# EXTENDING THE FEATURES OF SOFTWARE FOR RELIABILITY ANALYSIS OF FAULT-TOLERANT SYSTEMS

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**Abstract:** The developed software ASNA-2, which is an improved version of the software ASNA-1, is based on the technology of automated estimation of reliability indexes of fault-tolerant systems. This software is designed for automated evaluation of the reliability indexes of fault-tolerant hardware – software systems. This paper describes a software ASNA-2 with the peculiarities of procedures of reliability analysis of fault-tolerant systems.

**Key words:** reliability, fault-tolerant systems, modelling, software

## 1. Introduction

The complexity of modern engineering systems causes a large dimension of mathematical models of reliability (hundreds of thousands) that makes it practically impossible for them to be formed and analysed manually. Therefore, apart from the requirement of high reliability of the models, there is another requirement of the appropriate level of formalization which enables the automation of their development and analyzing the reliability using modern computer facilities. The combination of analytical research methods of reliability with the computing capability of modern computers is a perspective direction of the further development of methods for the analysis of complex systems reliability. Among the analytical methods, most widely used methods are those based on the theory of Markov discrete-continuous processes which consider random events (failures and recovery of system elements), which follow one after another in a certain sequence as stream of random events and thus describe the trajectory (state-to-state transition) of a complex technical system. These methods allow you to determine the reliability of systems with different types of redundancy and recovery which provide the system with a fault tolerance feature.

A mathematical model (MM) of the reliability of a technical system, which describes in time the process of transition of the system from one state to another, is a system of the Chapman-Kolmogorov differential equations, whose solutions describe time dependences of the probabilities of being the technical system in all possible states, and, thus, allow to determine necessary reliability indexes (probability of failure-free operation, function and coefficient of availability, MTTF, mean time between failures, mean recovery time, etc.). The construction of the mentioned MM implies the formation of a graph of states and transitions for the object under research. This problem is complicated because for real fault-tolerant systems, the number of states exceeds hundreds and the number of transitions – thousands [1 – 3].

In [1], the Markov models development technology, which enables the process of forming a graph of states and transitions to be automated, is proposed. This technology foresees the use of formalized representation of the object of study in the form of structural-automatic model (SAM). On the basis on this technology, structure of a tool for the automated assessment of reliability indixes of fault-tolerant systems has been developed, and on the same basis as well as the software ASNA-2, which is an improved version of the software ASNA-1 [10], [11, pages 109-121] and is designed for automated assessment of the reliability of fault-tolerant hardware and software radioelectronic systems.

This article describes the structure and specificity of the software ASNA-2 realizations taking into account the peculiarities of the procedures of reliability analysis of fault-tolerant systems.

## 2. Software structure

The software ASNA-2 has advanced features which include:

- Selection of an algorithm for the formation of matrix of the Chapman-Kolmogorov diferential equation coefficients.
- Introduction of random initial conditions.
- Selection of a numerical method for solving the systems of differential equations.
- Processing the results obtained due to solving the systems of differential equations.
- Entering start and end points of integration as well as the number of integration steps.
- Viewing the matrix of coefficients of the systems of differential equations
- Exporting final and intermediate results in MS Excel format.

In order to ensure these functional capabilities, there have been made the following developments:

- a software unit that implements the input of initial conditions for the solution of the Chapman-Kolmogorov differential equations.
- a software unit that implements connection of modules with the implemented methods for solving the Chapman-Kolmogorov differential equations in the form of DLL (Dynamic Link Library – library of dynamic layout).
- units in which 4 methods of numerical solution of the Chapman-Kolmogorov differential equations were implemented.
- a software unit and an interface that handle the solutions to the Chapman-Kolmogorov differential equations.
- a unit which exports the output data (**out**).

A generalized structure of the software considering the requirements [4, 5] is shown in Fig 1.

The input data is a structural automatic model which includes a set of formal parameters, components of the state vector and their initial values and a tree of modification rules of state vector components. Based on these data, there are formed a model as a matrix of coefficients of the system of the Chapman- Kolmogorov differential equations (SDE), and a list of all states and transitions of the research object.

The next step is solving the existing SDE. The given program implements four algorithms for solving the existing SDE in the form of dynamically loading libraries (DLL) and a unit that is responsible for their connection. Реалізований модуль визначає правила створення функцій розв'язання СДР, які потрібно враховувати при створенні нових бібліотек з алгоритмами їх розв'язку при подальшому удосконаленні програмного засобу ASNA-2.

The implemented unit establishes the rules for creating functions of a SDE solution that you should consider when compiling new libraries with the algorithms of their solution in the process of improvement of the software ASNA-2.

Another element of the software is a unit for processing SDE solutions, which can be carried out by three methods.

The results having been processed, and the necessary efficiency indexes having been obtained**,** exportability of all the results obtained, using the software was realized.

The main unit in the software ASNA-2 is the unit UnitMain, to (**in**) which Interface and Implementation units are connected. The Interface unit in turn contains:

- • Common is a unit, which describes the procedures and functions for input data processing (structure-automatic model and constants) and calculation of the matrix of the Chapman-Kolmogorov SDE coeffi-cients, using the method of complete enumeration.

- uCalcul is a unit which describes various procedures and functions of processing string-type variables and other types of variables.
- The Implementation unit contains:
- UnitProgress is a unit which describes the form whose components can display of program execution.
- UnitAbout is a unit which describes the form of FormAbout.
- UnitExport is a unit which implements the export of calculation results, namely **a** matrix of the SDE coefficients, a list of state vectors, solutions to SDE in a file with txt or xls extension, and solutions to SDR as an image file.
- FOM is a unit which describes the form of choosing a calculation algorithm for the matrix of the Chapman-Kolmogorov SDE coefficients (**a** complete enumera-tion algorithm, and **a** Treelike algorithm).
- Matrix implements a form **on** which the matrix of the Chapman-Kolmogorov SDE coefficients is displayed.
- UnitP79 is a unit in which **a** Treelike algorithm for finding the matrix of the Chapman-Kolmogorov SDE coefficients is implemented.
- PidklDLLInterface is a unit that is responsible for downloading of a selected dynamically connecting library in which the algorithm of solving the Chapman- Kolmogorov SDE is implemented.
- VibMeth is a unit that is responsible for selecting a dynamically connecting library in which the algorithm of solving the Chapman-Kolmogorov SDE is implemented.
- PochUmov is a unit in which the form for introducing initial conditions of the Chapman- Kolmogorov SDE is described.
- Exeption is a unit in which a shape which implements the input of the maximum number of steps, and the coefficient of multiplying the number of steps which eliminates a situation that could occur during the execution of the program due to the insufficient number of steps is described

### 3. Features of the software ASNA-2 implementation

The software is implemented according to the structure (Fig. 1) as a single exe-unit that is Analyze1.exe and dll-units of the dynamically loading libraries located in the folder SRC Interface, each of which corresponds to a particular method of solving the Chapman-Kolmogorov SDE, namely: BG_DLL.dll is implemented on the basis of the Runge – Kutta – Merson algorithm, R_KDLLInt.dll is implemented on the basis of the Runge – Kutta, DLLInt algorithm adapt.dll is implemented on the basis of the Runge- Kutta algorithm with an adaptive step, R_K_Adams.dll is implemented
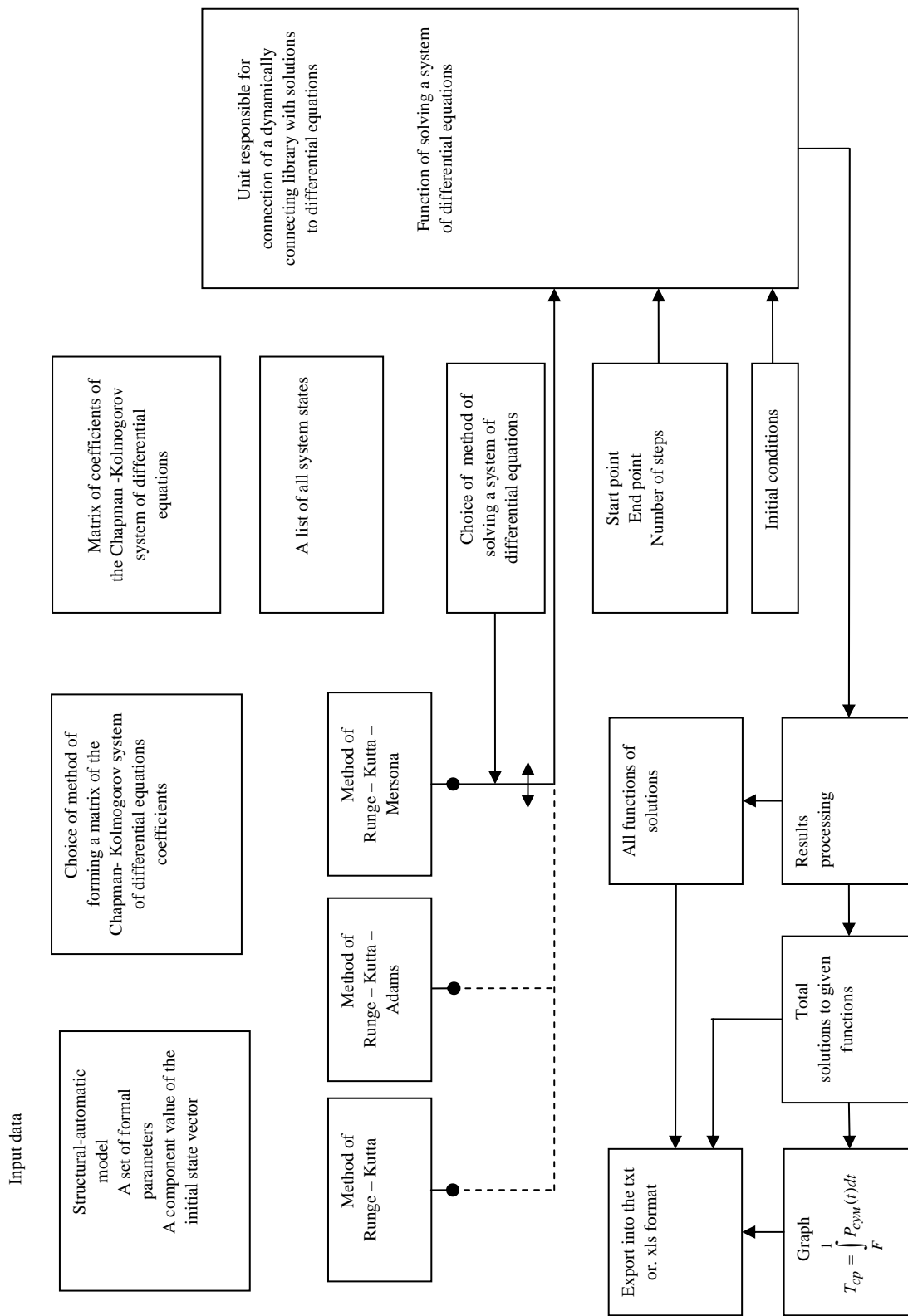
Fig. 1. Structure of the software ASNa-2 for the reliability analysis of fault-tolerant systems.

The diagram contains the following labeled blocks:

- Input data
- Structural-automatic model / A set of formal parameters / A component value of the initial state vector
- Choice of method of forming a matrix of the Chapman-Kolmogorov system of differential equations coefficients
- Matrix of coefficients of the Chapman-Kolmogorov system of differential equations
- A list of all system states
- Choice of method of solving a system of differential equations
- Start point / End point / Number of steps
- Initial conditions
- Unit responsible for connection of a dynamically connecting library with solutions to differential equations
- Function of solving a system of differential equations
- Method of Runge – Kutta – Mersona
- Method of Runge – Kutta – Adams
- Method of Runge – Kutta
- All functions of solutions
- Results processing
- Total solutions to given functions
- Export into the txt or. xls format
- Graph

$$T_{cp} = \int_{F}^{1} P_{CYM}(t)dt$$

on the basis of the Runge – Kutta – Adams algorithm. Besides, this software includes the file manual.txt, which contains a help file and a user manual.

A complete cycle of testing separate units and testing the software as a whole according to [6-9] is carried out. From the obtained results of testing the software units, one can conclud that the developed algorithms for the solution of systems of differential equations work correctly, and dynamically loading libraries were properly implemented and tested to a sufficient extent.

***Features of the user interface.*** The user interface is implemented as a set of tabs divided into two parts – for data input, and analysis results output. Switching between these modes is performed by the buttons Input and Output (Fig. 2). Entering the sets of formal parameters of the object under research is carried out in the tab Constants and Info. Entering the components of a state vector, their initial values and conditions of critical failure is carried out in the tab Vectors and Refuse expression. Entering the tree of modification rules is carried out in the tab Event tree. Each tab contains buttons for adding a new record (Add), inserts of additional record (Insert), modification of an existing record (Replace), delete of the existing records (Delete) and cleaning the current data (Clear).
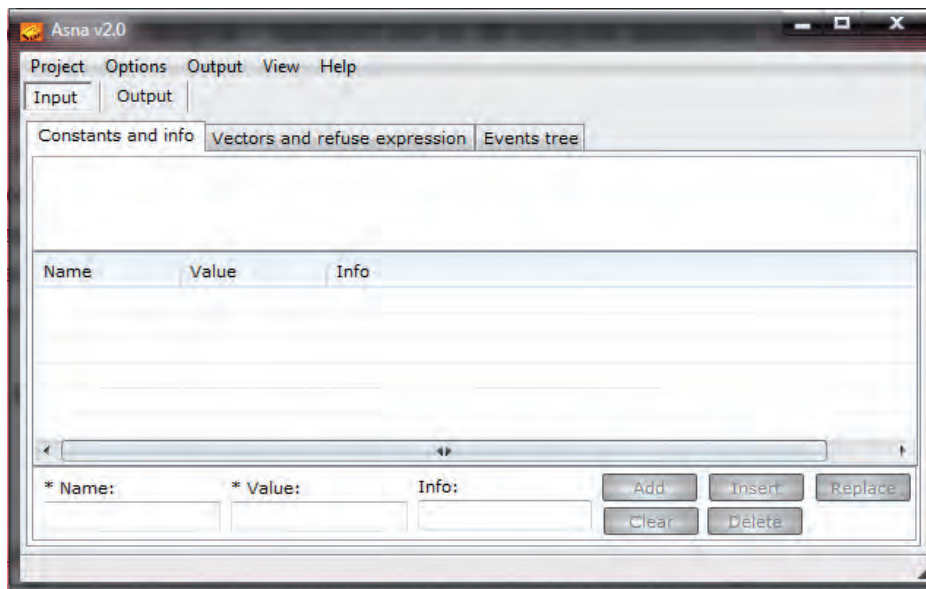


*Fig. 2. Interface of data input (structural-automatic models of a target object).*

***Selection of initial conditions***

To enter initial values of probabilities of being in of the target object's states at time t = 0, a special form is developed: Options → Initial conditions. In the left hand column, the number of the state is entered, and in the right hand one, the same is done with the initial value of the probability of being in the state at time t = 0 (Fig. 3).

***Choice of a method to solve the Chapman-Kolmogorov SDE***

To choose a method for solving the Chapman-Kolmogorov SDE, one needs to select an appropriate dynamically loading library – DLL-file. ASNA-2 implementes such methods of the solution to the Chapman-Kolmogorov SDE as:

- Method of Runge – Kutta with a fixed step
- Method of Runge – Kutta with an adaptive step

- Method of Runge – Kutta – Mersona
- Method of Runge – Kutta – Adams

The form for choosing a method appears as a result of pressing Options → Choice of method (Fig. 4).

***Choice of a method for the formation of a coefficient matrix which corresponds to the Chapman- Kolmogorov SDE***

Unlike ASNA-1, the software ASNA-2 implementes two different methods of forming the coefficient matrix that correspond to the Chapman- Kolmogorov system SDE, namely: the method of defining states through the sequential view of all situations, and then through the determination of PKMVS and the optimized method based on treelike representation. The form for the selection of a method of forming a coefficient matrix appears as a result of pressing Options → Forming of Matrix (Fig. 5).

The ASNA method is a complete enumeration algorithm, which was implemented in ASNA-1.

Page79 Method is a Treelike algorithm described in [1].

A coefficient matrix formed in accordance with the chosen method can be seen in the tab "Vectors and Matrixes", or by selecting View → Matrix of coefficients (Fig. 6)
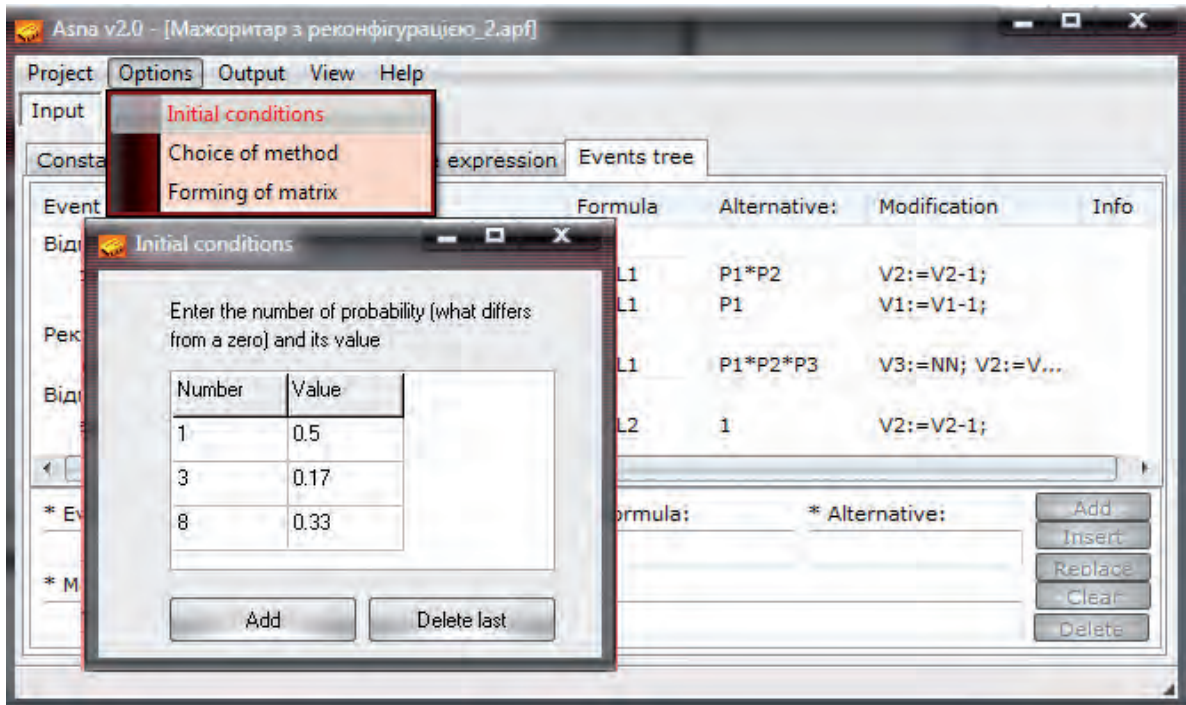


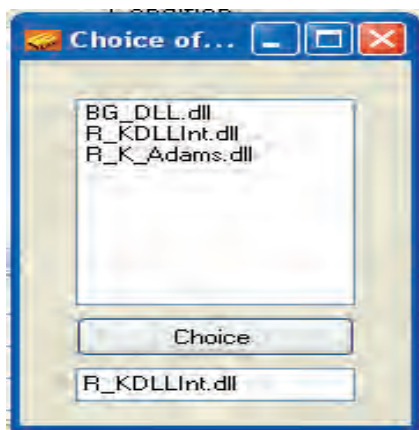*Fig. 3. Entering the initial conditions.*



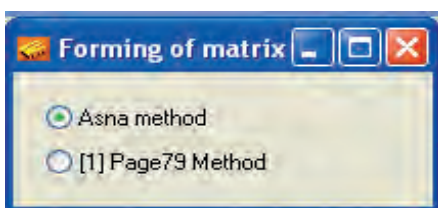*Fig.4. Choice of a method for solving differential equations.*



*Fig. 5. Choice of a method for forming a coefficient matrix.*

### *The results of calculating the reliability indexes of fault-tolerant hardware-software*

The results of calculating the reliability indexes of fault-tolerant hardware-software radioelectronic systems can be obtained by switching to the mode of data output, using the button Output. There are three tabs available in this mode: Debug is used for debugging the model, Vectors and Matrix is designed for processing the modeling results (solutions to the Chapman-Kolmogorov SDE), and Graph is to output the results of the solution to the Chapman-Kolmogorov SDE. Handling the solutions to the Chapman-Kolmogorov SDE consists in summing up the solutions selected by a user (Fig. 7). The choice can be of three types, as shown in the panel:

**Total** (Total) – summarizes the values of all the solutions that are found in the range from 1 to N and correspond the argument tk, for example, P1 (tk)…PN (tk).

**Total, except for** (total, except for) – summarizes the values of all the solutions that correspond to the argument tk, except the selected functions, for example, P5 (tk), P25 (tk), PN (tk).

**Set** (set) – summarizes the values only of the specified solutions P1 (tk)…PN (tk) which correspond to the argument tk, for example, P5 (tk) + P25 (tk) + PN (tk).

*Fig. 6. Matrix of coefficients.*



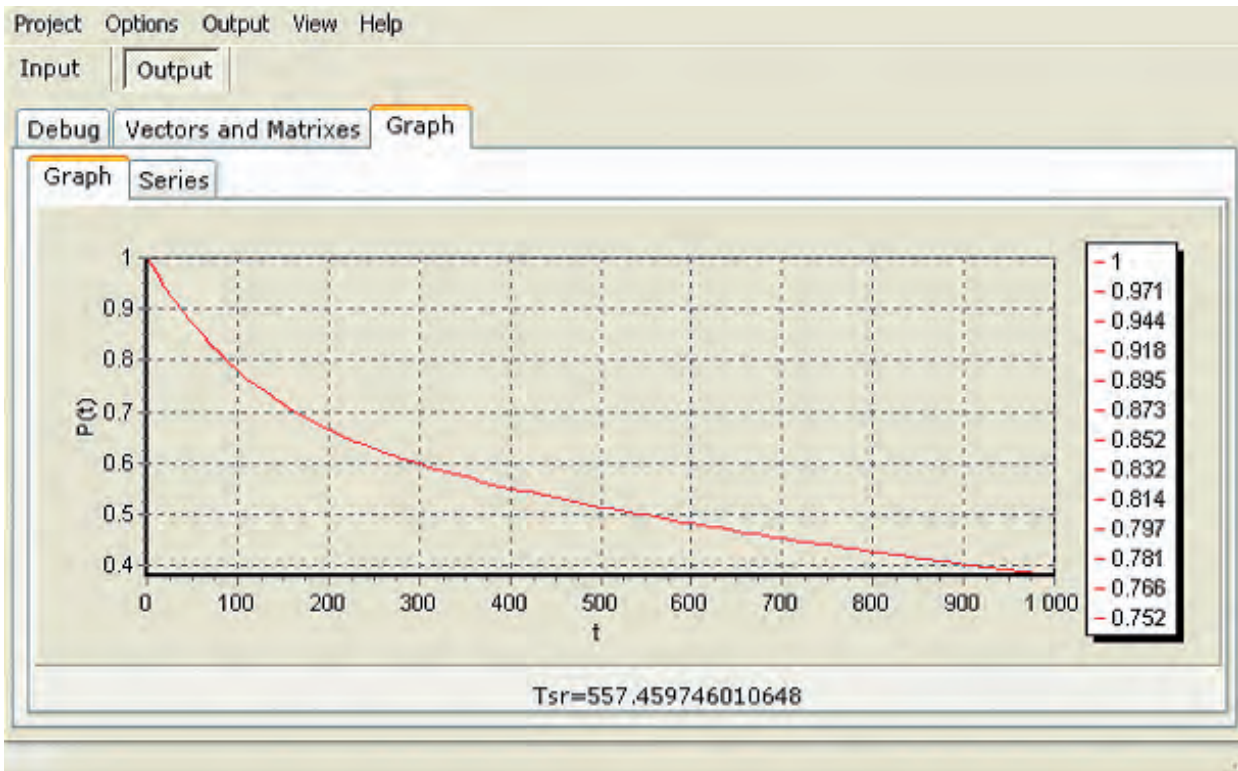*Fig. 7. Handling the solutions to differential equations.*

*Fig. 8. Results of processing the solutions to SDE in the form of dependencies of probabilities*
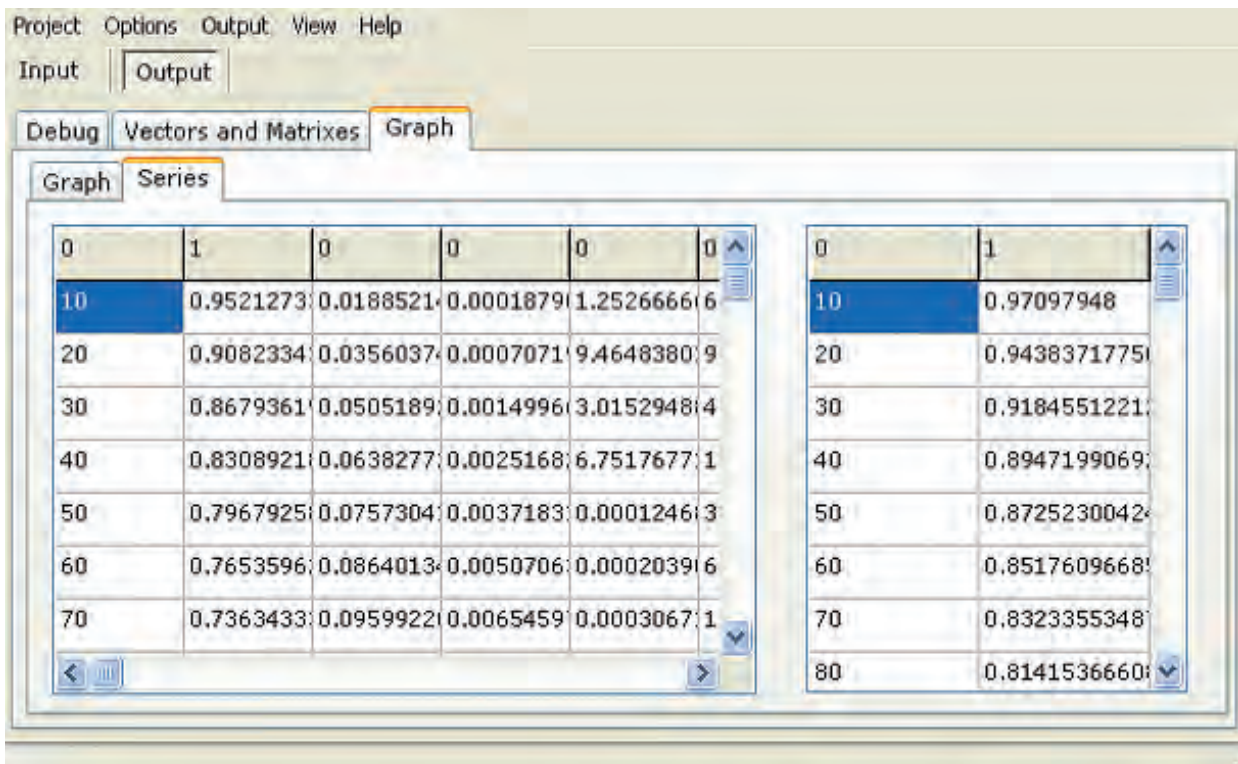*of failure-free operation on the duration of operation time.*



*Fig. 9. Results of processing the solutions to differential equations.*

The solutions to the Chapman-Kolmogorov SDE, and the results of processing the solutions are on tab Output → Graph → Graph and Series (Fig. 8, Fig.9)

***Export of results***

In order to process the results of automated assessment of the reliability of fault-tolerant hardware-software radioelectronic systems at different stages of modeling by means of MathCAD, MatLab, Excel, etc., the program ASNA-2 is capable to export the modeling results into various formats – text, dat files, and files of xls format – MS Excel format, and in an image format.

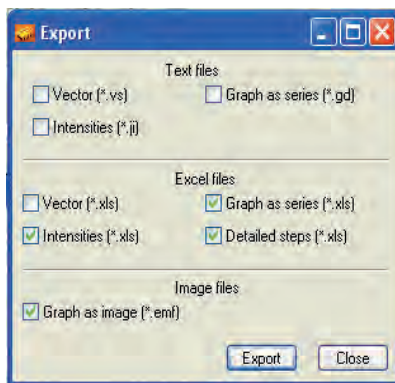The export of the results is implemented as follows: Output → Export ... (Fig. 10)



*Fig. 10. Export of results.*

Implementation of the software ASNA-2 suggests that it is possible to connect the new dynamically loading libraries (DLL) which are responsible for the solution of SDE and are created by third-party developers.

### 4. Conclusions

1. Functionalities of the software ASNA-2 allow developers to effectively carry out the comparative analysis of alternative fault-tolerant systems that differ among themselves multiplicity and methods of redundancy, recovery strategies, etc., and on this basis to choose the best options.

2. For the effective use of the software ASNA-2 a user must master the technique of developing structural-automaton models, which are formalized by a description of the modeling object that requires some investment of time, which thus fully justify themselves at carrying out a multivariate comparative analysis.

3. Experience of using the software ASNA-2 for solving the problem of reliability analysis of radioelectronic systems, the number of states of which reaches hundreds, and the number of possible transitions between states reaches thousands, has shown that it takes only a few minutes to determine the reliability of the systems.

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## РОЗШИРЕННЯ МОЖЛИВОСТЕЙ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ ДЛЯ НАДІЙНІСНОГО АНАЛІЗУ ВІДМОВОСТІЙКИХ СИСТЕМ

Богдан Волочій, Богдан Мандзій, Леонід Озірковський

У статті представлено нові можливості спеціалізованого програмного забезпечення ASNA-2, яке призначене для автоматизованої оцінки показників надійності відмовостійких програмно-апаратних систем. Розроблене ПЗ засноване на оригінальній технології автоматизованої оцінки показників надійності відмовостійких систем, розробленої авторами.

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