Information systems research

UDC 681.324 **doi:** https://doi.org/10.20998/2522-9052.2025.2.07

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METHOD FOR CALCULATING THE SUFFICIENCY CRITERION OF DIAGNOSTIC INFORMATION FOR EXECUTING THE SELF-DIAGNOSIS ALGORITHM IN MULTI-MACHINE INFORMATION SYSTEMS

Abstract. Subject, theme and main goal. When multi-machine system is working in autonomous mode, it’s critical to realize an algorithm of self-diagnosis of this system. There are many algorithms of self-diagnosis of multi-machine systems, and many of modern ones purpose a decoding of diagnostic information. But conditions, when we may start decoding of diagnostic information, are not studied enough good. These work purpose and justifies a new condition of this type, based on minimal volume of diagnostic information, realization of which may be interpreted as allow of start of decoding of diagnostic information. **Methods.** When diagnostic information accumulates, a general scheme of this accumulation may be described using ordered graph, which sometimes is called as diagnostic graph. If we know diagnostic graph of studied multi-machine information system, we may try to formulate some properties of self-diagnosis of the system. Using certain assumptions, some properties of volume of diagnostic information may be formulated too. Using assumptions like equivalent number of elementary checks, provided by every machine in the system, we may easily calculate a minimal volume of diagnostic information, the achievement of which guarantee, that every machine is checked at least one time. In this work some similar assumptions are used for calculation of minimal volume of diagnostic information, what potentially is enough for start decoding of diagnostic information. **Results.** In the work a a new condition for start of decoding of diagnostic information, what is enough for start of its decoding, is purposed and justified. **Conclusions.** The work purpose and justifies a minimal volume of diagnostic information, what is enough for start of its decoding, method of calculation of which is based on diagnostic graph of studied multi-machine system. A usage of this minimal volume is demonstrated on two examples with different diagnostic graphs. In other hand, some properties of this volume. As the result of number of simulations a range of this volume, depends on number of machines, was calculated.

Keywords: information systems; self-diagnosis; graph; criterion.

Introduction

At the current stage of human development, information systems are gaining increasing importance. They are used in a wide range of fields: from medicine [1] and astronomy [2, 3] to banking [4]. Due to the growing significance of information systems, the issue of their functional stability [5–7] is becoming increasingly relevant.

As is known [5], functional stability refers to a system's ability to ensure the fulfillment of its designated tasks, at least partially, in the face of various destabilizing factors. During the design and operation of information systems, ensuring their functional stability requires addressing several key aspects. One of the most important is the diagnostic process. Specifically, since in many scenarios, information systems are expected to operate autonomously, they must be capable of self-diagnosis.

Currently, many methods for collecting and analyzing diagnostic information have been developed to enable system self-diagnosis. However, despite the diversity and extensive research in this area, the issue of determining the volume of diagnostic information required for a final conclusion about the operability of machines within the system remains unresolved. Therefore, this paper examines a method aimed at addressing this problem.

Literature review. The self-diagnosis process can be conditionally divided into the collection of diagnostic information and its analysis. Possible methods for implementing the first stage are well described, for instance, in [5, 6, 8]. These works present an information collection method based on conducting elementary checks between randomly selected machine pairs at random moments in time.

Regarding the decoding of collected diagnostic information, this process can be implemented in various ways.

For example, [5] describes a diagnostic information decoding method based on Bayesian analysis.

In [10, 11], a more specific approach is proposed, also rooted in probability theory.

Several studies propose methods related to performing self-diagnosis at the system or hardware levels.

In [8, 9, 12], a diagnostic processing algorithm for system-level self-diagnosis using combinatorial analysis is suggested.

Similar ideas, but applied at the software level, are demonstrated in [13].

Methods for hardware-level self-diagnosis, or those closely related to it, are examined in [14, 15].

In addition to self-diagnosis itself, researchers explore its applications during the design and operation of information systems. For instance, [16] considers the use of self-diagnosis in intelligent integrated systems, while [17] proposes it as a method for monitoring functional stability.

In [18], the redistribution of computations in systems where the self-diagnosis result may play a key role is discussed. Related tasks, where the self-diagnosis process can also be crucial, are explored in [19, 20].

However, despite the variety of studies, the question of how much diagnostic information is sufficient to enable analysis and draw conclusions about the system's state remains poorly addressed.

Problem statementю Let we have an information system with N machines. Let consider, that diagnostic graph of this system is known. It’s needed to calculate a minimal enough volume of diagnostic information, when every from N machines is checked at least one time.

Calculation of minimal volume of diagnostic information

Let us begin by introducing a few auxiliary concepts. Diagnostic information or a syndrome will be understood as a set of results from elementary checks [21]. Now, let us define the concept of an elementary check. Suppose there is a certain pair of machines $\left(v_i, v_j\right)$, chosen randomly and connected by a communication line. An elementary check will be understood as the following process. Let machine v_i, which we will call the testing machine, send a specific task to machine v_j, which we will call the tested machine, for processing. Upon receiving the result, the testing machine compares it with a reference value. Upon receiving the result, the testing machine compares it with the reference value. If the obtained result matches the reference, the outcome of such a check r_{ij} and it is assumed that the testing machine v_i trusts the tested machine v_j. In this case, the testing machine sends all diagnostic information stored in its memory to the tested machine, along with the result of the check. If the obtained result differs from the reference, the outcome r_{ij} is set to 1, indicating that the testing machine v_i does not trust the tested machine v_j. In this case, the result of the check is added to the diagnostic information stored in the testing machine.

In the future, the concept of a diagnostic graph will also be useful to us [22]. A diagnostic graph of a system will be considered a directed graph where the vertices represent the machines in the system, and the edges connect the testing machines at the start to the tested machines at the end.

When sufficient diagnostic information has been accumulated on a particular machine, the so-called process of system self-diagnosis begins [23, 24]. This process involves evaluating the operational status of all machines in the system based on the collected syndrome. However, at this stage, a logical question arises: what volume of the syndrome is sufficient? Next, we will consider the method for calculating the volume of the syndrome required to initiate self-diagnosis.

Let there is an information system of N machines. Suppose, that every machine v_i do in average K elementary checks per unite of time and checks N_i other machines with same probability.

Let suppose, that every machine checks previously fixed set of other machines.

In order to start self-diagnosis, it is necessary that each machine has been checked at least once. So, let machine v_j is checked by n_j machines $\overline{v}_{1j}, \overline{v}_{2j}, \ldots, \overline{v}_{n_j j}$. It’s easy to see, that a number of elementary checks of this machine per unit of time equals

$$S_j = K \sum_{i=1}^{n_j} \overline{p}_{ij}, \tag{1}$$

where $\overline{p}_{ij}$ is a probability, that at the moment of check machine v_j. will be checked by $\overline{v}_{ij}$. It’s easy to see, that to guarantee, that every machine will be checked at least once, we need T units of time, what equals

$$T = \frac{1}{\min\limits_{j=1,2,\ldots,N} S_j}. \tag{2}$$

In other hand, on one unit of time we will have

$$S = \sum_{j=1}^{n} S_j = \sum_{j=1}^{n} K \sum_{i=1}^{n_j} \overline{p}_{ij} = K \sum_{j=1}^{n} \sum_{i=1}^{n_j} \overline{p}_{ij} \tag{3}$$

elementary checks. As the result, a minimal volume of diagnostic information, what guarantee, that every machine will be checked at least once, may be calculated by formula

$$\begin{gathered} V = TS = \frac{K \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}}{\min\limits_{j=1,2,\ldots,N} S_j} = \\ = \frac{K \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}}{K \min\limits_{j=1,2,\ldots,N} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}} = \frac{\sum\limits_{j=1}^{n} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}}{\min\limits_{j=1,2,\ldots,N} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}}. \end{gathered} \tag{4}$$

Since right side of (4), in general, is not natural, a minimal volume of diagnostic information we may calculate by formula

$$V = \left\lfloor \frac{\sum\limits_{j=1}^{n} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}}{\min\limits_{j=1,2,\ldots,N} \sum\limits_{i=1}^{n_j} \overline{p}_{ij}} \right\rfloor + 1. \tag{5}$$

Thus, we have derived the formula for determining the volume of the diagnostic information at which it can be expected that every machine will be tested at least once. Based on equation (5), two key observations can be noted.

Firstly, if all machines in the system perform, on average, the same number of elementary checks, the average volume of the syndrome does not depend on this number.

Secondly, the question arises regarding how to calculate the probabilities $\overline{p}_{ij}$.

To solve it let study diagnostic graph of studies information system. Let define matrix

$$A = \left\| a_{ij} \right\|_{i,j=1,2,\dots,n}, \qquad (6)$$

where $a_{ij} = 1$, if machine v_i checks machine at least once v_j, and $a_{ij} = 0$ in opposite case.

Let call this matrix as checking matrix.

It's easy to see, that probability $\bar{p}_{ij}$ may be calculated by formula

$$\bar{p}_{ij} = \frac{a_{ij}}{\sum\limits_{k=1}^{n} a_{ik}} \qquad (7)$$

So, volume of diagnostic information V, what we want to find, may be calculated by formula

$$V = \left[\frac{\sum\limits_{j=1}^{N}\sum\limits_{i=1}^{N} \frac{a_{ij}}{\sum\limits_{k=1}^{n} a_{ik}}}{\min\limits_{j=1,2,\dots,N} \sum\limits_{i=1}^{N} \frac{a_{ij}}{\sum\limits_{k=1}^{N} a_{ik}}} \right] + 1. \qquad (8)$$

As the result, we found a mark of minimal volume of diagnostic information, what is enough for start of self-diagnosis of information system.

Testing

Let demonstrate a usage of formula (8). Let study information system with topology, drawn in Fig. 1.

Let purpose, that diagnostic graph of the system is shown in Fig. 2.

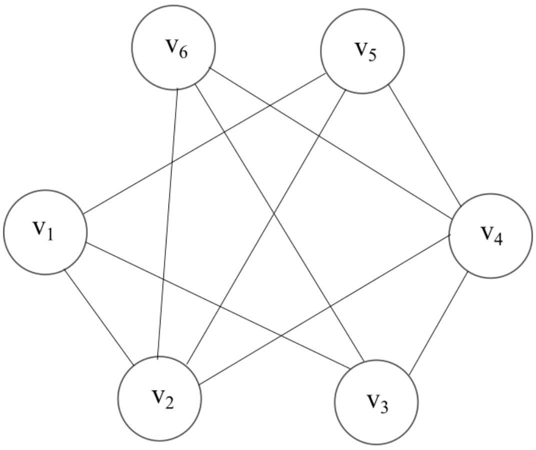

Fig. 1. An Example of studied system

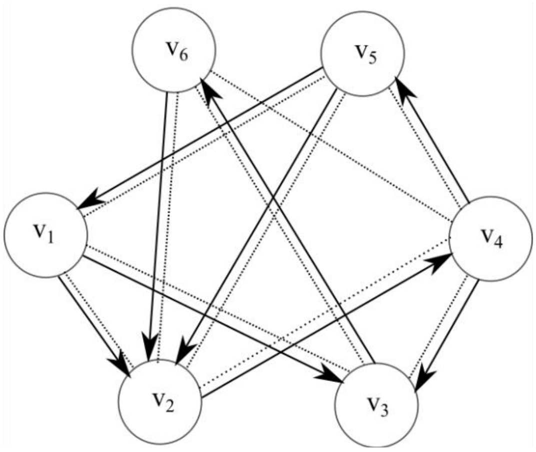

Fig. 2. Diagnostic graph of the system

In this case checking matrix may be written as

$$A = \begin{pmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{pmatrix}.$$

So, according to (8), $V = 19$. In case, when diagnostic graph of the system is demonstrated on Fig. 3, we will have $V = 13$.

As we see, minimal number of elementary checks, what is enough for start of self-diagnosis, depends of diagnostic graph.

To be sure in this let study other situation, when topology of information system may be demonstrated by graph from Fig. 4.

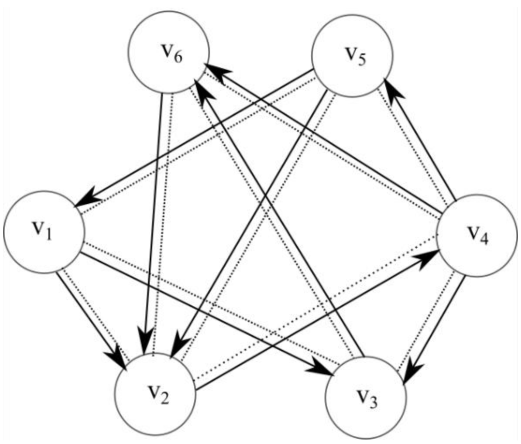

Fig. 3. Other diagnostic graph of the system

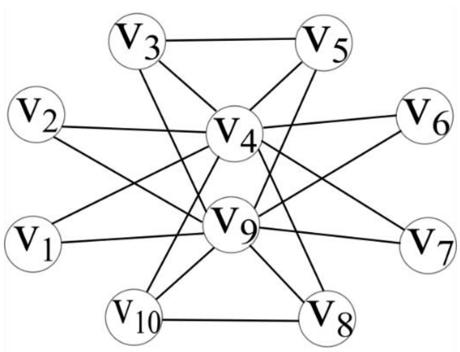

Fig. 4. Other example of information system

In case of diagnostic graph from Fig. 5 using (8) it may be shown, that minimal needed volume of information system equals 51 elementary checks.

In case of diagnostic graph from Fig. 6 minimal needed volume of diagnostic information equals 61 elementary checks.

So, we see, hat for realizing of described method of calculation of minimal volume of diagnostic information, what is enough for start self-diagnosis of information system, may be calculated with use only of diagnostic graph.

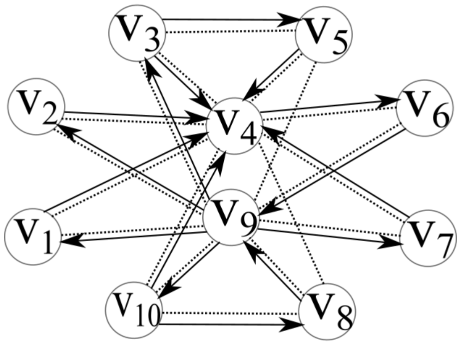

Fig. 5. First variant of diagnostic graph

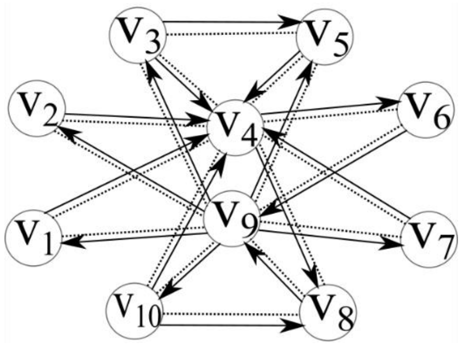

Fig. 6. Second variant diagnostic graph of the system

Specifics of described method of calculation of minimal needed volume of syndrome

The method for calculating the neded minimum volume of the syndrome, based on the application of formula (8), has several important properties that must be considered before its implementation.

Firstly, to apply this approach, it is necessary that every machine in the information system is not only checked by at least one other machine but also conducted check on at least one other machine.

In other words, the testing matrix (6) must satisfy condition

$$\forall i, j = 1, 2, ..., N : \sum_{i=1}^{N} a_{ij}, \sum_{j=1}^{N} a_{ij} > 0. \quad (9)$$

Secondly, it may be shown, that minimal volume of diagnostic information, calculated by (8), will satisfy a condition

$$N \le V \le N^2 + 1. \quad (10)$$

Let show inequality (10) graphically (Fig. 7).

Inequality (10) may be confirmed experimentally. For example, we may realize simulations by random selection of graphs with small number of machines (see Fig. 9) and middle number of machines (see Fig. 9) in studied information system.

Thus, based on the conducted mathematical modeling, it is evident that the volume of the syndrome required to initiate the self-diagnosis process cannot be less than the number of machines in the diagnosed system and does not exceed the square of this number plus one. In other words, the double inequality (10) is valid, and Fig. 7–9 accurately depicts the range of possible values for the sufficient syndrome volume depending on the number of machines in the system.

This statement is confirmed by the simulation results presented in Fig. 8.

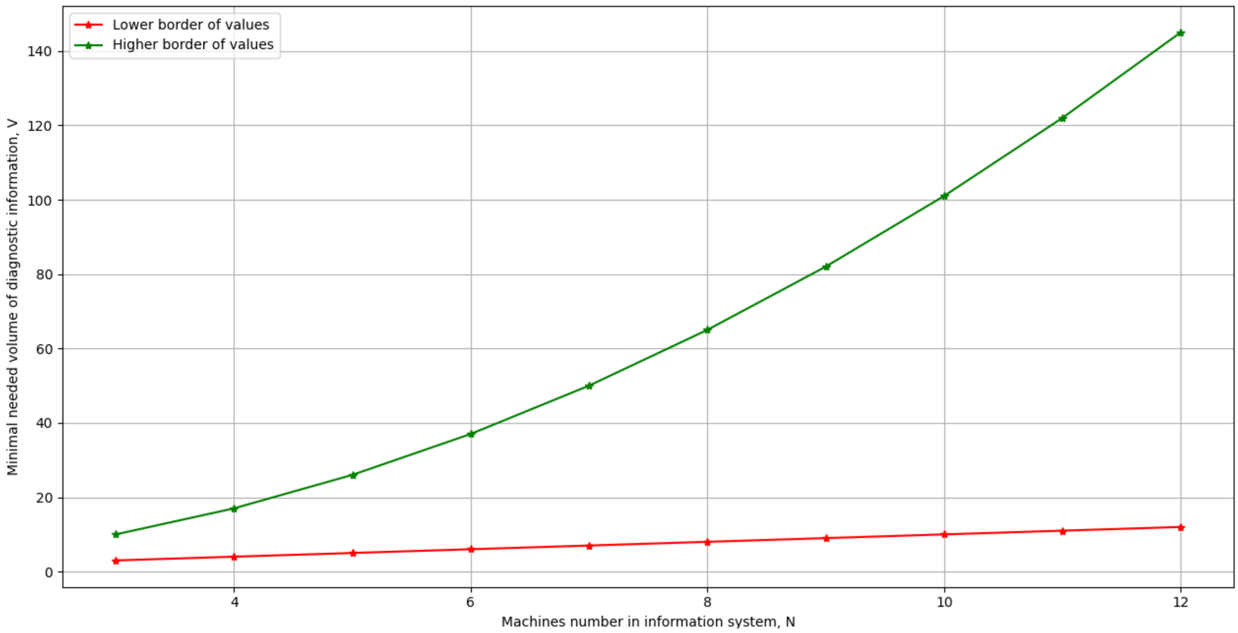

Fig. 7. Mark of interval of minimal volume of diagnostic information, calculated by (8)

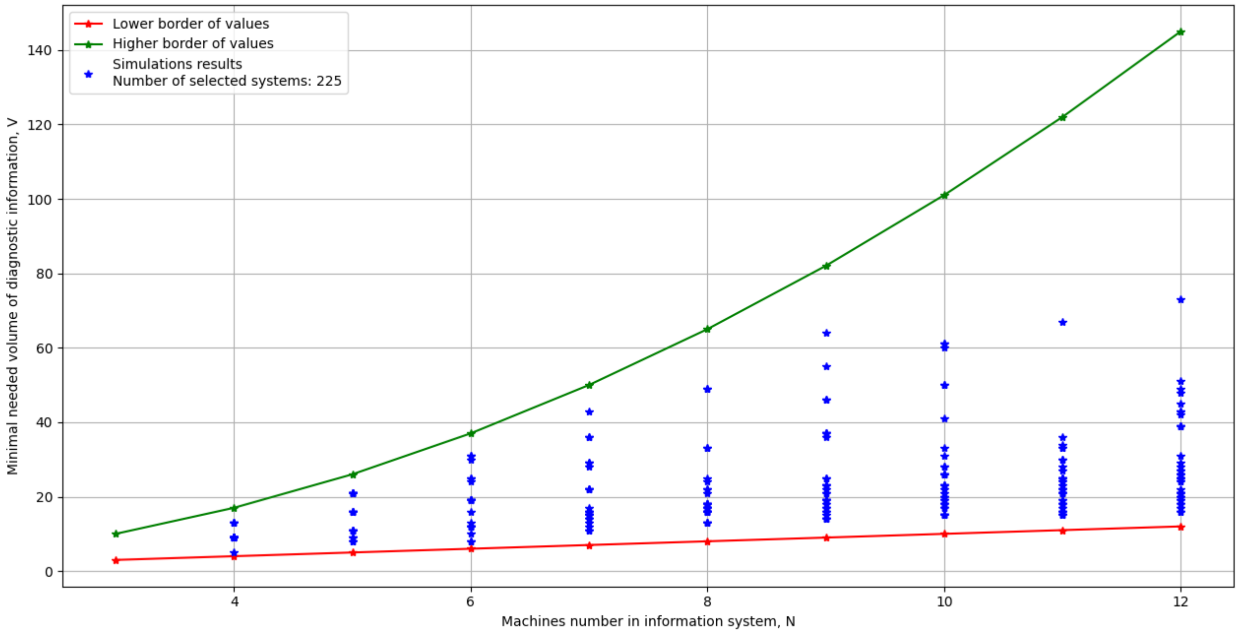

Fig. 8. Result of simulations by random selection of graphs with small number of machines

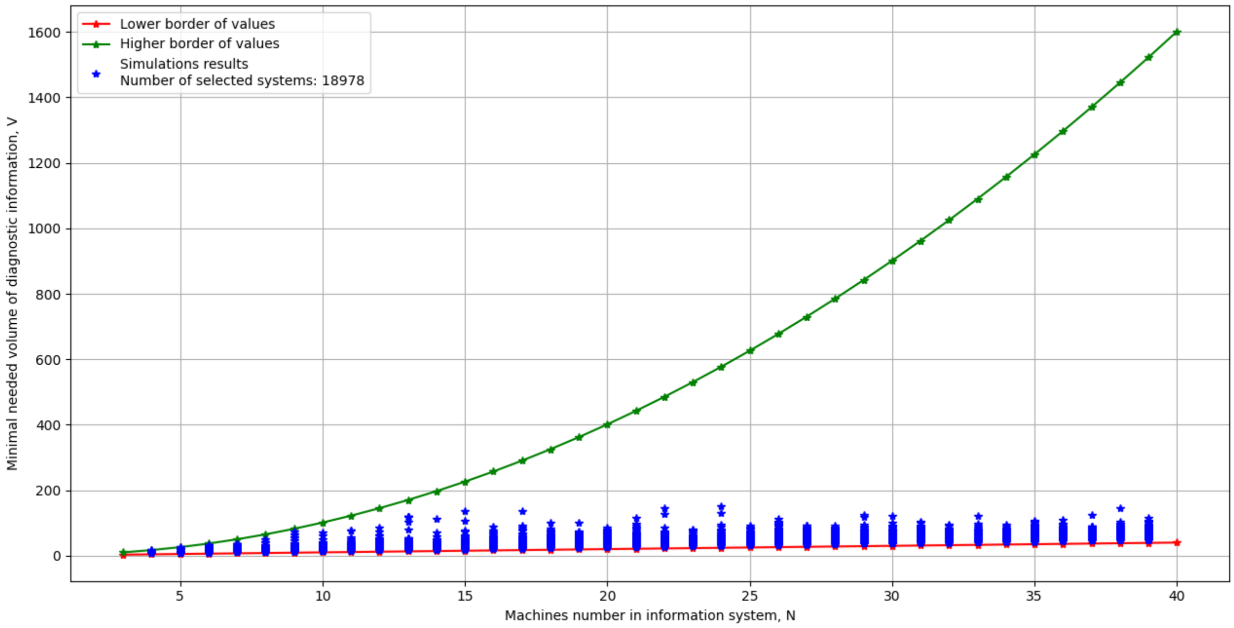

Fig. 9. Result of simulations by random selection of graphs with small and middle number of machines

With a significantly larger number of simulations, as shown in Fig. 9, the following can be observed: for a large number of machines, the sufficient syndrome volume is considerably smaller than the square of the number of machines. This observation suggests the possibility of refining inequalities (10). Additionally, it is quite interesting to note that for systems with fewer machines, the sufficient syndrome volume is not necessarily smaller than that for systems with a larger number of machines. This is evident, for instance, in Fig. 9.

Conclusions

The paper proposes a method for calculating the syndrome volume required to ensure that each machine is checked at least once. As demonstrated, this calculation requires only know of the diagnostic graph of the studied information system. A formula for calculating the syndrome volume has been derived, which is well-suited for software implementation.

As simulations show, usage of formula (8) for calculation minimal volume of a syndrome, enough for start of decoding diagnostic information, is enough quickly. If we analyze (8), it may be shown, that realization of (8) have difficulty equals $O\left(N^3\right)$. In other hand, in program realization of (8) we may achieve difficulty approximately equals $O\left(N^2\right)$, what is proportional of traversal of the adjacency matrix diagnostic graph of studied multi-machine information system.

The application of this formula is illustrated using two examples of systems with different diagnostic graphs, and the specifics of its use are discussed. While studying the properties of the established relationship, upper and lower bounds of the required syndrome volume were determined, and their correctness was validated through a large number of simulations, the results of which are presented in the paper.

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Надійшла (received) 28.01.2025
Прийнята до друку (accepted for publication) 09.04.2025

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Метод обчислення критерію достатності діагностичної інформації для виконання алгоритму самодіагностування у багатомашинних інформаційних системах

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Анотація. Предмет, тема та головна мета роботи. При роботі багатомашинної системи в автономному режимі критично важливо реалізувати алгоритм її самодіагностування. Існує багато алгоритмів самодіагностування багатомашинних систем, і значна частина сучасних передбачає декодування діагностичної інформації. Проте умови, за яких можна починати декодування цієї інформації, залишаються недостатньо вивченими. У цій роботі пропонується та обґрунтовується нова умова такого типу, яка базується на мінімальному об'ємі діагностичної інформації, при виконанні якої можна розшифровувати діагностичну інформацію. **Методи.** У процесі накопичення діагностичної інформації загальну структуру цього накопичення можна описати за допомогою орієнтованого графа, який часто називають діагностичним. Знаючи діагностичний граф досліджуваної багатомашинної інформаційної системи, можна сформулювати певні властивості її самодіагностування. Виходячи з певних припущень, також можна визначити властивості, що стосуються об'єму діагностичної інформації. Наприклад, за умови, що кожна машина в системі виконує однакову кількість елементарних перевірок, можна обчислити мінімальний об'єм діагностичної інформації, необхідний для того, щоб кожна машина була перевірена хоча б один раз. В даній роботі використано подібні припущення для обчислення мінімального об'єму діагностичної інформації, який потенційно достатній для початку її декодування. **Результати.** У роботі запропоновано та обґрунтовано нову умову для початку декодування діагностичної інформації, що забезпечує достатній об'єм для цього процесу. **Висновки.** У роботі запропоновано та обґрунтовано метод визначення мінімального об'єму діагностичної інформації, достатнього для початку її декодування, обчислення якого базується на діагностичному графі досліджуваної багатомашинної системи. Застосування цього мінімального об'єму продемонстровано на двох прикладах із різними діагностичними графами. Окрім цього, розглянуто ключові властивості цього об'єму. Як результат численних симуляцій визначено діапазон можливих значень об'єму залежно від кількості машин у системі.

Ключові слова: інформаційні системи; самодіагностування; граф; критерій.