Modern Tools for Expert Evaluation of the Quality of Innovative Software Projects

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Abstract

In the modern economy, the implementation of innovative software projects for planning and managing the productive activities is an important factor in ensuring the stable development of enterprises. In this paper, we suggest treating the economic essence of such software projects as soft goods used in the productive activities of enterprises and analyze the modern models for expert assessment of their quality. The main tasks of the present study are: to perform a comparative analysis of existing models; to determine the scope of quality indicators and their main characteristics; and to provide a rationale for choosing a mathematical apparatus to obtain the target values of integral indicator for the expert quality assessment of innovative software projects. The basic methodology of the study is the system-oriented analysis; we have also used the theory of expert estimates and the theory of probability in terms of estimating the random variables, analysis of hierarchies, as well as the methodology of fuzzy sets. In addition, the combinatorial coefficients, binomial and normal distribution tools, and Bernoulli mathematical testing apparatus were used to obtain the results.

The paper contributes to the literature by suggesting the composition of indicators for the assessment of the quality the innovative software projects. A developed hierarchical network of indicators makes it possible to determine the target values of integrated quality indicator for the innovative software projects. For practical applications of this methodology for the formation of a hierarchical network of indicators' properties, it is advisable to use different models simultaneously and create an individual expert system of indicators, their properties, characteristics and sub-characteristics applicable to each specific innovative software project.

Keywords: *quality assessment; software project; expert models; innovations; mathematical apparatus.*

1. Introduction

The rapid development of the knowledge economy and the increase of management information predetermined the need for accelerated development and implementation of innovative software projects (ISPs) in almost all spheres of society. Today, the ISPs take a leading place in the management systems of many organizations and enterprises, as they allow them to gain serious competitive advantages and strengthen their position in the markets. At the same time, the desire to accelerate the development, purchase, and implementation of various ISPs in production without their adaptation to the enterprises' activities often lead to deterioration in the results that were before the application. Statistics show that only 10% of new ISPs completely satisfy customers (Huijgens et al., 2017). This circumstance can be explained by many reasons, one of which is the inconsistency of the software used for the purposes of development and the tasks of the practical application of ISPs (Isaev, 2006; Dittrich, 2014; Sudhaman & Thangavel, 2015; Lamandi et al., 2015).

The complexity of the ISP development process is largely predetermined by the specific requirements imposed on their quality. Many of them are caused by the need for timely processing of constantly growing management information. This circumstance increases the importance of using formalized methods for determining the quality of ISP development, for which in most cases expert assessment methods are used (Féris et al., 2017).

Until recently, there were practically no unified approaches, methodologies for assessing and the composition of the requirements for the quality of ISP development. In many ways, the responsibility for the quality of their development fell on the team of programmers (Hoegl et al., 2003; Licorish & MacDonell, 2018) and the customer (Madzík & Chocholáková, 2016; Huijgens et al., 2017), at best, was limited to a narrow set of requirements specified in the terms of reference. Therefore, the greatest problem in the expert evaluation of the quality of ISP development was the absence of a clear formulation of requirements that determine the qualitative characteristics of these products and the rationale for choosing a mathematical apparatus to determine their quantitative values (Maranhão et al., 2015).

At the same time, nowadays the practice of ISPs application for planning and managing the productive activities of organizations and enterprises in many sectors of the economy and various forms of ownership is constantly expanding. The quality of ISPs development acts a decisive role in the successful resolution of these strategically important issues for the further development of organizations and enterprises. To assess it, according to (Larin & Zhilyakova, 2015; Larin & Zhilyakova, 2017) one needs to determine the composition of quality indicators; perform their decomposition by properties and characteristics; formulate clear requirements for determining their quantitative values; and also justify the methods and choose the mathematical tools that will be used by experts in the ISPs quality assessment.

2. Materials and Methods

2.1. The concept of "Quality" regarding innovative software projects

We come across with the concept of "quality" all the time. Its perception depends more on the awareness of the object, which is subject to the qualitative assessment. Relation to the quality in time cannot be constant because the changes in the information entropy are always happened about the estimated object and associated with the emergence of new information or with the loss of relevance of already existing information (Madzík & Chocholáková, 2016). In this sense, we can speak of quality as a predetermined quantitative expectation for the evaluation of object's characteristics under different conditions. At the same time, the concept of quality cannot be reduced to the individual characteristics of the object under study, since it is inseparable from the object itself and covers it as a whole.

Turning to the economic interpretation of the concept of quality regard to the ISPs, one should speak of the existence of a large number of its definitions, which are based on the aggregation of different qualitative characteristics of certain elements, which are subsequently used to assess its consistency with the initial requirements. Thus, the International Organization for Standardization (ISO) defines "quality" as the completeness of properties and characteristics of a product, a process or a service that provides the possibility to meet stated or perceived needs. At the same time, each property can be correlated only with one or several characteristics of the ISP, which are the manifested and measurable attributes of a given property. In turn, the said characteristics can be evaluated by both a single indicator and the integrated quality indicators. A single quality indicator usually refers only to one of the ISPs' properties. While the integrated quality indicator of ISPs always refers to its several properties. Accordingly, a quantitative assessment of those characteristics will allow determining a degree of availability of a specific property in the ISPs, as well as the level of its quality (Larin et al., 2017).

For the modern ISPs, three types of specifications are usually developed. They contain the requirements for their functional properties, quality and resource characteristics (Gorbachenko, 2013). Thus, the ISP quality is a generalization of its functional characteristics and performance indicators, which are used by experts to assess its ability to meet the requirements specified by the specifications. At the same time, all the quality characteristics can be divided into two different groups: functional and design characteristics.

The most interesting are the functional characteristics that determine the purpose, qualitative properties and composition of tasks solved by their users using the ISPs. The specificity of these characteristics is difficult to unify, since they are very diverse, and their division into categories is possible only at a large number of qualitative properties. Ensuring the availability of a set of such characteristics is the main purpose of creating the ISP, and it also allows determining its integral quality index.

2.2. Models of the expert assessment of the quality of innovative software projects and their characteristics

A set of characteristics and their qualitative properties actually create a basis, both for determining the compliance of requirements for the quality indicators specified in the specifications with their actual values, and for evaluating the software, which is usually defined in the quality models. In a number of works (Fitzpatrick, 1996; Seffah & Padda, 2006) there is an evidence that the quality models are used to structure and decompose the said sets of properties into a number of additional characteristics/sub-characteristics required to evaluate the ISPs achievement level regard to the specified purposes of its functioning.

All the quality models can be divided into three types, according to the methods on which they were created. The first type includes the theoretical models based on the hypothesis of relations between the variable quality characteristics. The second type includes the "data management" models based on the statistical analysis. And, finally, the third type includes the combined models, in which the researcher's intuition is used to select the right models, and analysis of their qualitative properties is used to determine the quality characteristics of the model.

The first model for the software quality assessment was proposed in the works of McCall (McCall et al., 1977). To assess the software quality, the McCall's model takes three main characteristics:

- application, the metrics for which are correctness, reliability, efficiency, integrity, and practicality;
- modification, the metrics for which are testability, flexibility, and also maintainability;
- portability, the metrics for which are mobility, reusability, interoperability.

The second fundamental model for the software quality assessment is the Boehm model (Boehm et al., 1978). This model allows to more accurately determining the quality of basic software characteristics given by a set of indicators and metrics. The Boehm's model also refers to the hierarchical quality models, where the indicators structuring is performed by first high-level, then intermediate and, finally, individual characteristics, one of which contributes the formation of software quality assessment. At the same time, the Boehm's model does not lack the drawbacks inherent in many modern models that assess the software quality automatically and, therefore, not always accurately.

By analogy with the models of McCall and B. Boehm for evaluating the software quality, R.B. Grady and D.L. Caswell suggested using the FURPS model (Grady & Caswell, 1987). It differs from previous models in the presence of two levels of quality indicators. At the same time, only the main qualitative characteristics of the indicators are determined at the first level, and on the second level all the attributes associated with them are determined. The modern modification of this model is the FURPS + model. The FURPS/FURPS + model is named after the first letters of main categories for the software quality indicators: Functionality; Usability; Reliability; Performance; Supportability;

Symbol "+" – this symbol provides expansion of the FURPS model.

The conceptual basis of the FURPS / FURPS + quality model is the decomposition of the software characteristics into two categories, namely functional (F) and non-functional (URPS). Currently, the feasibility of using the FURPS + model in software development and in identifying the requirements for developing ISPs is determined by a fairly complete and most universal list of characteristics for assessing the quality of software used in ISPs developing.

The model by K. Gezzi and his co-authors uses different approaches to determine the software quality in the composition of ISP during its operation (Ghezzi et al., 2002). According to this model, software quality is determined by the following indicators: integrity, reliability, stability, performance, practicality, verifiability, efficiency, maintainability, mobility, understandability, reusability, user interaction and timely response to its actions.

The basis of the quality model by J. Dromy (Dromey, 1995) represents a set of criteria for assessing the quality characteristics and their sub-characteristics. The main purpose of this model is to assess the quality of ISP as an information system, taking into account the fact that the quality assessment of each ISP due to known reasons will differ from the quality assessments of other ISPs. This model obtaining the quality assessments of certain properties and characteristics of both software and its components, and the ISP as a whole.

The model of SATC (Software Assurance Technology Center) metrics developed at the NASA Quality Assurance Center is of great interest for the quality assessment of software. The fundamental difference between this model and all those considered earlier is that initially the quality assessments are determined for each component of the ISP separately. That is, first we assess the quality of requirements development for the specifications, software and its components, documentation for the information project, its components testing, and functional operations performance. Then, based on the received estimations, the integral quality index is forming for the developed ISP. For this purpose, in the SATC quality model, a set of purposes is formed. Such purposes are associated with the ISP and the attributes of functional operations in accordance with the structure of software quality model, which is developed under ISO 9126. The ISO 9126 quality model defines the software quality as a certain set of its characteristics that ensure the solution of a different set of production tasks by persons, who make the managerial decisions.

The ISO 9126 quality model introduces the following shading of “software quality”: internal quality; external quality; quality on the view of specific users; quality of the technological development processes. The quality assessment of all the above characteristics is performed under the introduction of special metrics, which make it possible to obtain their target values.

A hierarchical model for the quality assessment of the object-oriented design of information projects (QMOOD – Quality Model for Object-Oriented Design) was proposed by J. Bansia and C. Davis (Bansiya & Davis, 2002). This model significantly expands the methodology of quality assessment used in the model by J. Droomey. The QMOOD model presents a slightly different approach to assessing the quality of developed ISPs, which is based on a number of new object-oriented metrics introduced to measure it.

L. Bass, P. Clements, and R. Kazman presented a model for assessing the ISP quality, which was based on two different approaches to select indicators for assessing its quality, taking into account the duration of the entire lifecycle of the software used therein (Bass et al., 2003). At the same time, the authors of this model identified two groups of the main quality characteristics, namely:

1) efficiency, security, availability, and functionality;
2) modifiability, mobility, returnability, heritability, and testability.

K. Khosravi and others proposed a model of software quality assessment, which was based on the multiple uses of one of the global quality characteristics (Khosravi &. Gueheneuc, 2005). Depending on the assessment purpose, it allows for reuse of global and other main quality characteristics, such as intelligibility, flexibility, modularity, reliability, scalability, and ease of use. The quality assessment in K. Khosravi's model consists of the sequential solution of two tasks: 1) selection of a global characteristic; 2) selection of sub-characteristics associated with the global characteristic.

K. Chang and others proposed an approach for assessing the software quality based on the method of fuzzy sets and the method of analyzing hierarchies (Chang et al., 2008). In the same period, A. Sharma and others (Sharma et al., 2008) proposed a component-based model for the software quality assessment, which includes not only all the characteristics/sub-characteristics of ISO 9126 quality assessment model, but also proposes a number of new sub-characteristics, such as: reusability, flexibility, complexity, and scalability. To assess the ISPs quality using this model, it is suggested to use the well-known method of hierarchy analysis.

Begier B. in his paper (Begier, 2011) showed that problems with uncertainty relate to various aspects of the development of knowledge. An open list of indeterminate elements in the development of the ISP was provided, as well as their sources were listed. Periodic assessment of ISP quality by its users can reduce uncertainty. Therefore, to ensure the quality of ISP during its evolutionary development, the participation of users is certainly required. Users provide regular feedback to the ISP. The experience of ISP development was described based on the users' quality assessment.

The work of Kim-Hung Lotto Lai (Lai, 2017) is oriented on the implementation of a systematic approach model called "QStarMS", which integrated the Business Side by using Business Model Generation / Canvas (BMG / C) and Management Side in accordance with the ISO 9001:2015 Quality Management System. Moreover, this model has simplified the compliance of ISP development with certain requirements and limitations.

Rehacek P. presented the essence and usefulness of quality management systems (QMSs) involved in the management of the company, which should lead to liquidity supply, production growth and costs optimization, as well as ensuring a stable position in the competitive market (Rehacek, 2017). Quality costs, such as improving the quality and effectiveness of management, are important tools for assessing ISP quality. The article shows the essence of quality expenditures, calculation and analysis of costs, and also the conditions for their usefulness in decision-making. The author also disclosed the importance of accounting costs for ISP quality and these costs in terms of the company's practical experience. It was stressed that the QMS efficiency assessment at the enterprise is carried out on basis of the ideas implementation analysis contained in the quality policy and at the expense of the ISPs registration and analysis.

ISP quality management system standards are used by many organizations around the world. Many companies implement more than one management system standard. These include organizations that work in at least two directions on the basis of ISO and analyze approaches to the implementation of the quality system for the development of ISP. The authors of the work (Kopia et. al., 2016) are paying special attention to the integration aspect in the context of the high-level structures of the ISO quality management system standards. Results show that most companies with more than one ISP quality management system are trying to integrate them into one ISP quality management system using the SL Application. Proceeding from this, the authors of this work offer a number of specific improvements to Appendix SL.

In 2011 analog of ISO 9126 in Russia, it is GOST R ISO/IEC 25010-2015 (GOST R ISO/MEK, 2015). This standard defines two quality models:

- a model of quality in use, including five characteristics related to the results of product interactions, when its applied in a given context of use; this model is applicable to the complete human-computer systems, including both the used ISP and software;
- information project quality model, including eight characteristics related to the software static properties and the ISP dynamic properties; this model is applicable to both the ISP and software.

Quality in use characterizes the impact that an information product (system or program) has on the rights holders. It is determined by the quality of software, hardware, and operating environments, as well as the competence characteristics of tasks users.

The information project quality model divides the quality properties of ISP into eight characteristics: functional compliance, operational efficiency, compatibility, practicality, reliability, security, maintainability, and mobility. The differences of this model from the model of internal and external quality determined by ISO 9126 are highlighted further in the text in italics.

Thus, the process of quality assessing of ISP software content is inextricably linked with the definition of values of properties and characteristics of specific indicators and their functional attributes that can be measured and which specific users are interested in. Taking into account the variety of users' interests, an expert evaluation of the ISP quality used for planning and managing the productive activities of enterprises and organizations seems to be quite a challenge. As practice shows, it is impossible to use only one universal quality indicator to solve it. Therefore, it is necessary to form a certain set of quality indicators, the variable properties and characteristics, which cover the entire set of requirements for the quality of functioning of modern information systems and ISPs in the productive activities of enterprises and organizations.

2.3. Toolkit for measuring the quality indicators of innovative software projects

Even a brief description of the nature of ISPs characteristics/sub-characteristics allows for a free abstraction on a wide range of issues of assessing its quality. This is important in two complementary ways. First, by deciding on the qualitative characteristics that are more important for the ISP successful operation, it becomes easier to focus on a variety of issues related to solving real problems. Second, since this categorization is complex, it reduces the risk of incorrect solution of a number of important issues due to their mutual dependence. In general, ISO/IEC 25010:2011 and its Russian analog GOST R ISO/IEC 25010-2015 describe a high-level detail model for assessing the quality of ISPs and the software used in it, by using more characteristics/sub-characteristics of quality indicators. In this case, each characteristic/sub-characteristic describes the quality degree of any indicator in such detail that it makes it possible to obtain a quantitative estimate of a particular characteristic. This approach greatly facilitates the evaluation of the ISP quality, and the characteristics sufficiently cover its qualitative description, making it possible to assess the ISP quality and the software of any complexity used in it.

The process of assessing the quality of ISP and the software used in it is inextricably linked to the definition of measurable parameters in which the user is interested. Modern methods of quality assessment have a wide range of measuring instruments, among which one can distinguish applied statistical analysis of data, methods of expert assessments, as well as more sophisticated methods of data extraction, such as neural networks, machine learning methods, etc.

The most characteristic features of the mathematical apparatus used for these purposes are the following:

1) measurement tasks are based on the needs of the subject area, and not on the actual mathematics;
2) various assumptions are inherent in the measurement, which may differ from the rigorous apparatus of mathematical statistics;
3) considerable attention is paid to data collection for analysis and their processing in order to detect violations of formats, abnormal values, omissions, etc.

The need to produce objective measurements and obtain quantitative estimates of various characteristics of the ISP quality and the software used in it requires the application of a certain measurement system and evaluation methods. The system of measuring the ISP quality characteristics and the software used in it is a set of characteristics that can be measured by various measuring scales, the units of measurement characteristic and certain relationships between them. The measuring scales used to determine the range of values of the measured characteristics with the specified accuracy and in established units.

The modern range of methods and tools for measuring the values of specific indicators and attributes characteristics and their functional properties with subsequent evaluation of the quality of both ISP as a whole and its individual components (modules) is quite wide. Most often, for this purpose method of applied statistical data analysis, expert assessments are used, as well as more sophisticated methods of data mining, such as neural networks, hierarchy analysis method and a number of others. Since the main purpose of our study is to determine the calculated values of the integral indicator in the framework of expert systems for assessing the quality of modern ISP, it seems appropriate to move on to a more detailed justification for its achievement.

3. Results

The great interest to determine the possibility of using the theoretical provisions and practical tools of the hierarchy analysis method for developing expert systems for assessing the quality of ISP by decomposing the properties and characteristics of a certain set of indicators into an integrated indicator of the quality of ISP. The unification of a disparate set of indicators into a hierarchical structure with the top that determines the ISP quality with its further adaptation to specific implementation and conditions of the subject area of entrepreneurial activity is carried out through the formation of a hierarchical network of indicators of expert quality assessment. Synthesis of the network of indicators is made by obtaining a generalized expert opinion on the system of relations of properties $\{c_i\}$ assessing the quality of ISP, determining the hierarchical structure and its adaptation to specific evaluation conditions. In this case, the initial data matrix is the preference matrix $\|\alpha_{ij}^k\|$, $i, j, k \in N$, which is a simple matrix, with the following elements: $\alpha_{ij} \in \{0,1\}$, $i,j = \overline{1,\rho}$, (1)

where: ρ – the overall number of properties or ISP quality indicators that are taken into account in the evaluation, based on the following rule:

$$\alpha_{ij} = \begin{cases} 1, \text{ if } i \text{ indicator is more important than } j \text{ indicator;} \\ 0, \text{ if } j \text{ indicator is more important than } i \text{ indicator;} \\ 0.5, \text{ if both indicators of equal importance.} \end{cases}$$

Features for the matrix $\|\alpha_{ij}\|$:

$$a_{ii} = a_{jj} = 0 \quad (2)$$

A variety of matrix $\|\alpha_{ij}^k\|$ from k experts gives a possibility to estimate an intermediate matrix $\|z_{ij}\|$ using the equation:

$$z_{ij} = \sum_{k=1}^{K} \alpha_{ij}^k, \quad (3)$$

that is an evaluation of indicators by a group of experts.

Transformation of the intermediate matrix $\|z_{ij}\|$ into the matrix of strict order $\|d_{ij}\|$, where

$$d_{ij} = \begin{cases} 1, \text{ if } Ci \succ Cj \\ 0, \text{ or} \end{cases} \quad (4)$$

and $\succ$ means the relation of dominance, on the basis of the matrix $\|z_{ij}\|$ there is a process of verifying the probabilistic output. In the strict ordering language, the problem of verifying a probabilistic deduction consists in identifying the matrix $\|d_{ij}\|$ by analyzing $\|z_{ij}\|$ with the aim of partially strictly sequencing the properties or quality indicators of the ISP $\{C\rho\}$. The definition of such an order is to obtain the structure of the network G of the quality properties of ISP.

From the standpoint of the probability theory in the process of $\|z_{ij}\|$ formation, one can use the mathematical apparatus of Bernoulli's tests (Kremer, 2004), since it describes well the set of repeated independent tests. Assume the assumption of equal probability for the results of each test, which is reflected by the equation:

$$q = q_{ij} = q_{ji}\ , \quad (5)$$

where: q_{ij} is the probability that the order relation between the i and j properties of the indicators exists and $c_i \succ c_j$; q_{ji} is the probability that the order relation between the i and j properties of the indicators exists and $c_i \prec c_j$; q is the probability that the ratio of order between the i and j properties is absent. Therefore:

$$(q_{ij} + q_{ji} + q = 1) \Rightarrow q_{ij} = q_{ji} = q = 1/3 \quad (6)$$

In our case, the number of tests will be determined by the number of experts k that participate in the ISP quality assessment. Each element of the intermediate matrix $\|z_{ij}\|$ is, in fact, a random variable whose distribution agrees with the binomial law:

$$F(r, k, q_{ij}) = \binom{K}{r} q_{ij}^{r} (q_{ij} + q)^{k-r}, \quad (7)$$

where: $\binom{K}{r}$ – combinatorial coefficient, which corresponds to the number of combinations of k to r.

$$F(r,k,q_{ij}) = P(z_{ij} = r) \quad (8)$$

As is known, the binomial distribution $F(r,k,q_{ij})$ obtained in the limiting case can be approximated by the Poisson law (Popov & Sotnikov, 2011). Using the Poisson approximation, the binomial distribution $F(r,k,q_{ij})$ will take the following form:

$$F(r,K,q_{ij}) \approx (\mu \frac{K}{r!}) \exp(-\mu), \quad (9)$$

where $\mu = Kq_{ij}$ (10)

At the same time, for the continuous case, the Poisson distribution (9) can be generalized using the normal distribution law (Klimov, 2011), using the following equation:

$$F^{*}(r,K,q_{ij}) \approx \left(\frac{1}{\sqrt{2\pi}}\right) \int_{-\infty}^{K} \exp\left(\frac{-r^{2}}{2}\right) dr \quad (11)$$

with density

$$F(r,K,q_{ij}) \approx \left(\frac{1}{\sqrt{2\pi}}\right) \exp\left(\frac{r^{2}}{2}\right) \quad (12)$$

After generalizing the binomial distribution $F(r,K,q_{ij})$ by means of the normal law, it becomes possible to apply the standard probabilistic verification approach for the results of tests obtained using the mathematical apparatus of Bernoulli (Kremer, 2004). The essence of the standard verification apparatus is to determine the boundary value of the number of S_k, experts who favor the establishment of the order $c_i \succ c_j$ from the total number of experts k, which will, with the risk of α, define this order as the corresponding ratio. Therefore, for m expert assessments:

$$S_k \geq m^{-1}\left[K + t_\alpha \sqrt{K(m-1)}\right] \text{ for } \left(q_{ij} = \frac{1}{m}\right), \quad (13)$$

where: t_α – quantile of the normal distribution, obtained by the ratio;

$$\alpha = 1 - F^{*}(t_\alpha) \quad (14)$$

Usually, value $\alpha \in (0{,}1;\ 0{,}2)$. And it means $\alpha = 0{,}1$.

Assuming that the number of experts' estimates is $m = 3$, then equation (13) will have the following form:

$$S_k \geq \frac{1}{3}\left(K + t_\alpha \sqrt{2K}\right) \quad (15)$$

Consequently, the relation for transforming the intermediate matrix $\|z_{ij}\|$ into a strict order matrix $\|d_{ij}\|$ can be represented as follows:

$$d_{ij} = \begin{cases} 1, \text{ with } S_k \leq Z_{ij} \\ 0, \text{ with } S_k > Z_{ij} \end{cases} \quad (16)$$

The strict order matrix $\|d_{ij}\|$ describes the structure of the network G of the ISP quality assessment:

$$G = \langle C, U \rangle, \quad (17)$$

where: C is a set of values corresponding to the properties of the indicators used in assessing the ISP quality $\{C_\rho\}$; U is the set of arcs corresponding to the order of $\|d_{ij}\|$ relations.

On a set of arcs, it is necessary to remove transitive closing arcs. An arc $(c_i c_k)$ is determined as transitively closed if the following condition is met:

$$\forall c_i, c_j, c_k \in C\left(\left(c_i \prec c_j\right) \wp \left(c_j \prec c_k\right) \wp \left(c_i \prec c_k\right)\right) \quad (18)$$

After performing the transformations described above, we get a hierarchical network of $G+$ properties of indicators for ISP quality assessing which can be represented in the following form:

$$G+ = \langle C, U+ \rangle, \quad (19)$$

where: $U+$ ($U+ \in U$) is a set of arcs that do not correspond to the expression (18).

Due to the possible presence of C_i, quality indicators that are decomposed into ξ and more other (where ξ = (5±2) is the maximum number of alternatives that the expert can analyze in one act), the network of $G+$ indicators of the ISP quality assessment may not be suitable for determining the weighting coefficients of the quality indicators. To determine the indicated weight coefficients of the quality indicators C_i in such cases, it is necessary to adapt the $G+$ network to the working conditions of each expert. Such adaptation is made through the inclusion of a number of imaginary vertices in the decomposition of the composite or integral index c_i (c_i', c_i''...) with the separation of the c_i exponent on the graph $G+$, for the clustering of the lower vertices by the number less than ξ.

As a result of adaptation, a clustering of ISP quality indicators is formed, which usually is carried out according to various characteristics, but all the signs are based on the "proximity" between the properties of a more complex indicator $\{c_i\}$ occupied in one decomposition in a certain metric space. Therefore, we need to define a metric to characterize the level of proximity between two properties ci and cj in the space of the analyzed decomposition of the complex exponent $\{c_i\}$, and then determine the value of the distance at which any two properties of one index can be assumed to be close.

Moreover, if there is a function of the distance between the ISP quality indicators c_i and c_j in the metric space of rationalizing the properties of these indicators, then it must meet the following set of conditions:

1) $\bar{\rho}(c_i, c_j) \geq \bar{\rho}(c_i, c_i)$, (20)
2) $\bar{\rho}(c_i, c_j) = \bar{\rho}(c_j, c_i)$; (21)
3) space is always metric:

$$\bar{\rho}(c_i, c_j) \leq \bar{\rho}(c_i, c_l) + \bar{\rho}(c_l, c_j). \quad (22)$$

4. Discussions

With respect to a particular version of the ISP under consideration, it is necessary to determine the type of metric as an expression of proximity measure in the space of properties of quality indicators. The most popular metric, in this case, is the Euclidean distance, which is traditionally used for the purposes indicated above. The following equation is used to express the Euclidean distance:

$$\bar{\rho}_\alpha(c_i, c_j) = \sqrt{\sum_{k=1}^{p}\left(c_i^{(k)} - c_j^{(k)}\right)^2} \qquad (23)$$

If it is necessary to assess the importance of properties of quality indicators, an equation can be used to determine the weighted value of the Euclidean distance:

$$\bar{\rho}_\beta(c_i, c_j) = \sqrt{\sum_{k=1}^{p}\omega_k\left(c_i^{(k)} - c_j^{(k)}\right)^2}, \qquad (24)$$

where ω_k is the weight κ indicator.

In addition to using the Euclidean distance, other types of metrics can also be used, for example, such as the Hamming distance or the Mahalanobis distance [25]. To determine them, the following equations shall apply accordingly:

$$\bar{\rho}_\chi(c_i, c_j) = \sum_{k=1}^{p}\left|c_i^{(k)} - c_j^{(k)}\right| \qquad (25)$$

$$\bar{\rho}_m(c_i, c_j) = \sqrt{(c_i - c_j)\sum_{k=1}^{p}\left(c_i^{(k)} - c_j^{(k)}\right)^T} \qquad (26)$$

Thus, the clustering of properties of ISP quality indicators is an iterative multi-stage algorithm for combining the properties of c_i quality indicators into clusters (groups) according to their proximity level as per the grouping index. In the first step of the grouping process, each c_{ij} quality indicator represents a cluster of certain properties. At each step of the practical implementation of the algorithm, the two nearest clusters are combined into one larger cluster. So, for (ξ^ -1) steps it is possible to form a cluster combining the properties of all the c_{ij} quality indicators (where ξ^ is the number of vertices in the decomposition). In the next step, the most appropriate structure for the cluster formation is selected from the dendrograms of the U^+_{ij} + bond clusters (corresponding to the relations of the c_{ij} quality indicators properties) in accordance with the rationality requirement. With that, the most rational structure is considered to be the structure in which the ξ^ < ξ, the relation is true for all decompositions, provided that the number of imaginary vertices introduced has the smallest value. At the same time, the value of the validity of the order E ratio determined by the following equation, can be considered as a sign of grouping for ISP quality indicators:

$$E_{U^+_{ij}} = \frac{z_{ij}}{z_{ji}\left(K - \left(z_{ij} + z_{ji}\right)\right)} \qquad (27)$$

where: z_{ij} is number of experiments standing for U^+_{ij} bonds presence;

z_{ij} is number of experts standing for U^+_{ij} bond absence;

K-(z_{ij} + z_{ji}) is a number of experts who did stand for the absence/presence of U^+_{ij} bond.

As a rule, the distances between clusters in terms of the E exponent are determined on one dimensional linear space by the equation:

$$\bar{\rho}\left(E_{U_l}, E_{U_e}\right) = \left|E_{U_l} - E_{U_e}\right| \qquad (28)$$

When performing calculations, the commonly known equation of a step-by-step grouping is usually used:

$$\bar{\rho}\left(E_{(U_eU_l)}, E_{Um}\right) = \alpha\bar{\rho}\left(E_{U_m}, E_{U_e}\right) + \beta\bar{\rho}\left(E_{U_m}, E_{U_l}\right) - \\ -\gamma\bar{\rho}\left(E_{U_e}, E_{U_l}\right) + \delta\left|\bar{\rho}\left(E_{U_m}, E_{U_e}\right) - \bar{\rho}\left(E_{U_m}, E_{U_l}\right)\right|$$

with that

$$\bar{\rho}\left(E_{(U_eU_l)}, E_{Um}\right) = \min m \qquad (29)$$

where $\alpha, \beta, \gamma, \delta$ are the coefficients the values of which determine the algorithm of incremental connection of properties of clusters quality indicators.

For standard algorithms, the values of the coefficients $\alpha, \beta, \gamma, \delta$ are tabulated values. Specific values of these coefficients allow for setting different priorities in the sequence of merging smaller clusters into a larger cluster. In the absence of a specific priority, it is usually assumed:

$$\alpha = \beta = 0{,}5 \qquad (30)$$

K (30) refers to the above algorithm for clustering the properties of the quality indices C_{ij} for $E^+_{U_{ij}}$ in the absence of the expressed priority of joining new clusters to a cluster on a linear line with a linear metric (28).

The coefficient γ determines the degree of properties homogeneity of the quality indicators in the cluster. Practice shows that it is possible to achieve stable homogeneity if one accepts:

$$\gamma = -0{,}5. \qquad (31)$$

The value of δ defines the image, which takes into account the initial cluster on the one-dimensional linear space (28). It seems advisable to take into account the unified cluster as a whole. In this case, the value δ = 0,5 shall be used.

Thus, the previously cited equation for step-by-step clustering of the vertices of decompositions of the ISP quality assessment complex indicators (29) takes the following form:

$$\bar{\rho}\left(E_{(U_eU_l)}, E_{U_m}\right) = 0{,}5\bar{\rho}\left(E_{U_m}, E_{U_e}\right) + 0{,}5\bar{\rho}\left(E_{U_m}, E_{U_l}\right) - \\ -0{,}5\bar{\rho}\left(E_{U_e}, E_{U_l}\right) + 0{,}5\left|\bar{\rho}\left(E_{U_m}, E_{U_e}\right) - \bar{\rho}\left(E_{U_m}, E_{U_l}\right)\right| \qquad (32)$$

5. Conclusion

This article provides a brief overview and comparative analysis of the main quality models used for software evaluation. Its results allow us to identify the objective necessity to use the various sets of characteristics/sub-characteristics of software properties used for the functioning of specific ISPs to assess the ISP quality. In order to obtain a comprehensive evaluation of the ISP quality, it is advisable to use different models simultaneously. To obtain a comprehensive assessment of the quality of a specific ISP, an individual expert system of indicators, characteristics/sub-characteristics of its qualitative properties, and metrics for their measurement should be formed.

Based on the results obtained during the study, it is possible to draw the following conclusions:

1) competent use of the innovative developments and modern ISPs allows many organizations and enterprises to get serious competitive advantages and also to occupy a leading position in international markets;

2) the ISP quality development acts the important role in the successful resolution of the said strategically important issues;

3) the main issue of assessing the ISP quality is the selection and justification of methods and mathematical tools used by experts to determine and decompose the properties and characteristics of qualitative indicators;

4) to a large extent the ISPs quality depends on their purpose, functional properties and characteristics, which serve as the basis for the expert evaluation;

5) to determine the integral quality index of ISP, a methodology has been developed for the formation of hierarchical, systematized and ordered network, in which the procedure for decomposition of properties for the quality assessment indicators is implemented;

6) by constructing a hierarchical, systematized and ordered network, it is possible to determine the target value of integrated ISP quality indicator;

7) the content of properties for the ISP quality assessment

indicators in a hierarchical network will depend on the specific needs of users.

Approach for the formation of multi-criteria expert system is justified, including a set of particular indicators, their characteristics, weights, and metrics for computing, with which it is possible to obtain a rather close to reality evaluation of the efficiency and ISP quality and the software used in it at all stages of their operation.

Naturally, the proposed system is not a finally accepted toolkit for assessing the quality of ISP and software used therein. It is obvious that with the appearance of more advanced versions of both the ISPs and software used therein, the composition of partial indicators, their characteristics, weights and metrics for assessment will change in accordance with the users' requirements for functionality of new ISP's versions. Moreover, to obtain the sound assessments of quality for the particular ISP and software used therein, it seems more appropriate to formulate a multicriteria expert system, consisting of a number of particular indicators, their characteristics, weights and metrics for the calculation regarding this ISP and basic requirements stipulated for its functioning.

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