on the analysis of information from space surveillance systems, a model problem has been stated. As images from space surveillance systems, images obtained from the WorldView-2 spacecraft (USA) with a difference of four days (Fig. 2, 3) are considered. Image segmentation was carried out using a convolutional U-Net-like deep learning network. Segmentation was carried out for 6 segments (“Vegetation”, “Trees”, “Water”, “Infrastructure”, “Soil”, “Other”) – Fig. 4, 5.

The vegetation index is calculated, and the probabilities of degradation dynamics of plant segments are determined (Fig. 8–10). We calculated probabilities of differences in vegetation indices (Table 1). It is established that the maximal value of the estimated functional is achieved when choosing a solution ϕ_1, which is optimal according to the Bayesian criterion and the criterion of minimum variance (Table 2).

The quality of management decision-making is assessed by the well-known and developed methods. As a well-known method, a method is considered when a decision is made from the analysis of the most likely state of the environment (20), (21). To assess the quality of management decision-making, the concepts of objectivity of the decision-making method and the selectivity of the decision-making method (22), (23) were introduced by known and developed method. It has been established that both methods are objective (Table 3) and the improved method is more selective (the gain is 2.6 times (Table 4)). This becomes possible through the use of information from space surveillance systems.

When conducting the study, the following restrictions and assumptions were adopted:

– space systems of optoelectronic surveillance are adopted as space surveillance systems;

– the analysis of information from space surveillance systems is understood as the analysis of an optoelectronic image from a space surveillance system;

– the original image from the space system of optoelectronic observation is represented in the color space Red-Green-Blue (RGB);

– the image presents heterogeneous objects of interest;

– a priori information on the number and probabilistic characteristics of objects of interest is absent or has a limited volume;

– the size of objects of interest is taken much smaller than the size of the background objects;

– the effect of noise, rotation, and scaling on the original image is not taken into account.

The improved method of making a management decision based on the analysis of information from space surveillance systems can be implemented in management decision-making systems in management bodies of various levels.

The disadvantages of the improved method of making a management decision are the obligatory availability of information from space surveillance systems.

Further research can be aimed at studying the methods of making management decisions in various industries of states.

7. Conclusions

1. The main stages of the segmentation method using the genetic algorithm have been determined. Unlike the well-known ones, the method of making a management decision based on the analysis of information from space surveillance systems involves:

– segmentation of optoelectronic image;

– determination and prediction of a priori probabilities of possible environmental states;

– application for making a management decision of a combination of Bayes criteria and a minimum of variance.

2. Experimental studies have been carried out on making a management decision based on the analysis of information from space surveillance systems. To conduct experimental research on making a management decision based on the analysis of information from space surveillance systems, a model problem has been stated. The vegetation index is calculated, and the probabilities of degradation dynamics of plant segments are determined. It is established that the maximal value of the estimated functional is achieved when choosing a solution that is optimal according to the Bayesian criterion and the criterion of minimum variance.

3. The quality of management decision-making is assessed by the well-known and developed methods. To assess

the quality of management decision-making, the concepts of objectivity of the decision-making method and the selectivity of the decision-making method were introduced by the known and developed methods. It has been established that both methods are objective, and the improved method is more selective (the gain is 2.6 times).

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

All data are available in the main text of the manuscript.

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