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APPLICATION OF FUZZY MODELS FOR ANALYSIS AND EVALUATION OF QUALITY OF SOFTWARE FOR SPACE PURPOSES

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ABSTRACT

This article presents a method for quantifying software quality attributes using fuzzy set theory methods. The purpose of this work is a substantiation of possible approaches and the feasibility of using fuzzy models for assessing the quality of software for space purposes (Software for Space Purposes). The paper substantiates the feasibility of using fuzzy models for evaluation of the quality of Software for Space Purposes. An approach and a method for the integrated assessment of the quality of the Software for Space Purposes are proposed, which differs from the known ones in the use of fuzzy models for assessing the quality attributes. The novelty of our work lies in the application of fuzzy modeling methods to a new class of problems - the evaluation of the quality of Software for Space Purposes, described by a special hierarchical attributive model, taking into account their features, high requirements for reliability and safety. It is shown that the use of fuzzy models makes it possible to carry out an integral assessment of the quality of PSCN taking into account fuzzy quantitative and qualitative indicators of quality. The paper uses the basic provisions and methods of fuzzy set theory, graph theory, utility theory, numerical methods.

Keywords: *Evaluation Of The Quality Of Software For Space Purposes, Using Fuzzy Models, Integral Fuzzy Quantitative Indicator Of Quality*

1. INTRODUCTION

Throughout the entire life cycle of of software for space purposes (Software for Space Purposes), a number of quite complex problems arise in assessment and assurance of the set quality, which have not been fully reflected in modern research. As known, Software for Space Purposes belong to the category of critical software, to which high demands are placed on their quality and safety. The analysis of the features and the justification of the requirements for the quality of the Software for Space Purposes are considered in [1].

Known approaches to substantiating alternatives in the decision-making process for the selection and analysis of software quality characteristics use, as a rule, deterministic or probabilistic models [2,3]. At the same time, these tasks are characterized by uncertainty associated with random processes in the software life cycle, limited experimental data, lack of complete confidence in the distribution laws of input or output random variables, the significance of individual quality characteristics and the values of their indicators.

Standard characteristics and quality indicators of software products [4] do not fully reflect the features and requirements for Software for Space Purposes. The analysis of the Software for Space Purposes quality characteristics requires further development and generalization.

The above arguments determine the relevance of the development of the methodology and methods for constructing comprehensive models for analyzing and evaluation the quality of the Software for Space Purposes in conditions of significant uncertainty, taking into account the requirements for them and features, as well as quantitative and qualitative indicators.

The theoretical, methodological principles, quality models and standards that have been developed to date do not fully reflect the problems of analysis and evaluation of quality of Software for Space Purposes. The software quality characteristic established in the standards do not fully take into account the specifics of Software for Space Purposes; there is no unified methodological approach to assessing the integral indicator of software quality that takes into account the uncertainties inherent in this task.

The purpose of this article is to substantiate the expediency of applying the theory of fuzzy sets to assess the quality of Software for Space Purposes and the use of fuzzy models to assess the integral quality indicator.

2. THE EXPEDIENCY OF USING FUZZY MODELS IN THE ANALYSIS OF SOFTWARE FOR SPACE PURPOSES QUALITY

The widely known and applied in practice approach to assessing the quality of software based on standardized quality characteristics [4] does not take into account how useful one or another characteristic of a software is for a particular application. At the same time, in the process of developing and using Software for Space Purposes for specific conditions and requirements, it is necessary to make decisions on the choice of a nomenclature of quality characteristics and evaluation the integral quality of Software for Space Purposes.

The quality of Software for Space Purposes depends on a sufficiently large number of characteristics and attributes, which can be both quantitative and qualitative. A generalized assessment of the quality of Software for Space Purposes is a complex mathematical and practical problem, which is characterized by uncertainty.

Complex Software for Space Purposes, as well as the processes of their development and operation, are characterized by physical and linguistic uncertainty. Physical uncertainty manifests itself in the form of inaccuracies in the determination of characteristics and quality indicators, as well as the random nature of many development and functioning processes. Linguistic uncertainty in the Software for Space Purposes development arises when experts evaluate their quality characteristics.

The expediency of using fuzzy models in the analysis of the quality of Software for Space Purposes is determined by the following:

- currently, iterative approaches to software development require constant specification of requirements in the process of analysis, design, development. This leads to uncertain requirements for Software for Space Purposes, the use of quantitative and linguistic assessments, as well as fuzzy criteria, which are initially formulated and constantly updated in the process of creating a software system. Consequently, the design process of Software for Space Purposes is quite natural to describe with fuzzy models;
- fuzzy models of analysis and quality assessment of Software for Space Purposes allow us to formalize both quantitative characteristics that objectively have uncertainty, and qualitative, subjective assessments of experts, expressed in fuzzy concepts, as well as fuzzy descriptions using fuzzy numbers, linguistic variables and fuzzy data. The application of the Software for Space Purposes quality assessment methodology based on the application of fuzzy set theory also allows the use of fuzzy criteria, which is also important for various stages of Software for Space Purposes creation.

In relation to the task of analysis and quality assessment of Software for Space Purposes using fuzzy models, two groups of tasks can be distinguished:

1) obtaining values of quantitative and qualitative quality indicators in the form of fuzzy estimates;

2) formation and assessment of the integral quantitative quality indicator of Software for Space Purposes.

3. AN APPROACH TO THE INTEGRAL QUALITY ASSESSMENT OF SOFTWARE FOR SPACE PURPOSES BASED ON THE USE OF FUZZY MODELS

For the customer and the consumer of Software for Space Purposes who make a decision about its use in specific conditions of use, it is advisable to evaluate the quality of the software product by generalized (integrated) criteria. Existing approaches to assessing the quality of software, as a rule, are based on separate indicators. In the integrated assessment of the quality of the Software for Space Purposes, it is necessary to take into account both quantitative and qualitative indicators, as well as their inherent uncertainties.

The formation of an integral quantitative indicator of Software for Space Purposes quality seems to be a rather difficult task both from the point of view of its formation and from the point of view of interpretation. Wherein valuation models have a complex structure and are presented in the form of hierarchically related indicators [1].

For weakly structured problems under the conditions of significant uncertainty, to which can be possible include the problem of assessing the quality of the Software for Space Purposes, the theory of fuzzy sets provides an effective methodological approach for making a decision with a multi-criteria choice of alternatives [5]. At the same time, the effectiveness of the proposed approach is ensured, on the one hand, by the fact that alternative options for expert assessments of software quality characteristics can be represented quite well by fuzzy sets and numbers. On the other hand, quantitative estimates of the various characteristics of the Software for Space Purposes, which are obtained on the basis of limited sample sizes of statistical data, can also be represented by fuzzy variables and fuzzy numbers.

The solution to the task of assessing the quality of Software for Space Purposes by an integral indicator is to aggregate the results of a fuzzy evaluation of individual quality indicators and involves the following basic procedures:

- setting a hierarchical structure of indicators that form an integral quality indicator and setting their weight coefficients of significance;
- evaluation (measurement) of each individual quality indicator and presentation of the result as a fuzzy number;
- rationing of the obtained estimates of quantitative indicators;
- aggregation of fuzzy assessments of quality indicators and obtaining an integral assessment of the quality of the Software for Space Purposes;
- verification and interpretation of the obtained integrated assessment of the quality of the Software for Space Purposes.

As is known, the assessment of quality indicators is usually carried out by experts on a point scale using the terms "low quality", "acceptable quality" and "high quality". The main problem is to build a model for linguistic analysis of the quality of the Software for Space Purposes. With this approach, the characteristics that determine the quality of the software, it is advisable to consider from the point of view of the theory of fuzzy sets as linguistic variables. The linguistic approach allows you to transform the scores into more flexible and adequate quantitative estimates based on fuzzy numbers.

The results of assessing quantitative indicators used in the integrated assessment of Software for Space Purposes quality also have uncertainty. This is due to the fact that it is often impossible to assess their exact value of the indicator due to various limitations: complexity and measurement errors; the limitations of statistical sequences of experimental data obtained as a result of an active or passive experiment. In this case, it is advisable to use fuzzy models to evaluate quantitative indicators. Moreover, each quantitative indicator of quality can be represented as a fuzzy variable characterized by a membership function.

For example, reliability, which is one of the most important characteristics of software quality, which, in turn, is described by a number of subcharacteristics, among which an important place is occupied by recoverability, which characterizes the ability of a software to restore its operability and data in the event of a fault. One of the quantitative indicators of software recoverability is the "recovery time". Evaluation of this indicator is carried out according to the results of the tests, which, as a rule, have an uncertainty associated with random processes occurring in the system and with the limited statistical sequences of experimental data. Based on the test results, the investigated indicator is assessed and are set restrictions in the form of threshold values. For example, the recovery time is set to a valid time value ($t_{\max}$). In this case, if the value recovery time (t) is less than or equal to the allowable ($t \leq t$), then it is considered that the software recoverability index in relation to the recovery time is acceptable, otherwise it is unacceptably low. Considering that the influence of the recovery time on the characteristic (recoverability) of software quality, as a rule, is characterized not by an abrupt function, but by a continuous (decreasing or increasing) function, it is advisable to set not a threshold limit, but an interval at which the recoverability indicator smoothly changes from high to unacceptably low values.

In accordance with the methodology of the theory of fuzzy sets for the above example, we construct a fuzzy set "acceptable recovery time" ($\boldsymbol{TP}$), for this, it is necessary:

1) specify a universal set - these are possible values of the Software for Space Purposes recovery time. Let us denote this universal set by $T = (t_1; t_2]$;

2) on the set T, select an interval $[t_1; t_{min}[]]$, for which the recovery time is unambiguously considered acceptable;

3) on the set T, select an interval $[t2_{max}[]]$, for which the recovery time is unambiguously considered unacceptable;

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4) on the interval $(tmax_{min})$, each value of the recovery time is assigned a degree of belonging.

The membership function $\mu_{\text{TP}}(t)$of a fuzzy set ***TP*** on a universal set $T = \{t\}$ (TP), which allows one to quantitatively determine the degrees of membership of elements in a fuzzy set, can be written as the following formula:

$$\mu_{TP}(\text{t})=\begin{cases}1 & when\ \ 0\le t\le t_{\min}; \\ \dfrac{t_{mid}-t}{t_{mid}-t_{\min}} & when\ \ t_{\min}<t<t_{mid} \\ 0 & when t\ge t_{mid}\end{cases} \quad (1)$$

With this approach, if the execution time of some Software for Space Purposes function ***t*** less than or equal to t_{min} ($t \le t_{\min}$), then there is full confidence ($\mu_{\text{TP}}(t)$=1) in the high quality of the indicator (the execution time of the function) of the Software for Space Purposes. If the execution time of the function is in the range from t_{min} to t_{max} ($t_{min} < t < t_{max}$), then the quality of the indicator changes from high to unacceptably low ($1 < \mu_{\text{TP}}(t) < 0$). When the execution time of the function is greater than or equal to t_{max} ($t \ge t_{\max}$) the quality of the indicator is unacceptably low ($\mu_{\text{TP}}(t) = 0$). This approach allows you to specify a range in which a change in the value of the indicator smoothly affects the quality of Software for Space Purposes and varies from high to low.

An expert assessment of the influence of the recovery time on software reliability usually uses a linguistic interpretation in the form of a three-level scale "H-M-L", where the level H (high quality) corresponds to a short recovery time; level M (medium quality) corresponds to the acceptable recovery time; level L (low quality) corresponds to an unacceptably long recovery time. In this case, the linguistic variable "Quality of restoration" has three corresponding membership functions.

For integral evaluation of Software for Space Purposes quality, it is proposed to use quality scales and preference relations between quality attributes in the structure of the hierarchy of these attributes. The principles of forming a hierarchy of attributes that determine the quality of Software for Space Purposes, and the order relations between them should be determined by the requirements of the assignment. The quality of the Software for Space Purposes can be described by the following fuzzy model:

$$Q = < G, L, P, A>, \qquad (2)$$

where G – is a graph of a tree with vertices Fj (j = 0, ..., N_D), each of which is associated with a certain set of linguistic values $x_j^i \in L_j$, that characterize the state of the factor that determines a specific quality indicator of Software for Space Purposes; $L = \{Lj\ ,\ (j = 0, ..., N_D)\}$ – a set of linguistic values (qualitative assessments) of the levels of each factor; P – a system of relations of preference of one factors over another for one level of the hierarchy of factors; A – a set of information aggregation operators, which is defined for non-terminal vertices of the graph and allows its state to be calculated based on the state estimates of subordinate vertices.

When using a five-level classifier (a five-level scale) to software quality attributes, the set of linguistic values Lj may consist of the following elements [6]: {Very Low Level (VLL), Low Level (LL), Medium Level (ML), High Level (HL), Very High Level (VHL)}.

To solve this task, we present the system of relations of preference of one factors over another for one level of the model hierarchy as follows: $P = \{F_i\ (\varphi)\ F_j \mid \varphi \in (\succ, \approx)\}$, $F_i \succ F_j$ - strict preference attitude, $F_i \approx F_j$ - attitude of indifference. A preference relation is introduced based on information obtained from experts for attributes of the same hierarchy level F_i and F_j: a clear relation of non-strict preference, a relation of strict preference and an attitude of indifference. If the expert information on the form of the preference relationship is insufficient, then there is a relationship of indifference between the factors of the same hierarchy level F_i and F_j.

For a linguistic assessment of Software for Space Purposes quality, it is proposed to form an information aggregation operator for each non-terminal vertex of the graph, which, based on the state estimates of subordinate vertices, will allow calculating its state. The choice of the aggregation operator is largely determined by the features and conditions of the Software for Space Purposes application and is based on available information

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from experts and analysis of the functioning of the system.

For aggregation, it is proposed to use the OWA (Ordered Weighted Averaging) Yager operator and Fishburne coefficients as weights in the convolution [7,8]. Fishburne coefficients are calculated by the formula [8]:

$$p_i = \frac{r_i}{\sum_{j=1}^{N} r_j}, \quad (3)$$

where $i = \overline{1, N}$, N – the number of subordinate vertices involved in the information aggregation operation.

$$r_{i+1} = \begin{cases} r_i, if F_{i+1} \approx F_i; \\ i_N = 1, i = \overline{N, 2} \\ r_i + 1, if F_{i+1} \succ F_i. \end{cases}$$

If, for each indicator ($F_{k.1} \ldots F_{k.N}$) at the selected sublevel (k) of the graph G of the model, the linguistic estimates $L = (L_{k.1} \ldots L_{k.N})$ are known and the weight coefficients $p_k = (p_{k.1}, \ldots, p_{k.N})$, then the operator of aggregation of information of the sublevel k is a weighted sum and is characterized by its linguistic assessment determined by the membership function on the 01-classifier

$$\mu_k(x) = \sum_{i=1}^{N} \mu_{ki}(x)\, p_i. \quad (4)$$

The membership function $\mu_k(x)$ must be interpreted to obtain an estimate of the linguistic level of the indicator F_k. If a five-level fuzzy 01-classifier is used to estimate the level of the indicator F_k, then, based on the minimum distance ρ_{ki} between the fuzzy set given by the membership functions $\mu_i(x)$ and each of the fuzzy sets specified by the membership functions $\mu_i(x)$ $(i = \overline{1,5})$, it is necessary to determine the minimum proximity $\mu_k(x)$ to $\mu_i(x)$. To estimate the proximity between two fuzzy sets A and B, we propose to use the absolute Hamming distance.

Taking into account that the indicator F_k is defined by the membership function $\mu_k(x)$, which has a trapezoidal type $(a_L^k, a_1^k, a_2^k, a_R^k)$, as well as the membership function of the five-level fuzzy classifier $\mu_i(x)$ $i = \overline{1,5}$ on the 01-carrier, is also trapezoidal $(b_L^i, b_1^i, b_2^i, b_R^i,)$, the distance between the fuzzy sets is represented as

$$\rho_{ki} = max\{|a_L^k - b_L^i|, |a_1^k - b_1^i|, |a_2^k - b_2^i|, |a_R^k - b_R^i|\}, i = \overline{1,5} \quad (5)$$

Here a_1 (b_1) and a_2 (b_2) are the boundaries of the tolerance intervals $[a_1, a_2]$ ($[b_1, b_2]$), in which $\mu_k(x)$= 1; a_L (b_L) and a_R (b_R) are the left and right fuzzy coefficients for fuzzy sets A and B, respectively. These parameters affect the form and complexity of the mathematical equations of the membership function of quality indicators. For example, $a_1 = a_2$ we will have a triangular membership function, and for $a_1 < a_2$ - a trapezoidal one. Also, the specified parameters should be selected in such a way that the results of mathematical operations on fuzzy numbers are correct, and the result does not go beyond the limits.

The minimum value ρ_{ki} will determine whether the indicator F_k indicator to one of the linguistic levels of the five-level scale on the 01 classifier. The procedure for aggregating attributes for G graph should be carried out for each non-terminal vertex from the bottom up to the linguistic value of the quality indicator Software for Space Purposes — F_0.

The minimum value ρki will determine the belonging of the Fk indicator to one of the linguistic levels of the five-level scale on the 01-classifier. The procedure for aggregating the attributes for the G graph should be carried out for each non-terminal vertex from bottom to top until the linguistic value of the quality index of the PSCN - F0 is obtained.

4. CONCLUSION

Application of the theory of fuzzy sets opens up new methods and opportunities for solving problems of software quality assessment. First, fuzzy models make it possible to take into account the qualitative indicators of software characteristics, transforming them into a numerical form. Secondly, in relation to quantitative indicators of software quality characteristics, the theory of fuzzy sets provides a means to work with uncertainty even in cases where the available data are insufficient to draw statistical conclusions with the required level of confidence.

The proposed approach to the analysis of the quality of the Software for Space Purposes based on fuzzy models allows for an integral assessment of the quality, jointly using quantitative and qualitative indicators.

«In addition, the proposed approach allows us to modify the models and methods of analysis and evaluation of the quality and reliability of Software for Space Purposes [9, 10] proposed earlier by the authors, taking into account the inherent uncertainties for these problems».

Computational experiments to assess the effectiveness of the proposed fuzzy model for the problem of assessing the quality of the Software for Space Purposes is currently underway.

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Future Work:

- At present, computational experiments are being carried out to evaluate the effectiveness of the proposed fuzzy model for the problem of assessing the quality of the SWSP. Based on the results of these experiments, it is planned to develop a detailed methodology for assessing the quality of the Software for Space Purposes.
- The fuzzification process of the metrics can be further improved by considering different fuzzy sets for different metrics.
- For a more adequate representation of the uncertainties in the problem of assessing the quality of the software, it is planned to develop the proposed approach using the methods of the theory of possibilities [5].

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