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APPLICATION OF BAYESIAN APPROACH FOR DETERMINING THE RELIABILITY OF THE NAVIGATION COMPLEX

The paper discusses the methodology based on the Bayesian approach to the assessment of posterior probabilities of various hypotheses regarding the reliability of technical system elements. The problem of estimating posterior probabilities of failures for a system with two nodes is considered. Mathematical modeling of Bayesian probabilities of hypotheses

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depending on the probabilities of trouble-free operation of each node was carried out. The modeling results were visualized and it was shown that the posteriori probabilities of the hypotheses significantly exceed the a priori ones. This allows you to use them as more accurate for calculating the probabilities of future events.
Keywords: *Bayesian probability, navigation complex, reliability, trouble-free operation, mathematical modeling.*

Абрамов Г.С., Плотніков В.І. Застосування підходу Байєса для визначення надійності навігаційного комплексу*. В роботі обговорюється методологія, заснована на Байєсівському підході, до оцінки апостеріорних ймовірностей різних гіпотез щодо надійності елементів технічної системи. Такий підхід дозволяє досліджувати причинно-наслідкові зв'язки, поглибити розуміння проблемної області та прогнозувати ймовірність відмови навігаційного обладнання при виході з ладу його компонентів. Розглянута задача по оцінці апостеріорних ймовірностей відмов для системи з двох вузлів. Здійснено математичне моделювання Байєсівських ймовірностей гіпотез в залежності від ймовірностей безвідмовної роботи кожного вузла. Проведена візуалізація результатів моделювання і показано, що апостеріорні ймовірності гіпотез значно перевищують апріорні, і це перевищення тим більше, чим ближче добуток ймовірностей безвідмовної роботи вузлів до одиниці. Отримано результати, які відображають низку закономірностей: ймовірності того, що перший вузол вийшов з ладу, а другий працює, зменшуються зі збільшенням надійності першого пристрою та зростають із збільшенням надійності другого, тоді як ймовірності того, що другий вузол вийшов з ладу, а перший працює, зменшуються зі збільшенням надійності другого пристрою і зростають зі збільшенням надійності першого. При цьому ймовірність того, що обидва вузли відмовили, зменшується як зі збільшенням надійності першого пристрою, так і зі збільшенням надійності другого. Це дозволяє використовувати апостеріорні ймовірності гіпотез, як більш точні, для розрахунків ймовірностей майбутніх подій, таких як відмови навігаційного обладнання, на основі наявної інформації про його надійність. Наприклад, якщо після досліду, в результаті якого мала місце подія А, здійснюється дослід, в результаті якого відбувається або не відбувається подія В, то умовна ймовірність події В розраховується по формулі повної ймовірності, в яку підставлені замість початкових (апріорних) ймовірностей гіпотез, нові (апостеріорні) ймовірності гіпотез.*
Ключові слова: *Байєсівська ймовірність, навігаційний комплекс, надійність, безвідмовна робота, математичне моделювання.*

Description of the problem. Electronic transport systems play a role in numerous transportation systems. The safety and efficiency of transporting humans and cargo are greatly affected by their effective operation. Safety hazards can occur due to the unreliability of electrical equipment and errors made by operators [1-4]. The concept of unreliability focuses on studying how equipment damage and operator errors affect specific measures of unreliability. The theory of safety focuses on the outcomes of harm and mistakes that result in safety risks. The correct identification of permissible and impermissible states in the system is crucial from a safety perspective.

The state of safety hazard can sometimes be reversed by taking actions to restore full worthiness, such as diagnosing damage and attempting repairs, correcting operator errors, or neutralizing external events. The counter-measure must be carried out within the time it is accessible. If the counter-measure doesn't work or is too slow, the system transitions from the safety hazard state to the hazard state, also known as the safety unreliability state.

Enhancing the reliability parameters of electronic transport systems can lead to a boost in their safety levels. Improved reliability can result from the enhanced reliability of components or by implementing redundant structures [5-8]. The initial solution focuses on avoiding harm. In the second scenario, employing double or triple redundancy may increase the size of the system but allows for the acceptance of any damages that may occur. Redundancy can apply to the components of devices, system modules, and computers that oversee transportation operations. The importance of the data received by sensors for the systems is also crucial. Certain research papers suggest utilizing fuzzy logic [9] or artificial neural networks [10]. Vibrations have a significant impact on electronic transport systems [11], however, they are not discussed in this article.

Analysis of the latest research and publications. Understanding system reliability is crucial for effective maintenance strategies, offering valuable information on machinery performance and the consequences of failures on machinery availability, extending to system-wide effects [12-14]. Reliability analysis tools are commonly utilized to aid in determining maintenance strategies that align with organizational goals. They typically assess the impact and potential for failure by analyzing both quantitative and qualitative aspects of maintenance and operational data from machinery [15].

Various techniques like Bayesian belief networks, Monte Carlo simulation, Markov chains, Petri Nets, and Weibull analysis have been utilized for modeling maintenance planning [16-18]. Conversely, analyzing the reliability of complex systems that involve non-binary inputs and continuous stochastic failure behavior would necessitate a unique approach to consider the temporal state of the system or a repairable mechanical system that can function acceptably even when degraded. Recent studies have also concentrated on real-time anomaly detection in ship machinery for diagnosing faults [19]; utilizing Bayesian and machine learning for fault detection and diagnostics; evaluating real-time data-driven imputation of missing data in short-term sensor data from marine systems [19]; and creating a time series imaging method for fault classification [20]. Hence, more flexibility will be needed to create a model that represents all possible factors.

As a result, researchers have turned to various tools to address system dependencies and complexities in multi-system setups [19-22]. This approach allows for the utilization of various data types for conducting reliability analysis and employing tools in a more adaptable way [23]. In this research, there will be a thorough assessment to examine the pros and cons of the reliability tools that have been utilized.

It is believed that the true failure rate of a physical process can be determined using Bayesian analysis rather than the traditional method [24]. Although a confidence distribution can be generated by extending the traditional idea of a confidence interval, this method has not been fully formalized according to Fraser [25]. The advantage of using the Bayesian approach is that it provides a more intuitive way of representing the posterior distribution of the estimated random parameter. In addition, considering this factor as constantly changing and unpredictable simplifies the analysis of situations where the method is appropriate.

Purpose and objectives of the publication. Consider the task of estimating Bayesian posterior probabilities of failure for a two-node system. Carry out mathematical modeling of Bayesian probabilities of hypotheses depending on the trouble-free operation of each node.

Summary of the main material. The navigation complex of a sea vessel is a complex system of interconnected devices, nodes, and elements, the failure of each of which can lead to a whole series of consequences that will significantly worsen the reliability and stability of the system as a whole.

In this regard, to calculate the probability of failures or the probability of failure-free operation of both individual elements and the navigation complex as a whole, it is necessary to use the concept of full probability and Bayesian probabilities of the corresponding hypotheses.

If *n* mutually exclusive hypotheses $H_1, H_2, \dots H_i, \dots H_n$ can be made about the circumstances of system functioning (in our case, the elements of the navigation complex) and if the event *A* that interests us (for example, system failure) can appear together with one from these hypotheses, the full probability of this event *P(A)* is calculated by the so-called full probability formula:

$$P(A) = \sum_{i=1}^{n} P(H_i) P_{H_i}(A), \tag{1}$$

where $P(H_i)$ – the probability of the hypothesis H_i, a $P_{H_i}(A)$ – conditional probability of event *A* under this hypothesis.

Essentially (1) is the sum of the products of the probabilities of the hypotheses on the conditional probability of the event under this hypothesis.

If event *A* occurred as a result of the experiment, then the new (conditional) probabilities of hypotheses $P_A(H_i)$ can be calculated using the Bayes' formula:

$$P_A(H_i) = \frac{P(H_i) P_{H_i}(A)}{\sum_{i=1}^{n} P(H_i) P_{H_i}(A)}. \tag{2}$$

The initial (pre-experimental) probabilities of the hypotheses $P(H_i)$ are called a priori, and the post-experimental ones, calculated according to Bayes, $P_A(H_i)$ are called a posteriori.

Based on the above theory, consider the following problem. Consider a device consisting of two nodes, in which the functioning of both nodes is necessary for the operation of the device as a whole. Let the reliability (probability of trouble-free operation during the given time) of the first device be P_1, and of the second P_2. Let the device be tested, and it turned out that it failed.

Let's find the following probabilities:

1. Only the first node failed, the second is working;
2. The second node failed, the first one is working;
3. Both nodes failed.

Before the test, the following hypotheses were likely:

H_0 = {both nodes are working}

H_1 = {the first node has failed, the second is working}

H_2 = {the second node has failed, the first is working}

H_3 = {both nodes failed}

Let's determine the a priori probabilities of the hypotheses:

$$P(H_0) = P_1P_2;\ P(H_1) = (1-P_1)P_2;\ P(H_2) = P_1(1-P_2);\ P(H_3) = (1-P_1)(1-P_2). \quad (3)$$

An event A = {device failure} was observed, and since the conditional probabilities in this case are equal to $P_{H_0}(A) = 0, P_{H_1}(A) = P_{H_2}(A) = P_{H_3}(A) = 1$, then the full probability $P(A)$ is equal to:

$$P(A) = \sum_{i=1}^{3} P(H_i)P_{H_i}(A) = (1-P_1)P_2 + P_1(1-P_2) + (1-P_1)(1-P_2) = 1 - P_1P_2. \quad (4)$$

Then the posterior probabilities of the hypotheses, according to the Bayes' formula:

$$P_A(H_1) = \frac{(1-P_1)P_2}{1-P_1P_2}; \quad (5)$$

$$P_A(H_2) = \frac{P_1(1-P_2)}{1-P_1P_2}; \quad (6)$$

$$P_A(H_3) = \frac{(1-P_1)(1-P_2)}{1-P_1P_2}. \quad (7)$$

Thus, the posterior probabilities of hypotheses increase by $(1-P_1P_2)^{-1}$ times, that is, the closer P_1 and P_2 are to 1, the larger this multiplier is.

In the work, expressions (5)-(7) are tabulated for different values of P_1 and P_2, and in fig. 1-6 they are visualized and compared with the a priori probabilities $P(H_i)$ (i=1, 2, 3).

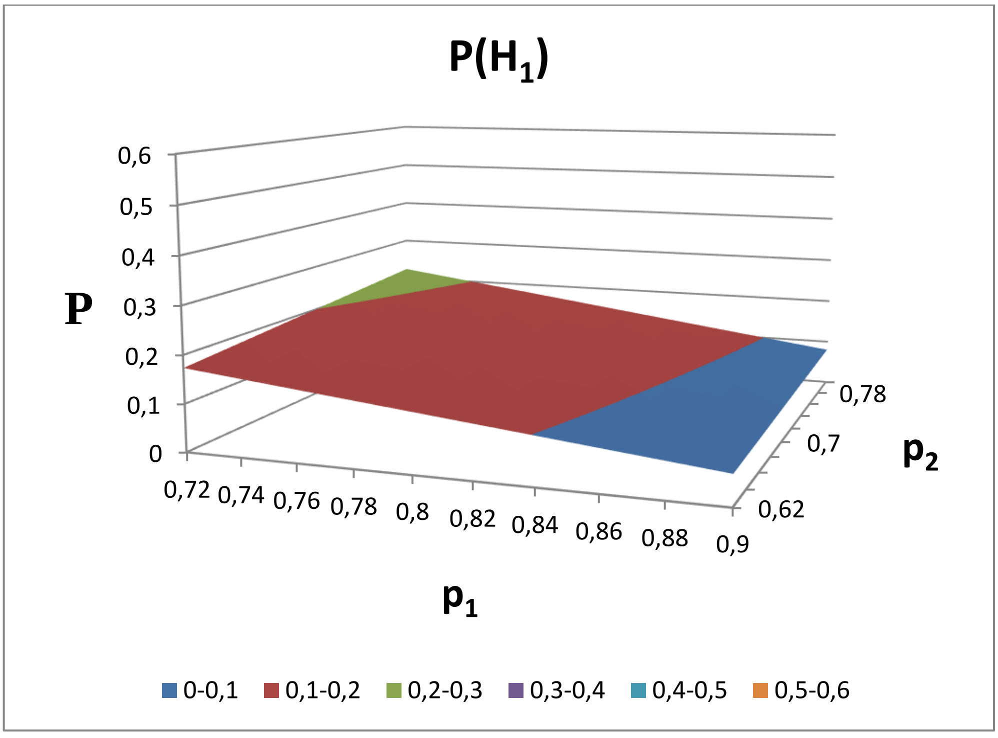

Fig. 1 – A priori probabilities of the hypothesis H_1

It can be seen that the surfaces of the posterior probabilities $P_A(H_i)$ are located much higher than the a priori ones.

It can also be seen that the a priori and a posteriori probability of the hypothesis H_1 decrease with the growth of P_1 and increase with the increase of P_2, while the probabilities of the hypothesis H_2, on the contrary, decrease with the growth of P_2 and increase with the increase of P_1.

The probability of the hypothesis H_3 decreases both with the growth of P_1 and with the growth of P_2.

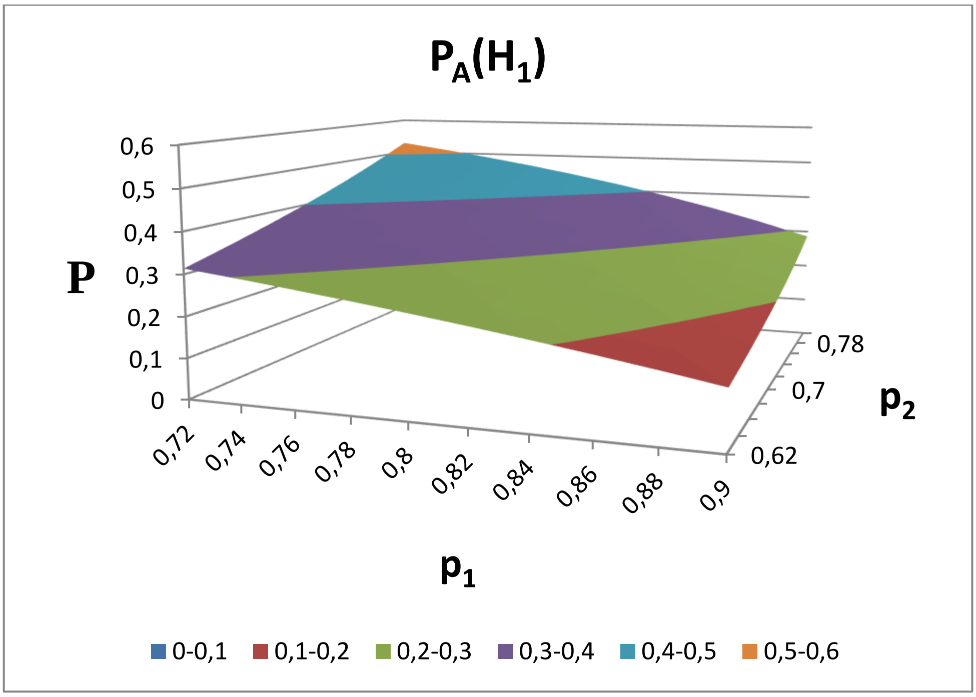

Fig. 2 – A posteriori probabilities of the hypothesis H_1

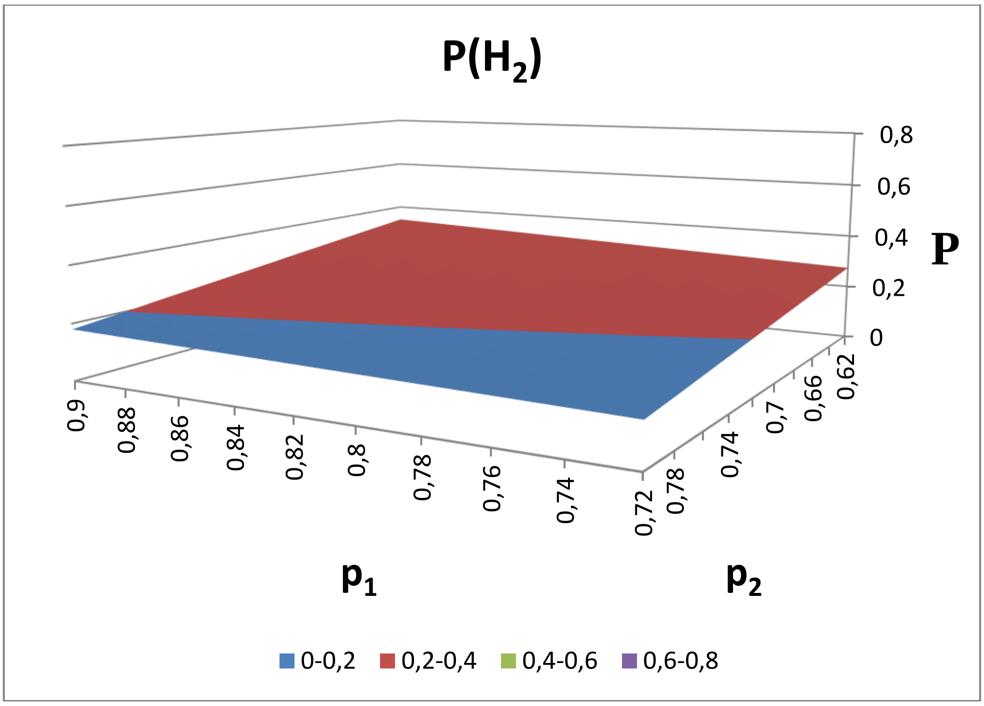

Fig. 3 – A priori probabilities of the hypothesis H_2

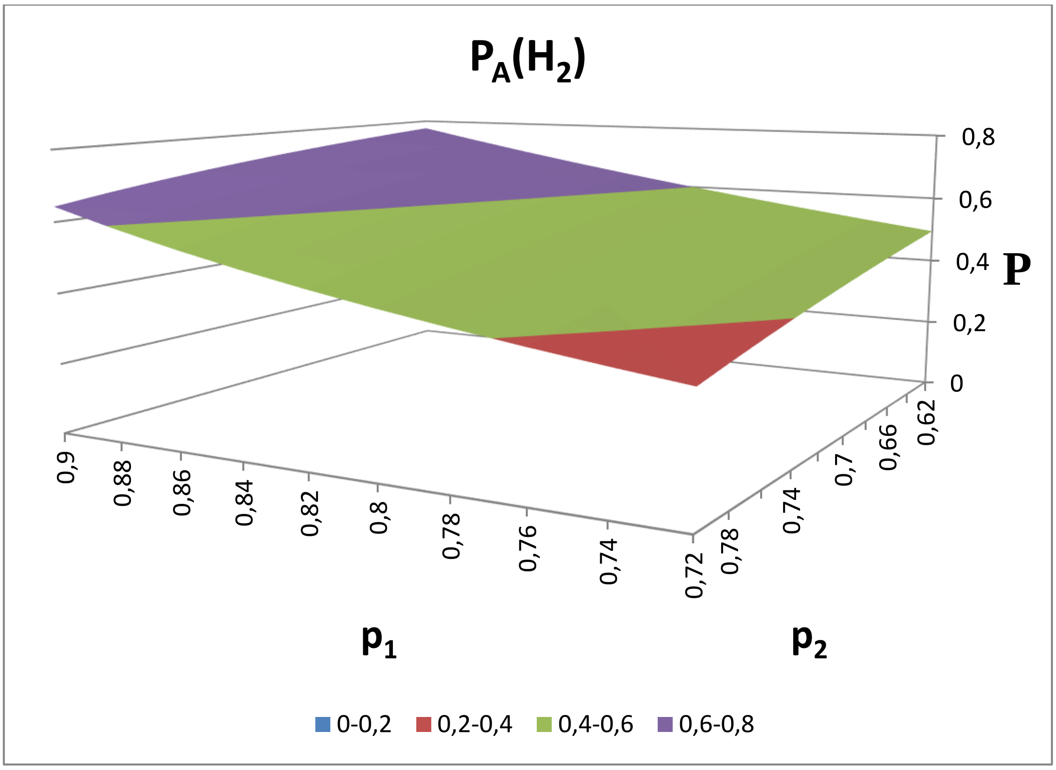

Fig. 4 – A posteriori probabilities of the hypothesis H_2

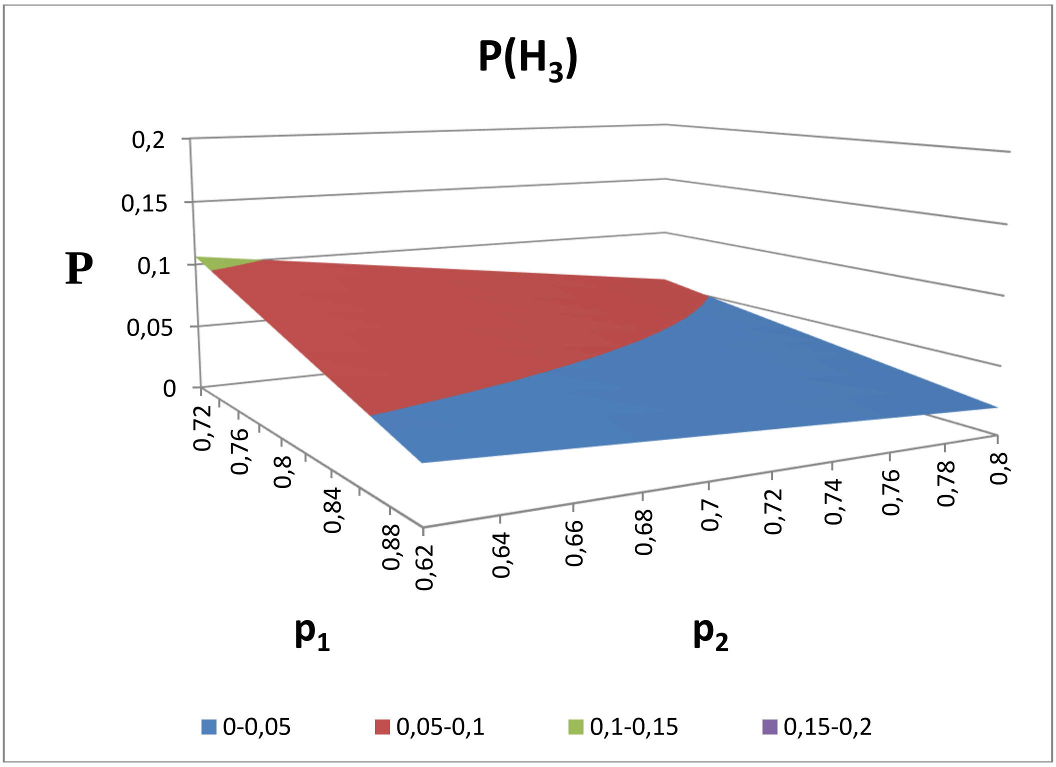

Fig. 5 – A priori probabilities of the hypothesis H_3

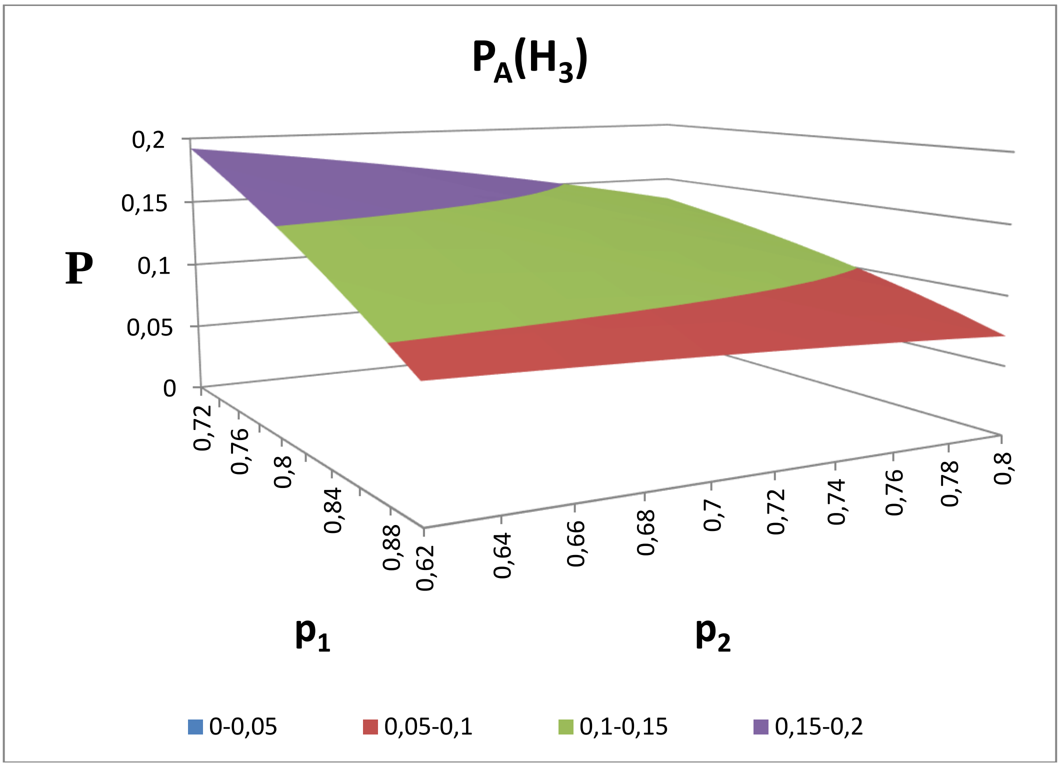

Fig. 6 – A posteriori probabilities of the hypothesis H_3

The obtained values of the posterior probabilities of the hypotheses are important because they can be used to calculate the probabilities of future events.

So, if after an experiment, as a result of which event A occurred, an experiment is carried out, as a result of which event B occurs or does not occur, then the conditional probability of event B is calculated according to the formula of full probability, in which the initial (a priori) probabilities of hypotheses $P(H_i)$, are substituted new (posterior) probabilities of hypotheses $P_A(H_i)$:

$$P_A(B) = \sum_{i=1}^{n} P_A(H_i) P_{H_i A}(B). \quad (8)$$

Therefore, formula (8) is called the formula for probabilities of future events. It can be used to predict the probability of failure of navigation equipment based on available information about its reliability.

Conclusions

The effectiveness of the Bayesian approach in assessing the reliability of a navigation complex is demonstrated. This approach makes it possible to study causal relationships, deepen understanding of the problem area, and predict the probability of failure of navigation equipment when its components fail.

It is evident that the posteriori probabilities of the hypotheses significantly exceed the a priori ones, and this excess is greater the closer the product of the probabilities of failure-free operation of the nodes is to one. As shown in fig. 1-6, the obtained results reflect a number of regularities: the probabilities that the first node has failed and the second one is working decrease with increasing reliability of the first device and increase with increasing reliability of the second; and vice versa, the probabilities that the second node has failed and the first one is working decrease with increasing reliability of the second device and increase with increasing reliability of the first; in turn, the probability that both nodes failed decreases both with increasing reliability of the first device and with increasing reliability of the second.

The Bayesian approach is highly effective in assessing the reliability of a navigation complex due to its ability to handle uncertainty, incorporate prior knowledge, and update reliability estimates as new information becomes available.

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СУЧАСНІ ТЕХНОЛОГІЇ СПОСТЕРЕЖЕННЯ ЗА ОКЕАНОМ: АНАЛІЗ ТА ПЕРСПЕКТИВИ РОЗВИТКУ

Океани відіграють ключову роль у формуванні клімату Землі та підтримці глобальних екосистем, однак їх вивчення пов'язане зі значними труднощами через величезні розміри та складність процесів, що в них відбуваються. Створення комплексної системи спостережень, яка б забезпечувала отримання точних і оперативних даних про стан океану в глобальному масштабі, є актуальною проблемою сучасної океанології. Традиційні методи дослідження океану за допомогою науково-дослідних суден мають обмежені можливості і не дозволяють отримувати дані з достатньою просторово-часовою роздільною здатністю. Мета статті – систематизація та аналіз сучасних технологій спостереження за океаном, визначення їх можливостей, обмежень та перспектив розвитку для формування цілісного уявлення про комплекс методів і засобів дистанційного моніторингу океану. У статті проаналізовано основні типи технологій спостереження за океаном: заякорені буї, океанські дрифтери, глайдери та супутникові технології. Розглянуто їх принципи роботи, переваги та обмеження. Виявлено основні напрямки розвитку технологій спостереження за океаном, включаючи вдосконалення датчиків та вимірювальних систем, розробку нових типів автономних платформ, розвиток методів обробки даних з використанням штучного інтелекту та інтеграцію різних систем спостереження в єдину глобальну мережу. Підкреслено важливість створення нових типів платформ, таких як автономні апарати типу надводних та підводних глайдерів, здатних здійснювати тривалі місії з мінімальними витратами енергії. Зроблено висновок, що комплексне використання різних технологій спостереження дозволяє отримувати найбільш повну картину стану океану. Підкреслено важливість міжнародного співробітництва у створенні глобальної системи моніторингу океану, прикладом якого є глобальна система спостережень за океаном. Визначено перспективні напрямки подальших досліджень, зокрема розробку методів комплексного аналізу даних від різних систем спостереження, вдосконалення алгоритмів обробки супутникових даних, дослідження можливостей використання нових технологій для підвищення точності вимірювань океанографічних параметрів.

Ключові слова: *океанографія, дистанційне зондування, буї, дрифтери, супутникові технології, моніторинг океану, глобальна система спостережень, альтиметрія, глайдери, обробка даних.*

G.G. Tomchakovsky. Modern technologies for ocean observation: analysis and development prospects. *The oceans play a key role in shaping the Earth's climate and maintaining global ecosystems, but their study is fraught with significant difficulties due to the enormous size and complexity of the processes taking place in them. The creation of a comprehensive observation system that would provide accurate and timely data on the state*

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