Запропоновано методику комплексного застосування методів сценарного аналізу та прогнозування, представлених графами типу «дерево». Розглянуто задачу аналізу ризиків програмних проектів, пов'язаних з можливими помилками програмування, що призводять до порушення працездатності систем та програмного забезпечення. Спільне застосування дерева відмов та дерева ймовірностей дозволяє генерувати послідовності сценаріїв настання негативної події, спричиненої потенційно можливими дефектами або помилками в програмах та даних, та оцінювати ймовірності їх реалізації. Такий підхід дозволяє виявляти спільний результат впливу окремих ризикоутворюючих факторів (дефектів) на розвиток можливих негативних наслідків (відмов та збоїв) або збиток при функціонуванні складних програмних систем. Це дає можливість завчасно розпізнавати та запропонувати ефективні механізми управління програмними ризиками з метою їх скорочення та ліквідації.

Запропонована процедура агрегування індивідуальних ймовірнісних оцінок експертів реалізації сценарію настання ризикової події. Такий підхід дозволяє отримувати групові експертні оцінки можливості настання ризикової події на основі сформованої системи випадкових подій в узагальнену експертну оцінку. Отримані таким чином ймовірності реалізації ризикової події застосовуються при побудові дерева ймовірностей та розрахунку співвідношень ймовірнісного виведення на ньому. Агрегування індивідуальних експертних оцінок здійснюється шляхом їх комбінування на основі математичного апарату теорії свідоцтв та теорії правдоподібних і парадоксальних міркувань. Встановлено, що для підвищення якості результатів комбінування доцільно визначати порядок комбінування експертних свідоцтв та використовувати одне з правил перерозподілу конфліктів в якості правила комбінування.

Наведені чисельні розрахунки запропонованої методики комплексного застосування дерева відмов та дерева ймовірностей. Одержані результати дозволяють проводити більш глибокий аналіз програмних систем та об'єктів, що досліджуються, та покликані сприяти підвищенню якості та ефективності управління ризиками програмних проектів, викликаними дефектами в програмах та даних

Ключові слова: дерево відмов, дерево ймовірностей, ризики програмних проектів, аналіз сценаріїв, правила комбінування

UDC 004.052
DOI: 10.15587/1729-4061.2019.163871

DEVELOPMENT OF THE PROCEDURE FOR INTEGRATED APPLICATION OF SCENARIO PREDICTION METHODS

I. Kovalenko
Doctor of Technical Sciences, Professor*
E-mail: ihor.kovalenko@chmnu.edu.ua
Ye. Davydenko
PhD*
E-mail: davydenko@chmnu.edu.ua
A. Shved
PhD*
E-mail: avshved@chmnu.edu.ua
*Department of Software Engineering
Petro Mohyla Black Sea National University
68 Desantnykiv str., 10, Mykolaiv, Ukraine, 54003

1. Introduction

The development of scenario prediction led to the development of two basic instrumental methods. They are a tree of objectives and a prediction graph. The objective of the methods is analysis of complex systems or processes, where allocation of many structural or hierarchical levels is possible. We build a tree of objectives based on formation of the main objective and various sub-objectives, which lie at the less significant levels of the hierarchy.

The base of the methodology of construction of a prediction graph is initial implementation of sub-objectives and events, which lie at lower levels of the hierarchy with a final exit to a main objective. In other words, we build of a tree of objectives based on the «top-down» principle and we build a prediction graph using the «down-top» principle.

A number of modifications of graphs of the «tree» type arose at expansion of spectrum of problems, which use scenario prediction for their solution. For example, a fault tree and a tree of events appeared for solution of problems of analysis of reliability of different systems. We can use decision trees as decision-making tools, and we can solve probabilistic inference problems using probability trees, etc. However, we should note that each of the listed trees implements the «cause-effect» principle within a frame of a specific problem.

The analysis of scenario prediction methods presented by «tree» graphs shows that the above principle is not taken into consideration at performing of several interconnected problems of scenario prediction. However, there is a «bow-tie» method based on the methods of a fault tree and a tree of consequences, which gives possibility to investigate causes of occurrence of risk events and to analyze their possible consequences in a simple graphical way. This method gives possibility to establish a connection between causes and consequences of dangerous (risk) events for development of a set of measures aimed at prevention and/or reduction of their consequences. However, the method performs analysis of complex situations in a rather simplified form and does not give possibility to asses adequately probability of occurrence of a combination of factors, which lead to negative consequences, especially if they are dependent. It also does not make it possible to reflect a set of reasons that arise simultaneously and cause negative consequences (emergencies).

The solution of this problem lies in the integrated application of existing methods and means of scenario prediction aimed at identification of causes of emergence of risk factors and prediction of possible scenarios of development of their consequences. In this context, the combined use of methods aimed at identification of causes of negative events and probabilistic methods is expedient. This, in turn, makes possible to model complex uncertain situations (consequences of negative events), generate and assess possible scenarios for their development.

For example, we should pay special attention to the risk management process when implementing software (SW) development projects. It is necessary to be able to identify, analyze and predict possible consequences at each stage of the software development process in accordance with the chosen software development methodology for effective program risk management.

There are formal methods of analysis of failure risk widely used to predict risks associated with possible programming errors that result in software failure. The most common of them are Event Tree Analysis (ETA), Fault Tree Analysis (FTA), and Failure Modes and Effects Analysis (FMEA) methods. In particular, we can consider programming errors as causes, and software failure as a consequence when applying the FTA method. A software failure can cause a number of negative consequences (risks of software projects), for example, additional software development costs, violation of terms of delivery to a customer, etc. It is possible to perform an analysis of such effects using a probability tree.

2. Literature review and problem statement

Authors of papers [1–4] consider the main principles of construction of scenarios and methods for their analysis. Paper [1] defines the ways of using the scenario approach for analysis of complex social systems. It proposes general guidelines for organization and conduction of scenario studies. The objective of works [2, 3] is analysis of modern methods and techniques of scenario planning and prediction. Paper [4] presents classification of methods and methodologies of system analysis. It pays special attention to methods of the «target tree» type, methods of expert assessments, structuring and statistical analysis, etc. It investigates the methods and methodologies of the system analysis that became widely used in analysis and quality management of enterprises. Paper [5] describes the method of construction of «scenarios of the future» in strategic management of enterprises. There are unresolved problems related to the choice of methods for prediction and analysis of the studied scenarios in works [1–5].

The option for solution of the indicated problem is the use of the technique of probabilistic inference based on scenarios constructed using probability trees. Authors of work [6] use this approach on example of the solution of the problem of risk factor analysis of organizational and organizational-technical tasks of ship repair under conditions of uncertainty and risk. However, authors do not pay attention to the analysis of reasons for occurrence of risk factors that affect a course of the ship repair process, which in turn is the basis for analysis, assessment and definition of risk reduction directions.

We can use a fault tree method as an approach that gives possibility to analyze a cause of a risk factor.

Paper [7] considers general problems of using of a fault tree method for solution of a wide range of problems in various fields and its modern modifications aimed at overcoming of existing disadvantages of the method.

Researchers widely use the fault tree method to analyze risks of technogenic origin. Authors of paper [8] propose a methodology for assessment of reliability, safety and technogenic risk based on logical-and-graphical methods of analysis. They pay considerable attention to the method of a fault tree; in particular, they consider the methods of qualitative and quantitative assessment of a fault tree, methodology of analysis of a fault tree with repeating events. Work [9] considers peculiarities of application of the fault tree method for assessment of the industrial risk of enterprises.

Work [10] proposes an approach based on construction and analysis of a fault tree. It makes possible to perform computer and mathematical modeling of a risk of a technological process. This approach gives possibility to identify weak spots of a system (an object under study), to identify the most likely events and system parameters, which lead to negative events.

For today, a fault tree is an effective tool for risk analysis of software failures. It gives possibility to analyze causes of failures (hardware, software) and their consequences. Work [11] proposes the method of qualitative risk analysis of software development based on the complex use of the fault tree method and the method of assessment of the indicator of the net reduced cost of a software development project. Author of paper [12] uses the method of a fault tree to analyze types and consequences of failures of options of structures of information processing systems on the example of analysis of duplicate structures with the version-time redundancy.

There is a reverse trend in works [7–12]. There is analysis of causes of emergence of risk situations conducted, but the task of analysis and prediction of possible ways (scenarios) to overcome or reduce risks remains unresolved.

Works [5–12] consider the methods of scenario analysis and prediction autonomously, without taking into consideration their combined application for cases with interconnection of problems, which require solution. Only paper [13] investigates possibility of integrated application of formal methods of specification requirements and reliability analysis. It considers the method of analysis of types and consequences of critical failures and the method of a fault tree analysis on the example of a computer control system of motor traffic control. However, outstanding issues related to estimation of probability of occurrence of emergencies in the absence of accumulated accident statistics (emergencies) with a use of a tree failure method remain unresolved. As well as determination of probability of the most critical failures in construction of a critical matrix by the method of analysis of types and consequences of critical failures.

Authors of paper [14] use the «bow-tie» method to analyze possible causes and consequences of implementation of risks. In particular, paper [15] proposes modification of the «bow-tie» method and methodology of partial quantitative risk assessment method. Authors applied and tested it in the shipbuilding industry. However, this methodology does not make it possible to assess probability of implementation and possible combinations of risk factors, which lead to negative consequences.

Consequently, all of the foregoing confirm the expediency of a study devoted to the search for approaches that make it possible timely detection and analysis of risk factors, which lead to possible negative consequences and provide a mathematical apparatus for modeling and assessment of an impact of adverse events (risks), prediction of possible scenarios for development of risk events and study of possible consequences.

3. The aim and objectives of the study

The aim of this study is to construct a method for the integrated application of formal methods of scenario prediction represented by graph models of the hierarchical structure on the example of the integrated application of a fault tree and a probability tree.

We set the following tasks to achieve the objective:

– to develop a procedure for aggregation of individual expert assessments of possibility of manifestation of a negative (risk) event in solution of probabilistic inference problems based on scenarios constructed using probability trees;

– to investigate a possibility for an integrated application of a fault tree and a probability tree on the example of generation of sequence of scenarios of occurrence of risk events caused by failures of software and analysis of their consequences;

– to run a computational experiment and analyze the results obtained.

4. Materials and methods to study the problem on integrated application of methods of scenario prediction

A fault tree is a deductive logical-and-graphical method, which serves to identify possible ways that lead to an undesirable event (for example, a failure of a system or a failure of its individual blocks). The key theoretical foundation of the FTA is the assumption that system components operate successfully or fail completely [16, 17].

We use a basic set of symbolic images for a graphic representation of the simplest fault tree (Fig. 1).

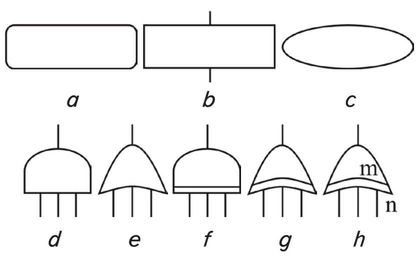

Fig. 1. Basic set of FTA symbols: *a* – input event; *b* – interim event; *c* – resultant event; *d* – «and» condition; *e* – «or» condition; *f* – priority «yes»; *g* – exclusive «or»; *h* – condition of the majority rule («*m*» with «*n*»)

Fig. 2 shows the example of a simple fault tree.

The fault tree (*Probability Tree Analysis, PTA*) serves to analyze a sequence of scenarios (options) for further development of events. They may be the result of manifestation of possible system failures with the use of the fault tree [18–20]. We form a set of system of random events and probabilities of their implementation for this purpose.

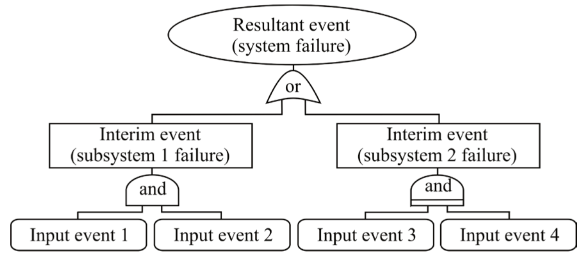

Fig. 2. Fault tree

Each branch of the tree displays a one-incident event from each system of random events (in this case, the system of random events consists of two events) and the probability (*P*) of their implementation. We obtain combinations of such trees by their integration, which lead to formation of a probability tree (Fig. 3), which is a tree-like graph.

Each node (vertex) of such a graph relates to one complete system of random events. A tree branch coming from the corresponding node represents each event and probability of its implementation. Each path from the root node to the final position on the tree reflects one of the possible combinations of events called the scenario.

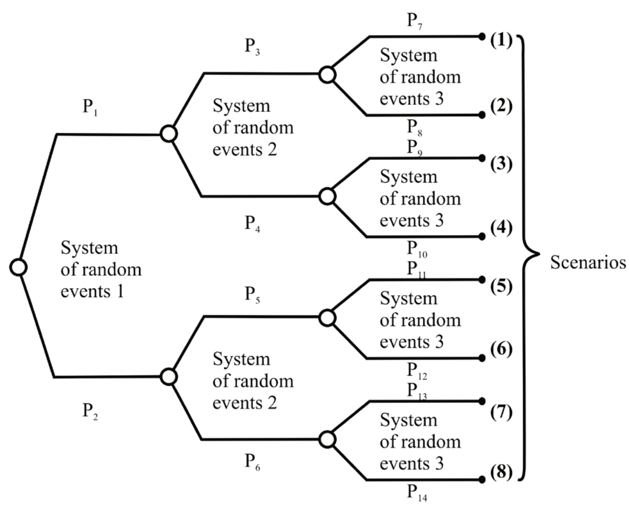

Fig. 3. Probability tree

We can calculate the total number of scenarios before building a probability tree:

$$N = \prod_{i=1}^{z} n_i, \qquad (1)$$

where n_i is the number of events in the *i*-th system of random events; *z* is the total number of such systems.

5. Procedure for determination of aggregated expert assessments of the implementation of a risk event when solving problems on probabilistic inference

We can use the probability tree as an effective graphical tool for risk analysis of software projects. There are two main approaches to obtaining of probability of occurrence of a risk event. They are an objective approach and a subjective approach. The basis of the objective method for determination of probability of occurrence of a negative (risk) event is accumulated statistical data based on calculation of the frequency of occurrence of risk events. If sufficient statistical information is absent, it is necessary to use the subjective method to determine probability of occurrence of risk. Its basis is methods of expert assessment. In this case, we asses possibility of occurrence of an adverse situation (risk) based on considerations and personal experience of a specialist (an expert).

We can engage several experts (a group of experts) to obtain more accurate assessment of possibility of occurrence of a risk event. In this case, the task of obtaining of aggregated expert assessments arises.

Let us consider the procedure of aggregation of individual probabilistic assessments of experts in solution of problems of probabilistic inference on probability trees.

Let us assume that there is a set of experts given $E=\{E_i \mid i=\overline{1,l}\}$, and a set of risk events $R=\{r_j \mid j=\overline{1,k}\}$. We assume that R represents a set of independent events. Each expert should assess the possibility (probability) of a risk event $r_j \in R$ on a scale from 0 to 1. Or, based on their knowledge and experience, experts can present their assessments of the implementation of a risk event within a given scale of expert measurement.

We can represent the results of an expert survey in the form of a set of individual expert assessments as a matrix of $l\times k$ dimension:

$$A=\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1k} \\ a_{21} & a_{22} & \dots & a_{2k} \\ \dots\dots & \dots\dots & \dots & \dots\dots \\ a_{i1} & a_{i2} & \dots & a_{ik} \\ \dots\dots & \dots\dots & \dots & \dots\dots \\ a_{l1} & a_{l2} & \dots & a_{lk} \end{pmatrix}, \qquad (2)$$

where a_{ij} is the possibility (probability) of occurrence of r_j risk event, which is formed by the i-th expert.

We get a set $B=\{b_i \mid i=\overline{1,l}\}$. Its each component is a vector of assessments of E_i expert: $b_i=\{p_j \mid j=\overline{1,k}\}$, where p_j is the possibility (probability) of the occurrence of risk r_j.

Thus, it is possible to construct k-systems of random events for each expert. It is possible to represent them graphically as a distribution tree. Each branch of the tree reflects probability of occurrence of the analyzed risk event.

We assume that we have the given basis for the analysis $\Omega=\{\omega_1, \omega_2\}$, where ω_1 is r_j risk, which is realized; ω_2 is r_j risk, which is considered as non-essential (absent) one. If $m(\omega_1)$ is probability of occurrence of r_j risk, we can express the probability of its absence as $m(\omega_2)=1-m(\omega_1)$.

Thus, for each r_j risk, we obtain $M_j=\{m_i^{(j)} \mid i=\overline{1,l}\}$, vector, where $m_i^{(j)}=\{m(\omega_1),m(\omega_2)\}$ is a vector of probabilistic assessments of r_j event formed based on the individual E_i expert assessments.

We use a mathematical apparatus of the theory of evidences to obtain aggregated assessments [21–23].

The aggregation of individual expert benefits occurs by combination of the obtained major probability masses for each r_j risk event by all experts $m_{rez}^{(j)}=m_1^{(j)}\oplus m_i^{(j)}\oplus\ldots\oplus m_l^{(j)}$. Authors of papers [22, 23] recommend using one of the proportional conflict redistribution rules (PCR rules) for the aggregation of expert assessments.

As a result, for each given r_j risk, we obtain a vector of probabilistic assessments of its implementation $m_{rez}^{(j)}=\{m(\omega_1),m(\omega_2)\}$.

Next, we analyze and calculate the obtained probability tree for independent systems of random events with corresponding probabilistic assessments of occurrence $m_{rez}^{(j)}(\omega_1)\in m_{rez}^{(j)}$ and non-occurrence (absence) $m_{rez}^{(j)}(\omega_2)\in m_{rez}^{(j)}$ of r_j negative event.

Authors of [24–26] propose to determine the order of combination of expert evidences, for example, taking into consideration a degree of difference and structure of expert evidences to improve the quality of combination results when constructing aggregate assessments.

6. Procedure for integrated application of scenario prediction methods

Let us consider an example of the integrated application of a fault tree and a probability tree in scenario prediction of possible software failures and their consequences.

We assume that a number of systems of random events is $z=3$, and a number of events in each of the systems is $n=2$. Then the number of the obtained scenarios is:

$$N=\prod_{i=1}^{3}2=2\cdot2\cdot2=8.$$

Here are schemes of formation of all scenarios:

(1): $P_1\to P_3\to P_7$;

(2): $P_1\to P_3\to P_8$;

(3): $P_1\to P_4\to P_9$;

(4): $P_1\to P_4\to P_{10}$;

(5): $P_2\to P_5\to P_{11}$;

(6): $P_2\to P_5\to P_{12}$;

(7): $P_2\to P_6\to P_{13}$;

(8): $P_2\to P_6\to P_{14}$.

Let us consider three typical project risks: $R=\{r_j \mid j=\overline{1,k}\}$, $k=3$: r_1 – additional software development costs (risk to exceed project cost); r_2 – violation of terms of delivery of software to a customer (risk to exceed terms of performance of works); r_3 – staff turnover (staff provision risk).

We propose to assess a possibility (probability) of occurrence of each risk within the given scale of assessments to the group of experts of 5 people $E=\{E_i \mid i=\overline{1,l}\}$, $l=5$. Experts express their judgments on a scale from 0 to 1: no risk (0); risk is insignificant – insignificant probability of implementation of a risk event (0.1); low probability of implementation of a risk event (0.3); it is not possible to say anything about possibility of implementation of a risk event (0.5); high probability of implementation of a risk event (0.7); critical probability of implementation of a risk event (0.9); it is clear that the risk situation will come (1). Values 0.2; 0.4; 0.6; 0.8 correspond to interim judgments between each gradation. Table 1 shows the results of the expert survey.

We use PCR5 rule of combination to obtain an aggregated (collective) assessment [22]. We calculate $m_{PCR5}(C)$ combined belief assignment in accordance with proportional conflict redistribution rule PCR5 based on the expression:

$$m_{PCR5}(C)=m_{12}(C)+$$
$$+\sum_{\substack{Y\in D^{\Lambda}\setminus\{X\}\\ X\cap Y=\varnothing}}\left[\frac{m_1(X)^2\cdot m_2(Y)}{m_1(X)+m_2(Y)}+\frac{m_2(X)^2\cdot m_1(Y)}{m_2(X)+m_1(Y)}\right], \qquad (2)$$

where $m_{12}(C)$ is the combined belief assignment for $C=X\cap Y$ subset calculated based on the conjunctive consensus.

Table 1

Expert assessments of risk events

r_i	$m(\omega_i)$	E_1	E_2	E_3	E_4	E_5	m_{12345}
r_1	$m(\omega_1)$	0.4	0.3	0.5	0.2	0.6	0.34
	$m(\omega_2)$	0.6	0.7	0.5	0.8	0.4	0.66
r_2	$m(\omega_1)$	0.2	0.4	0.7	0.3	0.4	0.29
	$m(\omega_2)$	0.8	0.6	0.3	0.7	0.6	0.71
r_3	$m(\omega_1)$	0.7	0.5	0.4	0.6	0.8	0.78
	$m(\omega_2)$	0.3	0.5	0.6	0.4	0.2	0.22

Fig. 4 shows the distribution trees based on aggregated expert assessments. Each of them reflects probability of occurrence of a negative event (risk) $r_j\in R$, which may affect implementation of the project.

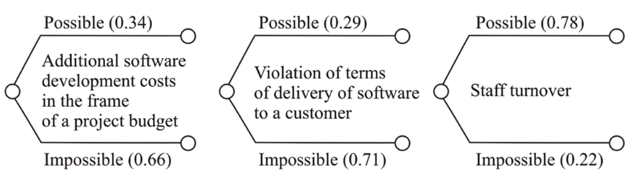

Fig. 4. Trees of distribution of systems of random risk events

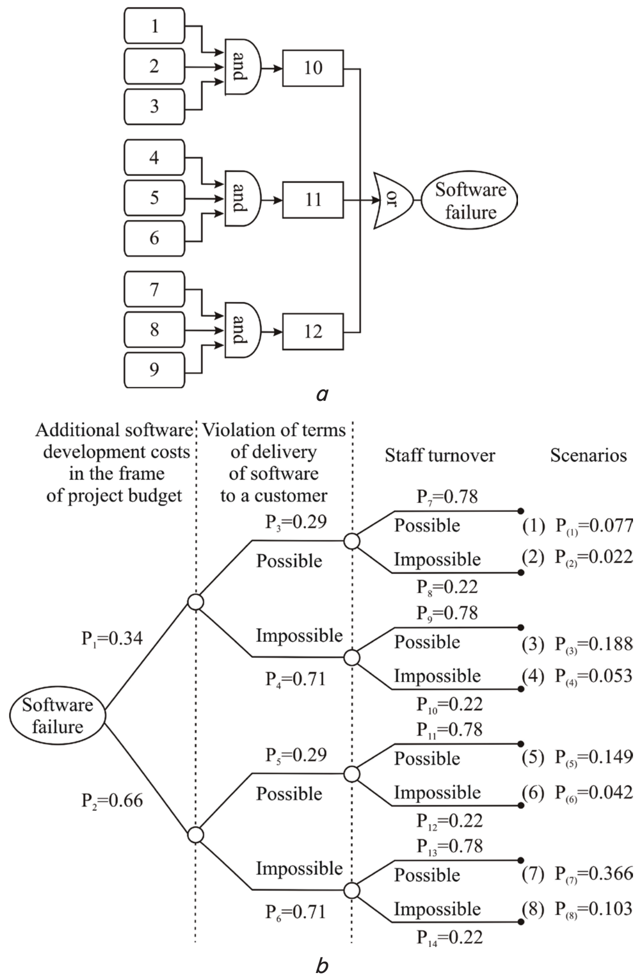

Fig. 5. Integrated application of scenario prediction methods: *a* – a fault tree; *b* – a probability tree

Not only individual risks can affect the successful implementation of the project, but also their possible combinations.

Fig. 5 presents integrated application of the fault tree and probability tree for scenario prediction of possible software failures and subsequent events, which can lead to negative consequences.

There are the following notations adopted on the fault tree [27]: 1 – errors in the specification; 2 – errors in output data; 3 – deviation from the specification; 4 – false logic or sequence of operations; 5 – lack of time for interruptions; 6 – lack of time for decisions; 7 – false arithmetic operations; 8 – inaccurate registration; 9 – distortion of programming rules.

«And» logical operations form respectively:

– and$_1$ $1\wedge 2\wedge 3\rightarrow 10$ – errors when setting a problem;

– and$_2$ $4\wedge 5\wedge 6\rightarrow 11$ – algorithmizing errors;

– and$_3$ $7\wedge 8\wedge 9\rightarrow 12$ – programming errors.

«Or» logical operation $(1\wedge 2\wedge 3)\vee(4\wedge 5\wedge 6)\vee(7\wedge 8\wedge 9)=$ $=10\vee 11\vee 12$ – may lead to a failure of software. We consider this as a manifestation of a certain set of programming errors on the fault tree.

At the same time, we can consider software failure as a cause, which can lead to a number of events reflected in the probability tree.

The considered example implies that all random risk events are probabilistically independent (the order of passing of nodes on a probability tree is arbitrary), Fig. 5.

The considered probability tree gives us a possibility to form 8 scenarios with the following probabilities of their implementation:

$$P_{(1)}=P_1\cdot P_3\cdot P_7=0.34\cdot 0.29\cdot 0.78=0.077;$$

$$P_{(2)}=P_1\cdot P_3\cdot P_8=0.34\cdot 0.29\cdot 0.22=0.022;$$

$$P_{(3)}=P_1\cdot P_4\cdot P_9=0.34\cdot 0.71\cdot 0.78=0.188;$$

$$P_{(4)}=P_1\cdot P_4\cdot P_{10}=0.34\cdot 0.71\cdot 0.22=0.053;$$

$$P_{(5)}=P_2\cdot P_5\cdot P_{11}=0.66\cdot 0.29\cdot 0.78=0.149;$$

$$P_{(6)}=P_2\cdot P_5\cdot P_{12}=0.66\cdot 0.29\cdot 0.22=0.042;$$

$$P_{(7)}=P_2\cdot P_6\cdot P_{13}=0.66\cdot 0.71\cdot 0.78=0.366;$$

$$P_{(8)}=P_2\cdot P_6\cdot P_{14}=0.66\cdot 0.71\cdot 0.22=0.103.$$

$$P=\sum_{i=1}^{8}P_{(i)}=0.077+0.022+0.188+0.053+$$
$$+0.149+0.042+0.366+0.103=1.$$

Given the results obtained, we can choose the scenario with the highest probability of its occurrence (scenario 7 with $P_{(7)}=0.366$), that is, the probability of implementation of scenario 7 is 36.6 %. The scenario (2) has a minimal probability of its implementation under conditions of accepted indicators of risk events.

We convert the tree under condition of the independence of random events and cause a new redistribution of probabilistic assessments between events. This makes possible to analyze and determine probability of implementation of each of possible scenarios formed with different combinations of random risk events.

It is necessary to determine a priori probabilities of implementation of risk events and conditional probabilities of occurrence of events in case of existence of the dependence between risk events. We should use the methodology proposed in [28] for assessment of conditional probabilities based on the expert assessment procedure.

7. Discussion of results of studying the integrated application of methods of scenario prediction

There are a number of instrumental methods of scenario analysis and prediction created for now. Various tree-like graphs represent them. The objective of each of these methods is solution of a specific prediction problem and it does not take into consideration possible presence of several interrelated problems, which determine a general problem. The studied approach of integrated application of scenario prediction methods gives possibility to perform deeper analysis of systems and objects under study.

The integrated use of the fault tree method and the probability tree method is an effective tool for analysis of possible scenarios for further development of events, which are consequences of failure of a software system. Such failures are reasons for violation of functionality and security of implementation of the main functions of a software system. The scenarios built in this way give possibility to identify possible risk events caused by system failures, which can lead to catastrophic consequences with significant damage in real complex software systems. The advantage of the proposed methodology is the ability to determine probability of implementation of a scenario based on a group expert assessment. The peculiarity of the approach lies in the fact that it makes possible to process experts' assessments generated under uncertainty (for example, an expert cannot assess possibility of occurrence of a risk), as well as contradictory and inconsistent expert judgments. The use of the combination mechanism for aggregation of individual expert assessments based on the mathematical apparatus of the theory of evidences and the theory of plausible and paradoxical reasoning makes possible to achieve such advantages.

We should note limitations imposed on a number of systems of random events analyzed when constructing a probability tree as a disadvantage. There is an exponential increase in its size and, consequently, in a series of possible scenarios with an increase in a number of analyzed systems of random events, especially if a number of events in such systems are significant. It is advisable to use a probability tree if a series of random events do not exceed 4.

It is possible to use the proposed approach as an add-on to existing methods of risk analysis for software projects, where the main cause of risks are defects in hardware and software, data or computing processes.

For example, we assess possibility of implementation of an adverse event (risk) and its impact on a project in the process of qualitative risk analysis. As a result, we get a list of risks ranked by a degree of their impact on a project and a risk map. It is possible to perform the risk ranking based on «probability/consequence» matrix analysis, according to the PMBOK standard. If a group of experts of the corresponding profile determines possibility of risk implementation based on subjective probabilities, we can form the collective assessment based on the proposed procedure of aggregation of individual probabilistic expert assessments.

Another example is a common sharing of the proposed methodology for generation of a succession of negative event scenarios and analysis of sensitivity of individual risk factors to deviations of system parameters. The approach makes possible identification of risk factors, which have the greatest impact on project implementation.

It is possible to apply the offered methodology under conditions of use of modern flexible methods of software development. The development of technology management software projects led to emergence of flexible and adaptive software development methodologies. The objective of the most of them is minimization of risks by reduction of development to a certain number of short iteration cycles, each of which should end with generation of the next interim version of software. Speaking about the class of iterative software development models, we can note that it is possible to apply the proposed approach at the stage of testing of current prototype software. This application will give possibility to analyze an impact of risks of possible failures (identification of their causes and consequences) on the state of a software development process.

The possible objective for further research is development of methods for improvement of the quality of the obtained expert information and exploring the possibility of using of Bayesian networks to analyze a sequence of scenarios for development of a negative event.

8. Conclusions

1. We have proposed in this study to use the combination mechanism based on one of the rules from the theory of evidence or the theory of plausible and paradoxical reasoning for the aggregation of individual expert assessments of a possibility of the occurrence of a risk event. We determined that we could obtain more effective results of combination if we use conflict redistribution rules. The establishment of the order of combination of expert evidences gave possibility to improve the quality and accuracy of the combination results. The approach makes it possible not to ignore and not to lose expert information obtained based on non-coincident and contradictory expert evidences.

2. We investigated the possibility of integrated application of formal methods of scenario prediction, namely a fault tree and a probability tree. The proposed method of integrated application of a fault tree and a probability tree gives a possibility to analyze sequences of scenarios of manifestation of a risk event caused by accidental negative influences of possible failures of functioning of a technical, software system, or its individual elements. It enables to identify risks in advance and to predict consequences of their impact on safe operation of a system, to offer effective and timely mechanisms for their management and to improve control and monitoring of possible threats. This, in turn, gives a possibility to improve performance and quality of operation of

technical and software systems and to reduce the potential financial loss associated with implementation of a risk event.

3. We presented the examples of practical implementation of the proposed methodology for the integrated application of a fault tree and a probability tree on the example of solution of the problem of risk analysis of software projects caused by failures in functioning of software and systems. The obtained practical results are intended to identify and analyze potentially possible defects in programs and data in a timely manner at the stages of design and implementation or in case of violation of the technology of implementation of a program project. Their application gives possibility to correct prediction of occurrence of a risk event associated with possible software failures promptly in order to apply effective methods and means to reduce risks and minimize the associated effects of their negative impact on all stages of the life cycle of software systems. This, in turn, helps to increase reliability of software systems due to identification of hidden errors and defects and analysis of possible scenarios of their impact on the quality of a product.

References

1. Pereverza K. Scenario method for analysis of complex social systems // System research and information technologies. 2011. Issue 1. P. 133–143.
2. Amer M., Daim T. U., Jetter A. A review of scenario planning // Futures. 2013. Vol. 46. P. 23–40. doi: https://doi.org/10.1016/j.futures.2012.10.003
3. Bishop P., Hines A., Collins T. The current state of scenario development: an overview of techniques // Foresight. 2007. Vol. 9, Issue 1. P. 5–25. doi: https://doi.org/10.1108/14636680710727516
4. Trofimova M. S., Trofimov S. M. The review of methods and techniques of the systems analysis in relation to management quality of the enterprise // Vestnik Permskogo nacional'nogo issledovatel'skogo politekhnicheskogo universiteta. Elektrotekhnika, informacionnye tekhnologii, sistemy upravleniya. 2015. Issue 14. P. 74–85.
5. Ispol'zovanie metoda «scenariev budushchego» v strategicheskom upravlenii // Obrazovatel'niy sayt Viktorovoy T.S. URL: http://www.viktorova-ts.ru/page299/page433/index.html
6. Kovalenko I. I., Shved A. V., Melnik A. V. Probability analysis of risk-contributing factors in organizational tasks of ship repair // Shipbuilding & Marine Infrastructure. 2014. Vol. 2, Issue 2. P. 111–119.
7. Baig A. A., Ruzli R., Buang A. B. Reliability analysis using fault tree analysis: a review // International Journal of Chemical Engineering and Applications. 2013. Vol. 4, Issue 3. P. 169–173. doi: https://doi.org/10.7763/ijcea.2013.v4.287
8. Shubin R. A. Nadezhnost' tekhnicheskih sistem i tekhnogenniy risk. Tambov: FGBOU VPO TGTU, 2012. 80 p.
9. Nikitenko Yu. V. Peculiaritys applying of construction metod of refusial for estimation of accident rate by military industry // Modern problems of science and education. 2015. Issue 2. URL: http://www.science-education.ru/ru/article/view?id=21831
10. Tonitsa O. V., Yeremenko I. V. Kompiuterne modeliuvannia system analizu bezpeky tekhnolohichnykh obiektiv // Visnyk Nats. tekhn. un-tu «KhPI». Seriya: Systemnyi analiz, upravlinnia ta informatsiyni tekhnolohiyi. 2010. Issue 67. P. 45–50.
11. Kovalenko O. Quality analysis and quantitative assessment of risks methods of software development // Control, Navigation and Communication Systems. 2018. Issue 3 (49). P. 116–125. doi: https://doi.org/10.26906/sunz.2018.3.116
12. Shurigin O. V. Methodical bases of analysis of refuses are in the systems of treatment information standards of armament and military technique // Systemy ozbroiennia i viyskova tekhnika. 2009. Issue 4. P. 178–181.
13. Example of complex application of formal methods of requirements specification and dependability analysis of computer-based control systems / Tarasyuk O. M., Gorbenko A. V., Kharchenko V. S., Motora Ju. V. // Systemy obrobky informatsiyi. 2010. Issue 8 (89). P. 83–89.
14. Targoutzidis A. Incorporating human factors into a simplified «bow-tie» approach for workplace risk assessment // Safety Science. 2010. Vol. 48, Issue 2. P. 145–156. doi: https://doi.org/10.1016/j.ssci.2009.07.005
15. Jacinto C., Silva C. A semi-quantitative assessment of occupational risks using bow-tie representation // Safety Science. 2010. Vol. 48, Issue 8. P. 973–979. doi: https://doi.org/10.1016/j.ssci.2009.08.008
16. Ruijters E., Stoelinga M. Fault tree analysis: A survey of the state-of-the-art in modeling, analysis and tools // Computer Science Review. 2015. Vol. 15-16. P. 29–62. doi: https://doi.org/10.1016/j.cosrev.2015.03.001
17. Fault and Event Tree Analyses for Process Systems Risk Analysis: Uncertainty Handling Formulations / Ferdous R., Khan F., Sadiq R., Amyotte P., Veitch B. // Risk Analysis. 2011. Vol. 31, Issue 1. P. 86–107. doi: https://doi.org/10.1111/j.1539-6924.2010.01475.x
18. Svetun'kov S. G. Metody social'no-ekonomicheskogo prognozirovaniya. Vol. 1: ucheb. Sankt-Peterburg: SPbGUEF, 2009. 147 p.
19. Uzga-Rebrov O. Modern concepts and applications of probability theory. Rezekne: RA Izdevnieciba, 2004. 292 p.
20. Kovalenko I. I., Shved A. V. Metody ekspertnogo ocenivaniya scenariev: ucheb. Nikolaev: CHGU im. Petra Mogily, 2012. 156 p.
21. Shved A. Probabilistic risk analysis of investment projects under uncertainty // 2017 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS). 2017. doi: https://doi.org/10.1109/idaacs.2017.8095072
22. Smarandache F., Dezert J., Tacnet J. Fusion of sources of evidence with different importances and reliabilities // 2010 13th International Conference on Information Fusion. 2010. doi: https://doi.org/10.1109/icif.2010.5712071
23. Uzga-Rebrovs O. I. Nenoteiktibu parvaldisana. Part 3. Rezekne: RA Izdevnieciba, 2010. 560 p.
24. Kovalenko I., Shved A. Development of a technology of structuring group expert judgments under various types of uncertainty // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 3, Issue 4 (93). P. 60–68. doi: https://doi.org/10.15587/1729-4061.2018.133299

25. Shved A., Davydenko Y. The analysis of uncertainty measures with various types of evidence // 2016 IEEE First International Conference on Data Stream Mining & Processing (DSMP). 2016. doi: https://doi.org/10.1109/dsmp.2016.7583508
26. Jousselme A.-L., Maupin P. Distances in evidence theory: Comprehensive survey and generalizations // International Journal of Approximate Reasoning. 2012. Vol. 53, Issue 2. P. 118–145. doi: https://doi.org/10.1016/j.ijar.2011.07.006
27. Pavlovskaya O. O. Static methods of assessment of software // Vestnik Yuzhno-Ural'skogo gosudarstvennogo universiteta. Seriya: Komp'yuternye tekhnologii, upravlenie, radioelektronika. 2009. Issue 10. P. 35–37.
28. Orlov A. I., Savinov Yu. G., Bogdanov A. Yu. Experience of expert estimation of the conditional probabilities of a rare events during developing automated system for forecasting and prevention of aviation accidents // Izvestiya Samarskogo nauchnogo centra Rossiyskoy akademii nauk. 2012. Vol. 14, Issue 4 (2). P. 501–506.

UDC 004.822:004.89

DOI: 10.15587/1729-4061.2019.155410

DEVELOPMENT OF METHODS FOR STRUCTURAL AND LOGICAL MODEL UNIFICATION OF METAKNOWLEDGE FOR ONTOLOGIES EVOLUTION MANAGING OF INTELLIGENT SYSTEMS

I. Kotov
PhD, Associate Professor
Department of Modeling and Software**
E-mail: rioexito@gmail.com

O. Suvorov
Senior Lecturer*
E-mail: o.suvorov@i.ua

O. Serdiuk
Assistant*
E-mail: o.serdiuk@i.ua

*Department of Automation, Computer Science and Technology**
**Kryvyi Rih National University
Vitaliy Matusevych str., 11, Kryvyi Rih, Ukraine, 50027

Актуальність роботи обумовлена важливістю і необхідністю уніфікації побудови і використання інтелектуальних систем підтримки рішень для управління складними промисловими об'єктами та системами.

Метою роботи є обґрунтування єдиного підходу до управління базами знань різних конфігурацій і розробка уніфікованих математичних моделей операцій над елементами онтологій.

Запропоновано метод управління еволюцією онтологій професійних областей, заснований на уніфікації структурно-логічної моделі репрезентації метазнань.

Розроблено спосіб уніфікації структурно-логічної моделі еволюції інкорпорації онтологій. Розроблено формально-лінгвістичні моделі, доведено подібність форм репрезентації знань і еволюційне спадкування в рамках загальної інкорпорації онтологій. Для синтезу моделі інкорпорації еволюційного успадкування онтологій вирішені завдання розробки моделей еволюційного успадкування концептів, графів і онтологій рівнів БЗ. Модель забезпечує можливість для всіх рівнів БЗ єдиного підходу до інтерпретації структур взаємодії концептів.

Розроблено узагальнену модель сигнального графа рівнів структури БЗ. Модель включає в себе атомарний концепт, сигнал, потенціал вузла, активність вузла, поріг чутливості вузла до вхідного сигналу. Розроблено набір формальних моделей множини базових операцій на сигнальному графі БЗ, необхідних для інтерпретації та обчислення форм знань. Розроблено синтаксис метаправил і формально-лінгвістичний базис. Введено формалізми параметра маркування та функції маркування сигнального графа БЗ. Моделі маркування введені в загальну модель сигнального графа БЗ.

Досліджено можливості застосування розроблених моделей сигнального графа бази знань в різних професійних галузях. Показано, що запропоновані моделі метазнань не залежать від форм подання і формалізмів професійних онтологій. Це дозволяє використовувати єдиний механізм управління знаннями в будь-яких інтелектуальних системах підтримки рішень. Запропоновано спосіб ефективного динамічного управління структурою всіх рівнів БЗ і процесом логічного висновку в залежності від вхідних параметрів функціонування інтелектуальної системи

Ключові слова: інкорпорація онтологій, контекст моделі, маркування графа, метапродукція, репрезентація знань, сигнальний граф, система підтримки рішень

1. Introduction

At the present stage of development of automated control systems for large industrial facilities, aspects of management in crisis situations with a lack of time are of particular importance. These situations are usually called crisis due to the significant amount of damage that occurs in a very limited period of time. In this regard, the period of time for making