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DEVELOPMENT OF A COMPREHENSIVE INDICATOR FOR DIAGNOSING MASSIVE MISSILE STRIKES

Abstract. Objective. Enhancing the efficiency of diagnosing the threat level of massive missile strikes by developing a comprehensive indicator. **Methodology.** The study examines the process of developing a comprehensive indicator based on a dataset of massive missile strikes. This involves preliminary data processing, the development of a comprehensive indicator model, and the integration of individual indicators. One of the integrated indicators is assigned a weight coefficient, which is determined using artificial intelligence methods and constrained by a sigmoid activation function. A comparative analysis of the proposed comprehensive indicator against existing indicators was conducted based on the standard deviation criterion. The assessments obtained using the comprehensive indicator are employed to determine the threat level of massive missile strikes. **Results.** Based on an existing dataset of massive missile strikes on Ukraine, a comprehensive indicator has been developed, consolidating attack characteristics into a unified assessment. The comprehensive indicator's evaluations regarding massive missile strikes are utilized to determine the threat level (Cluster 1 – low threat level, Cluster 2 – high threat level). **Scientific novelty.** The proposed comprehensive indicator model differs from existing approaches in that its integrated indicators account for mean values and variations in assessments, serving as a prototype of the regularization concept. As a result, the standard deviation is reduced to 0.0925, whereas the existing approach demonstrates a deviation of 0.447 on a single experimental set of assessments. **Practical significance.** The proposed comprehensive indicator of massive missile strikes serves as an additional measure for determining the state's threat level or may be considered an element of a decision-making system.

Keywords: comprehensive indicator; regularization concept; state security.

Introduction

Currently, the issue of ensuring national security is beyond question. Various methods exist for assessing the security level of a state, its regions, or even smaller administrative units [1].

Some practitioners employ diagnostics of an object's attractiveness for terrorist attacks or measure the resilience of critical infrastructure [2]. This enables the forecasting of potential enemy attacks on specified targets.

Key elements of security support include strategies for emergency evacuation [3], particularly in terms of evacuation timing [4].

Threat level diagnostics can be conducted in advance, considering an enemy's potential attack plans through various means, including physical assaults or cyber tools [5].

Another approach involves assessing the impact of combat operations on affected areas [6]. However, there is currently a lack of comprehensive indicators designed to diagnose the threat level of massive missile strikes.

This gap underscores the need for developing new methods for diagnosing national air threat levels.

The aim of this study is to enhance the efficiency of diagnosing the threat level of massive missile strikes.

Object of the study: Diagnosis of massive missile strikes.

Subject of the study: Method for diagnosing massive missile strikes.

Research tasks:

1. Develop a comprehensive indicator for diagnosing massive missile strikes.
2. Conduct an experimental evaluation of the assessments determined by the comprehensive indicator for the task of clustering air threat levels.

A review of related scientific publications. The development of a comprehensive indicator for diagnosing methods of massive missile strikes requires identifying the model’s determining factors. One of the key factors in assessing air threats, in addition to the number of launched and intercepted missiles, is the strategy for distributing weaponry across combat zones [7]. This concept is essential in developing relevant models, as it enables not only the prediction of threat levels but also the calculation of the efficiency of air defense systems in specific regions. The study in [8] further suggests incorporating logistical risks, which enhances the mobility of countermeasures against massive missile attacks.

Alongside the development of models for comprehensive indicators diagnosing massive missile attacks, research on information support for mobile fire groups is advancing [9]. The combat readiness of such a group can be reinforced through computer vision technologies, enabling the detection of various types of unmanned aerial vehicles (UAVs) [10]. Real-time object detection in video streams represents one of the diagnostic methods for massive missile strikes, ensuring object identification and the prediction of future actions. The work presented in [11] expands upon the ideas in [9, 10] by forecasting enemy actions aimed at striking key objects within military formations and units during combat. However, effectively neutralizing a specific enemy target necessitates improvements in identification methods [12], intelligent data analysis technologies [13], and information security measures [14]. Therefore, developing a method that integrates all these components into a unified assessment will facilitate faster decision-making regarding air attack threats.

The study in [15] explores an assessment method and optimization strategies for the resilience of aerospace defense systems. This method considers risk responses, system survivability, and recovery speed of combat capabilities. In addition to [15], other comprehensive methods for assessing air threats exist. For instance, [16] presents a method that incorporates three decision-making components: single-criteria, multi-criteria, and conditional decision-making approaches.

The research in [17] focuses on threat level assessment based on a cloud model in uncertain and fuzzy conditions for air combat simulation. This approach requires the use of cloud technologies [18] and complex mathematical apparatus [19, 20]. As indicated in [17], threats are evaluated under uncertain conditions.

Unlike [17] and previous works that rely on fuzzy logic tools, the findings in [21] are derived using predicate logic, allowing for the omission of the model verification process and thus accelerating model development. This unique approach [21] represents the model in the form of an uncertain finite automaton.

A probability assessment method for tornado missile strikes is proposed in [22]. The value of this method lies in providing solutions to the problem without utilizing the Monte Carlo method, enabling a clearer understanding of the issue and its root causes.

Beyond the range of methods presented in [7–22], the level of a massive missile strike can also be determined using seismic data [23]. The proposed approach's key advantage is the concept of sensor systems for detecting explosions. This process occurs almost in real-time, yielding a highly promising outcome.

One of the prototypes for diagnosing massive missile strikes is the missile trajectory prediction method for "ship-to-air" missile compatibility with dynamic firepower [24].

This method models the missile's flight trajectory before launch. However, it remains unclear whether data on a given missile can be obtained.

Existing research [7–24] offers numerous solutions for assessing the threat levels posed by aerial objects. However, fundamental components such as the number of launched and intercepted missiles, the type of UAV or missile, and the method of launch are not fully accounted for. Consequently, the need to develop a comprehensive indicator for diagnosing massive missile strikes remains indisputable.

Formal statement of the research task

The dataset "Massive Missile Strikes on Ukraine" [25] includes the following variables: the type of unmanned aerial vehicle or missile (model, x_1); the number of missiles launched (launched, x_2); the number of missiles destroyed (destroyed, x_3); and the launch method (carrier, x_4).

The values of variables x_2 and x_3 fall within the ranges [1, n_1] and [1, n_2], respectively, where $n_1 = max(x_2)$ and $n_2 = max(x_3)$. The values of variables x_1 and x_4 are categorical and need to be converted into numerical form. A limitation of the study is the possible existence of zero values for variable x_3, in which case the variable will be assigned a value of 0.

A composite indicator K_1 should be developed, consisting of two integrated indicators L_i, to combine the assessments of x_i into a unified evaluation, with the primary prerequisite being that the indicator values fall within the range [0, 1]. The composite indicator assumes the existence of a weighting coefficient within the range [0,1].

A target function should be constructed for optimizing a single weighting coefficient within the range [0,1] using neural networks.

Research methodology

The examined dataset contains 1855 rows and 16 columns with data of various types, where data preparation is carried out using standard techniques in Python and auxiliary libraries. To determine the weighting coefficient, libraries such as torch (for working with neural networks), torch.nn (for defining network components), and torch.optim (for specifying optimizers used in model training) are utilized.

Step 1. Preliminary analysis of the dataset "Massive Missile Strikes on Ukraine" [25] and identification of the number of unique variables.

Step 2. Conversion of categorical data into numerical values, accounting for missing values (NaN) and infinite values (inf).

Step 3. Conversion of fractional values into integers using the astype method from the numpy library.

Step 4. Formation of a table with the minimum, maximum, and total values of variables describing the degree of air alert, Table 1.

Step 5. Selection of the method for normalizing variables within the range [0, 1], specifically considering the MinMaxScaler and StandardScaler methods, which are implemented in the preprocessing module of the scikit-learn library. The final results of the prepared initial variables for the study on massive missile strikes on Ukraine are recorded in Table 2.

Table 1 – **The studied statistical indicators of massive missile strikes on Ukraine**

The indicator under study	Variable 1	Variable 2	Variable 3	Variable 4
Minimum value	min(x_1)	min(x_2)	min(x_3)	min(x_4)
Maximum value	max(x_1)	max(x_2)	max(x_3)	max(x_4)
Total value	sum(xn_1)	sum(xn_2)	sum(xn_3)	sum(xn_4)

Table 2 – **Initial assessments for determining the composite indicator for diagnosing massive missile strikes**

No.	Variable 1	Variable 2	Variable 3	Variable 4
1	x_{11}	x_{12}	x_{13}	x_{14}
…	…	…	…	…
n	xn_1	xn_2	xn_3	xn_4

Step 6. Analysis of variables graphically by constructing histograms and Q-Q plots to assess the normality condition of the distribution using tools from the scipy and seaborn libraries.

Step 7. Calculation of the composite indicator for diagnosing massive missile strikes using model (1):

$$K1 = (L_1 + (\alpha_1 \cdot L_2)) / 2, \quad (1)$$

where L_i – integrated indicators, the operations for determining which need to be proposed; α_1 – the weighting coefficient, which is selected using artificial intelligence methods [26]; 2 – values that have been selected experimentally.

Let us consider the process of determining the weight coefficient for calculating the integrated indicator $L2$ using the known procedure for building neural networks [26]. First, it is necessary to differentiate the dataset for mass missile strikes into a training and test sample. Since there is only one weight coefficient, the network model consists of a single parameter – nn.Parameter(torch.rand(1)). This parameter implies the use of the activation function torch.sigmoid (self.w), as the weight coefficient must lie within the range [0, 1]. Additionally, the Adam optimizer is used to create the model, with a learning rate of 0.001 and the Mean Squared Error loss function. During the training of the model, we compute the function $f(\alpha_1) = \alpha_1 \cdot L2$ and zero out the gradients using optimizer.zero_grad(). The training results are also presented graphically using matplotlib.

Step 8. After calculating the composite indicator, its normality of distribution is investigated, including through graphical methods and the Anderson-Darling test.

Step 9. The identification of anomalous values is performed using the interquartile range and graphical representation with the matplotlib library. The detected outliers are cleaned, and the number of rows and columns in the dataset is determined for control purposes. Additionally, descriptive statistics are calculated, including standard deviation, minimum/maximum values. The final results are presented in Table 3.

Table 3 – **Initial assessments and the composite indicator for the diagnosis of massive missile strikes based on these evaluations**

№	Variable 1	Variable 2	Variable 3	Variable 4	L_1	L_2	$K1$
1	x_{11}	x_{12}	x_{13}	x_{14}	L_{11}	L_{21}	$K1_{11}$
…	…	…	…	…	…	…	…
n	xn_1	xn_2	xn_3	xn_4	$Ln1$	$Ln2$	Kn_1

Step 10. The use of composite indicator scores as input data for the KMeans clustering method. The "Elbow" method is applied to determine the number of clusters. This method will allow for the assessment of the threat level.

Step 11. The KMeans model is built, and the threat level is determined. If the scores are within the range [0, 0.49], the threat level is low; otherwise, for $K1 > 0.5$, the threat level is high. Alternatively, scores assigned to the first cluster represent a low threat level, while others correspond to a high threat level. This enables the possibility of forecasting the cluster of a new composite indicator score.

Experimental research

According to the formal task formulation and the research methodology, the composite indicator $K1$ consists of two integrated indicators L_i, which need to be proposed. The first integrated indicator is defined as the arithmetic mean of the hi values according to formula (2):

$$L_1 = (x_1 + x_2 + x_3 + x_4) / 4, \quad (2)$$

where x_i – investigated variables.

When $x_i = 1$, the value of $L_1 = 1$. The second integrated indicator is defined as the Euclidean norm according to formula (3):

$$L_2 = \sqrt{x_1^2 + x_2^2 + x_3^2 + x_4^2}\ . \quad (3)$$

However, when $x_i = 1$, L_2 is 2.0, which does not meet the requirements of the study, as substituting the obtained result into formula (1) would make $K1$ equal to 1.5 when $L_1 = 1.0$ and $L_2 = 2.0$.

To resolve this contradiction, $K1$ can be normalized as $Ki/K\max$ or the expression for L_2 can be refined, see Step 1–Step 3.

Step 1. Divide each x_i by $n_1/2$, where n = 4, which corresponds to the number of variables in the expression for L_2:

$$L_2 = \sqrt{(x_1/2)^2 + (x_2/2)^2 + (x_3/2)^2 + (x_4/2)^2} = \sqrt{\left(x_1^2 + x_2^2 + x_3^2 + x_4^2\right)/4}\ . \quad (4)$$

Step 2. Perform a check to verify the condition $L_2=1$ when $x_i=1$, the results are presented:

$$L_2 = \sqrt{\left(1^2 + 1^2 + 1^2 + 1^2\right)/4} = 1, \quad (5)$$

where 1 – the maximum value of the variables.

Thus, the integrated indicator L_2 is determined by the formula (4).

Table 4 presents the results of determining the integrated indicator for diagnosing massive missile strikes and the primary assessments on the basis of which it is calculated.

As seen from Table 4, the variables x_i have the same maximum value of 1.0, while the minimum and total values are different. Notably, the results regarding the minimum values of the number of intercepted missiles show 0.00000. This means there were cases where no missiles were intercepted at all. The obtained values of the integrated indicators are used for a comparative analysis with the existing approach [27] based on the standard deviation criterion.

Table 4 – **The results of determining the integrated indicator for diagnosing massive missile strikes based on integrated indicators and primary assessments**

№	x_1	x_2	x_3	x_4	L_1	L_2	$K1$
1	0.01786	0.01724	0.62069	0.42424	0.27001	0.37612	0.32306
2	0.03571	0.01724	0.03448	0.05051	0.03449	0.03644	0.03546
…	…	…	…	…	…	…	…
1855	0.53571	0.01724	0.02069	0.03030	0.15099	0.26862	0.20981
Sum	371.786	103.345	114.331	125.202	178.524	270.153	224.338
Min	0.01786	0.01724	0.00690	0.00000	0.01302	0.01384	0.01343
Max	1.00000	1.00000	1.00000	1.00000	0.75410	0.78245	0.76827

As can be seen from Table 5, the proposed integrated indicator outperforms the existing one based on the standard deviation criterion. We will conduct an analysis of anomalous values of the proposed integrated indicator using the interquartile range method. The analysis of anomalous values of the proposed integrated indicator using the interquartile range method indicates the following. The interquartile range is 0.0807, with the first quartile at 0.0637 and the third quartile at 0.1445, as shown in Fig. 1.

Table 5 – **Comparative analysis of the proposed integrated indicator with existing ones based on the standard deviation criterion**

№	***K*1 proposed**	***K*1 known [27]**
1	0.32306	0.2
2	0.03546	0.25
…	…	…
1855	0.20981	1.0
STD	0.0925	0.447

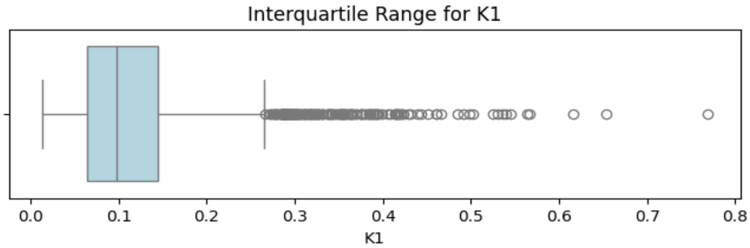

Fig. 1. Graphical interpretation of the verification of the integrated indicator of mass missile strikes for the presence of anomalous values

Thus, the analyzed array of integrated indicator scores contains 168 anomalous values, where scores greater than 0.265 are outliers, as shown in the graph. After cleaning, the dataset size reaches 1687. This has impacted the Anderson-Darling statistic, which is 37.921 at a 5% significance level, as well as the standard deviation, which is 0.053. Fig. 2 presents the graphical interpretation of the obtained research results in the form of a distribution chart of integrated indicator scores.

The histogram of the distribution of the integrated indicator further confirms the lack of support for the normal distribution assumption at a 5% significance level.

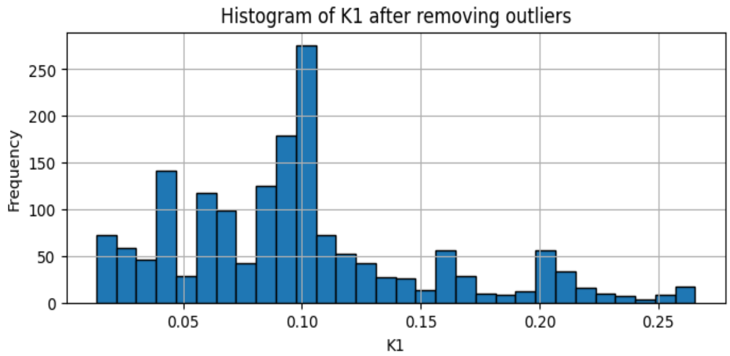

Fig. 2. Histogram of the distribution of the integrated indicator of mass missile strikes with anomalous values excluded

This is related to the asymmetry characteristics of the experimental set of scores. We will use the cleaned scores of the integrated indicator of mass missile strikes to determine the threat level of a missile strike. According to the methodology of the study, the number of clusters is selected using the "elbow" method, as shown in Fig. 3.

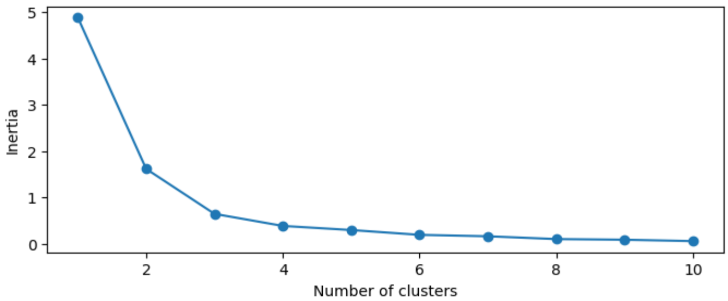

Fig. 3. Graphical interpretation of the "elbow" method for determining the number of clusters

As seen in Fig. 3, the optimal number of clusters is two or three. We select two clusters and proceed with building the clusterer, as shown in Fig. 4. As shown in Fig. 4, two clusters have been obtained, specifically on the left and right. Using these clusters, we have the ability to predict the level of threat.

Fig. 5 presents a formal example of using the clusterer to predict the type of cluster corresponding to a specific level of threat.

The obtained value of the integrated indicator, 0.6, is automatically assigned to the second cluster (to the right in Fig. 5). This indicates that the threat level is high. Thus, the evaluation values characterizing the threat level are differentiated into groups, specifically low or high. According to the input task, the evaluations of each cluster belong to the range [0, 1] and do not exceed its boundaries. The proposed method can be implemented using the tools of a specific framework for user use.

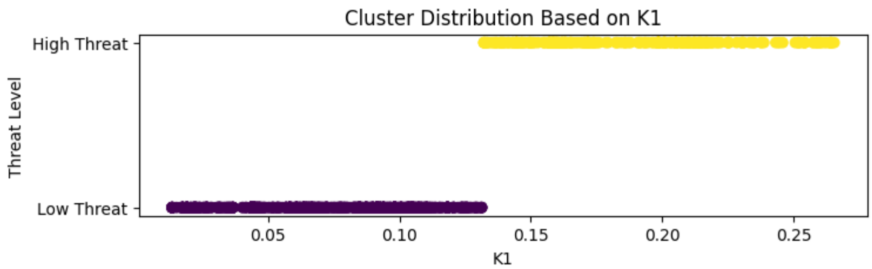

Fig. 4. Results of clustering the integrated indicator of mass missile strike diagnostics

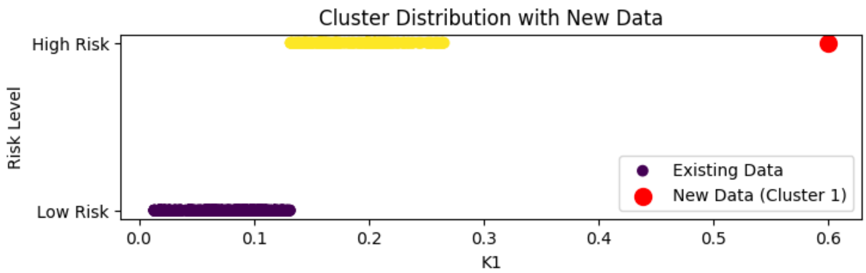

Fig. 5. Example of predicting the cluster type for a new value of the integrated indicator of mass missile strike diagnostics, which is 0.6

The limitations of the study include the input data set, the update frequency of which is not controlled by the authors of the study. In the future, it would be beneficial to create a custom feature set for mass missile strikes. From a practical perspective, the results of the study can be used to develop a decision-making system. The proposed approach can be scaled for different countries, where the number of features can be expanded.

Conclusions

1. The task of creating an integrated indicator for diagnosing mass missile strikes is solved through the development of a combined model. It includes linear and nonlinear integrated indicators, which take into account the mean values and variations in the evaluations and serve as a prototype for the regularization concept. This allows for the reduction of the standard deviation to 0.0925, whereas the existing approach demonstrates 0.447. A distinctive feature of the integrated indicator is also the independent method for determining the weight coefficient.

2. The task of experimentally verifying the evaluations determined by the integrated indicator is addressed by using the KMeans clusterizer to group the evaluations into two clusters (Cluster 1 – low threat level, Cluster 2 – high threat level).

3. In future studies, attention should be focused on expanding the number of factors in the integrated indicator.

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Розробка комплексного показника діагностики масованих ракетних ударів

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Анотація. Мета. Підвищення ефективності діагностики рівня небезпеки масованих ракетних ударів за рахунок розробки комплексного показника. **Методика.** Досліджено процес розробки комплексного показника на основі набору даних про масовані ракетні удари. Для цього здійснено попередню обробку даних, розроблено модель комплексного показника та інтегровані показники. Один із інтегрованих показників має ваговий коефіцієнт, котрий визначається методом штучного інтелекту й обмежується функцією активації sigmoid. Порівняльний аналіз запропонованого комплексного показника з існуючими показниками здійснювався за ознакою стандартного відхилення. Визначені оцінки, з використанням комплексного показника, використовуються для визначення рівня загрози масованих ракетних ударів. **Результати.** На основі існуючого набору даних, про масовані ракетні удари по Україні, розроблено комплексний показник, котрий об'єднує дані особливостей атаки у єдину оцінку. Оцінки комплексного показника, стосовно масованих ракетних ударів, використовуються для визначення рівня загрози (кластер 1 – низький рівень загрози, кластер 2 – високий). **Наукова новизна.** Запропонована модель комплексного показника відрізняється від існуючих тим, що її інтегровані показники враховують середні значення й варіації в оцінках, що є прототипом концепції регуляризації. За рахунок цього спостерігається зменшення стандартного відхилення до 0,0925, у той час як існуючий підхід демонструє 0,447 на єдиному експериментальному наборі оцінок. **Практична значимість.** Запропонований комплексний показник масованих ракетних ударів використовується як додаткова міра визначення рівня загрози держави або може розглядатися як елемент системи прийняття рішень.

Ключові слова: комплексний показник; концепція регуляризації; безпека держави.