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Information Support for the Management of the Efficiency of Enterprise Information Service Systems

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***Abstract*—We are considering a formal procedure to support the management of the efficiency of enterprise information service systems in a part of defects repair found at the stage of operation of such systems. The basis of the procedure is the system combination of some models and approaches. The term of "Defect Profile" is considered. The purpose of building a defect profile is development of a systematic basis for decision making in the allocation of resources for finding and eliminating defects, taking into account their importance from the point of view of various user groups and the degree of defects knowledge. An approach to constructing a defect profile from actual data with a limited number of observations is described. A method based on the BCG-approach has been proposed for adapting to eliminating defects. This approach is described in the marketing literature. It is used for making decisions on investing funds into the activities of an organization's units in the face of external and internal environment uncertainties. The use of the proposed approach creates an informational basis for the targeted distribution of limited resources to eliminate defects, taking into account their influence on the users' assessment of information systems quality.**

Keywords—Decision-making support, Information system, Software defect, Interval estimation of probabilities, BCG-matrix, Defect profile

I. INTRODUCTION

User satisfaction with consumer properties of an information system (IS) refers to the key conditions for investing in its development [1, 2]. The manifestation of defects in the software components of the information system at the operation stage is one of the factors that adversely affect the users' perception of the quality of systems.

Defects in the software components of the systems, which manifest themselves at the operation stage, are laid at different stages of the software life cycle, due to different reasons, belong to different classes [3]. The manifestations of different defects have a different impact on such a characteristic of quality as functional safety. Defects of different classes have not same significance and knowledge. These circumstances necessitate a differentiated approach to the elimination of various defects [4, 5, 6].

This paper examines a systematic procedure for information support for making decisions about the expediency of eliminating defects in software components. It is based on taking into account the degree of knowledge of different defects in different components, as well as the impact that the manifestation of defects has on user evaluation of information system quality.

II. TERM "PROFILE" AS DECISION-MAKING SUPPORT TOOL

Profiles are a kind of structural hierarchical system models. A profile is a full set of alternatives, for each of which there is a certain occurrence probability [5, 7 etc.]. Alternatives may be functions, operations, users, etc. Profile aggregates [8] are an information support tool for solving problems related to IS quality management.

The basis of building profiles is the desire of developers in the early stages of the systems life cycle to see the system through the eyes of end users, and also to take into account the expected conditions of its operation [5]. Ensuring the required quality of IS in the context of limited project resources is ensured by a selective approach to the assignment of requirements for the properties of system components, taking into account the role that different components play in ensuring the quality of IS.

The literature describes a significant number of different profiles, corresponding to different approaches to the study of the properties of systems [5 etc.]:

- user profile designed to investigation of target user groups;
- system mode profiles designed to investigation of the possible conditions of the system usage;
- functional profile designed to investigation of the functions that the system can implement;
- operational profile designed to investigation of the operations performed by the system, etc.

This paper introduces the "Defect Profile", presented in Figure 1.

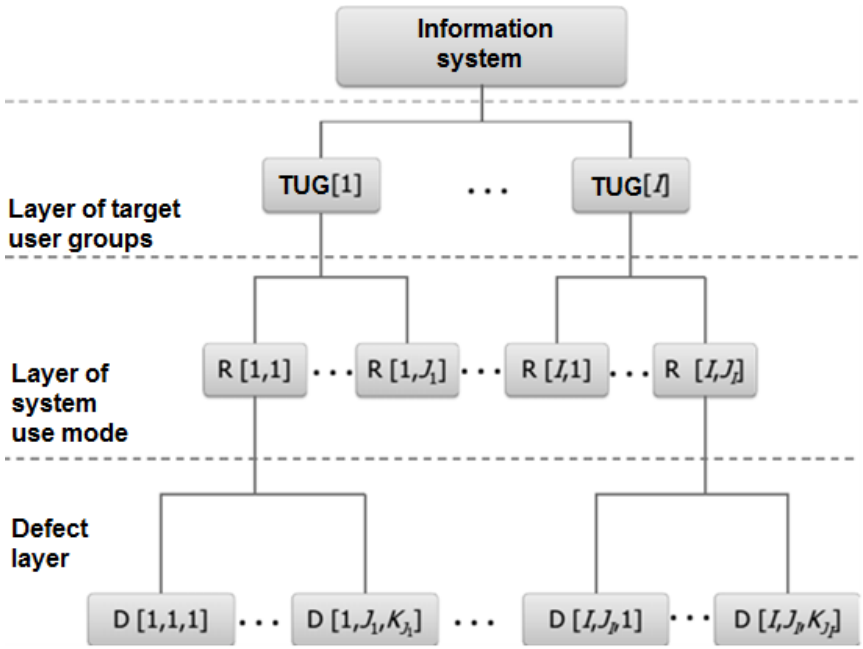

Fig. 1. Defect profile

The purpose of building the profile is development of a systematic basis for degree evaluation of defects knowledge. Knowledge is reciprocal value of uncertainty; knowledge can successfully delete the defect with restriction to available resources.

The methodical difference between the defect profile during IS operation and other types of profiles used in the early stages of the system life cycles is as follows.

When profile construction in the early stages of the system life cycles, point estimates of the alternative probabilities are used, the values of which ensure that the norming condition is done, namely sum of probabilities is equal to one. The basis of defect profile construction by exploitation results is actual data about defect manifestations. If the data is presented as documentary data, its volume is small (in a statistical sense). Often, documentary data is completely absent and is replaced by expert estimates, which are obtained by interviewing specialists who performed maintenance and operation of the system.

The consequence of this is that the probabilistic estimates of the profile characteristics are interval [9]. The use of interval estimates complicates the fulfillment of the norming condition for the full group of independent events [10]. In this case, the use of existing methods of profile analysis for the study of the defect profiles is impossible.

There is a description of the problem of studying the properties of the defect profile with interval estimates of the alternative implementation probabilities.

III. Task content of defect profile construction

A. Initial data

1) We know that number of target user groups (TUG) is I, number of IS usage mode by different TUG is J_i $(i = \overline{1;I})$, number of defect types is K_{J_i}, corresponding to the different modes of IS using of each of the TUGs

2) Because of IS operating experience we know:

a) Accession number to IS is n_i, $\left(i = \overline{1;I}\right)$ each of i's of TUG, at which defect manifestations were observed.

b) Varies types IS using number is m_{ij}, $\left(i = \overline{1;I}, j = \overline{1;J_i}\right)$ by different TUG, at which defect manifestations were observed.

c) Defect number is l_{ijk}, correlated with pre-defined classes $\left(k = \overline{1;K_{J_i}}\right)$, registered in the j's mode of using the IP of the i's TUG.

B. Assumption

1) While under different modes of using IS, different TUGs show manifestations of identical defects, they are considered as different defects when construction a profile. The reason is that the same deviation of IS behavior from the expected is perceived differently by different subjects who representatives of different TUGs (this substantiation is given in [11]).

2) The defects classification is invariant to the modes of use and to the characteristics of the IS. When defect profile construction, there are defect classes:

a) Errors of users and operating personnel;

b) Coding defects of IS software components;

c) IS projection defects;

d) Technical requirement defects.

IV. Defect profile construction under conditions of limited observations' number

The complexity of a defect profile constructing under conditions of a limited number of observations is due to the need for interval estimation of the probabilities of alternatives corresponding to different layers of the profile. It is controlled by the small amount of sampling data [12]. The consequence of the interval estimation of probabilities is the possibility of the norming condition violation (sum of

probabilities is equal to one). Compliance with the norming condition is a basic requirement for the profiles construction [5, 7].

In addition, as we move from bottom to top of the scheme (Fig. 1), the volumes of sampling data decrease, which lead to the expansion of the boundaries in which the true probability is found with a given confidence probability β [12].

The basis for constructing a defect profile for interval estimation of the alternative probabilities is as follows. Object containment probability in one of the possible states can be interpreted as a weight characteristic of the state [13]. We know the rule for converting weight characteristics of arbitrary size α_i, $(i = \overline{1;n})$ to the type of normalized weight characteristics $\alpha_i^{(N)}$:

$$\alpha_i^{(N)} = \frac{\alpha_i}{\sum_{i=1}^{n} \alpha_i}$$

that $\alpha_i^{(N)} \in [0;1]\ \forall\, i$.

Assume that as a result of an independent random selection of the values of the probabilities p_i, each of which belongs to the interval $p_i \in [p_i^{(L)}; p_i^{(U)}]$ ($p_i^{(L)}$, $p_i^{(U)}$ – the lower and upper limits of the interval, respectively), we obtained values for which the norming condition

$$\sum_{i=1}^{n} p_i \neq 1$$

is not observed. We transform the value of p_i to the normalized form

$$p_i^{(N)} = \frac{p_i}{\sum_{i=1}^{n} p_i},$$

which will provide the possibility of implementing the formal procedure for constructing a profile described in [11, 14].

The basis for assessing the defect study degree by the defect profile is carrying out the simulation experiment according to the scheme described below:

Step 1. Initial data as:

- n_i – given accession number of i's TUG to IS $(i = \overline{1;I})$, at which defect manifestations were observed. I – TUG quantity;
- m_{ij} – given accession number of i's TUG to IS in j's use mode $(i = \overline{1;I},\ j = \overline{1;J_i})$ at which defect manifestations were observed. J_i – number of IS use mode of i's TUG;
- l_{ijk} – given accession number of i's TUG to IS in j's use mode $(i = \overline{1;I},\ j = \overline{1;J_i})$ at which k-type $(k = \overline{1;K_{J_i}})$ defect manifestations were observed. K_{J_i} – number of defect types in j's use mode of i's TUG;
- H – boundary value of experiment iteration count.

Step 2. Calculation of the accession frequency to the IS of each TUG in each of use modes, in which different types of defects appear:

- $\hat{p}_i = \frac{n_i}{\sum_i n_i}$ – accession number of i's TUG to IS $(i = \overline{1;I})$, at which defect manifestations were observed.
- $\hat{q}_{ij} = \frac{m_{ij}}{\sum_j m_{ij}}$ – accession number of i's TUG to IS in j's using mode $(i = \overline{1;I},\ j = \overline{1;J_i})$, at which defect manifestations were observed.
- $\hat{w}_{ijk} = \frac{l_{ijk}}{\sum_k l_{ijk}}$ – accession number of i's TUG to IS in j's using mode $(i = \overline{1;I},\ j = \overline{1;J_i})$, at which k-type $(k = \overline{1;K_{J_i}})$ defect manifestations were observed.

Step 3. Setting the value of the confidence probability β and calculation based on the calculated frequencies of the confidence limits. The superscript (L) and (U) mark, respectively, the lower and upper confidence limits of the frequencies indicated in step 2:

$$p_i \in \left[p_i^{(L)}, p_i^{(U)}\right];$$

$$q_{ij} \in \left[q_{ij}^{(L)}, q_{ij}^{(U)}\right];$$

$$w_{ijk} \in \left[w_{ijk}^{(L)}, w_{ijk}^{(U)}\right].$$

Step 4. Generating of frequency random value is $p_i^{(\eta)}$, where η – experiment number $\left(\eta = \overline{1,\mathrm{H}}\right)$, i – TUG number $\left(i = \overline{1,I}\right)$, corresponding to a uniform distribution law with a density inversely proportional to $\left(p_i^{(U)} - p_i^{(L)}\right)$.

Step 5. Calculation of a random number of defects in i's TUG in the η's experiment:

$$n_i^{(\eta)} = N \cdot p_i^{(\eta)},\ \left(\eta = \overline{1,\mathrm{H}}; i = \overline{1,I}\right).$$

Step 6. Generating of frequency random value is $q_{ij}^{(\eta)}$ $\left(i = \overline{1,I}; j = \overline{1,J_i}\right)$, i – TUG number, j – number of IS use mode, corresponding to a uniform distribution law with a density inversely proportional to $\left(q_{ij}^{(U)} - q_{ij}^{(L)}\right)$.

Step 7. Calculation of a random number of defects in j's use mode of i's TUG in the η's experiment:

$$\left(\eta = \overline{1,\mathrm{H}}; i = \overline{1,I}; j = \overline{1,J_i}\right),\ m_{ij}^{(\eta)} = n_i^{(\eta)} \cdot q_{ij}^{(\eta)}.$$

Step 8. Generating of frequency random value is $w_{ijk}^{(\eta)}$ $\left(i = \overline{1,I}; j = \overline{1,J_i}; k = \overline{1,K_{J_i}}\right)$, corresponding to a uniform distribution law with a density inversely proportional to $\left(w_{ijk}^{(U)} - w_{ijk}^{(L)}\right)$.

Step 9. Calculation of a random number of *k*-type defects in *j*'s use mode of *i*'s TUG in the η's experiment:

$$l_{ijk}^{(\eta)} = m_{ij}^{(\eta)} \cdot w_{ijk}^{(\eta)} \ \left(\eta = \overline{1,\mathrm{H}}; i = \overline{1,I};\ j = \overline{1,J_i}; k = \overline{1,K_{J_i}}\right).$$

Step 10. The calculation of the empirical estimator of the references frequency to the IS with the defect manifestations, i.e. normalized characteristics of explicit defect profiles in the η's experiment:

$$p_i^{*(\eta)} = \frac{n_i^{(\eta)}}{\sum_i n_i^{(\eta)}};$$

$$q_{ij}^{*(\eta)} = \frac{m_{ij}^{(\eta)}}{\sum_j m_{ij}^{(\eta)}};$$

$$w_{ijk}^{*(\eta)} = \frac{l_{ijk}^{(\eta)}}{\sum_k l_{ijk}^{(\eta)}}.$$

Step 11. The calculation of the implicit profile the characteristics in η's experiment:

$$B_{ijk}^{*(\eta)} = p_i^{*(\eta)} \cdot q_{ij}^{*(\eta)} \cdot w_{ijk}^{*(\eta)}.$$

Increasing the value $\eta = \eta + 1$. Go to step 4, if $\eta \le \mathrm{H}$.

Step 12. Finding the boundary values of implicit profiles characteristics:

$$B_{ijk}^{(L)} = \min_{\eta}\left\{B_{ijk}^{*(\eta)}\right\};$$

$$B_{ijk}^{(U)} = \max_{\eta}\left\{B_{ijk}^{*(\eta)}\right\}.$$

Step 13. The calculation of the assessment of knowledge degree of defects corresponding to implicit profiles as:

$$H_{ijk} = \frac{1}{B_{ijk}^{(U)} - B_{ijk}^{(L)}}.$$

The basis for estimating the degree of defects knowledge by the ratio presented in step 13 is the following. According to [7], the quantitative characteristic of an implicit profile is probabilities multiplication corresponding to the edges of the simple path from the root to the *ijk*'s block of the scheme (Fig. 1).

In the absence of empirical data, a reasonable estimate of the range of possible values of the implicit profile will be $B_{ijk} \in [0,1]$, what corresponds to the length of the interval $d = 1 - 0 = 1$. After valuation the range of probable values $\left\{B_{ijk}^{(L)}, B_{ijk}^{(U)}\right\}$, the interval value will be reduced to

$$d_{ijk} = B_{ijk}^{(U)} - B_{ijk}^{(L)}.$$

In other words, the defect knowledge will increase by $H_{ijk} = 1\Big/\left(B_{ijk}^{(U)} - B_{ijk}^{(L)}\right)$ times.

A feature of the presented experiment scheme is that the volumes of random samples corresponding to different layers $m_i^{(\eta)}$, $k_i^{(\eta)}$ during the η's experiment realization (step 3) are determined taking into consideration random values $m_i^{(\eta)}$, $k_i^{(\eta)}$ of probabilities located within the limits of the intervals corresponding to the upper layer.

Compliance with the norming condition is ensured by the fact that for each η's experiment based on the generated random samples, point estimates of probabilities (frequencies) are determined, corresponding to different states of different profile layers (step 10). The notation used in step 3 emphasizes the fact that the width of the intervals is determined by the selected confidence probability β.

V. Information Support for Decision Making on the Elimination of Defects Using the BCG Approach

The refined model "Project Triangle", proposed in 2014 [1], [2], directs developers to create software systems that, firstly, are of value to users; secondly, resulting in satisfaction from working with them [15].

One of the basic provisions of the use of profiles as an IS quality management tool is a selective approach to improving consumer system properties, providing services for different TUGs and operating in different modes [11].

Defect profile can evaluate the degree of defect knowledge. However, when deciding on the appropriateness of resource costs to eliminate the defect, you should also take into consideration the degree of negative impact of the defect on the valuation of the IS quality by different users.

Taking into account consideration the difference in the roles that different TUGs can play when allocating resources to solving problems within the framework of strategic management of consumer IS properties, when analyzing defects one should take into consideration the interests of which TUGs and to what extent are affected by defect manifestations.

[16] described a tool for providing information support for decision-making on investing funds in the activities of organization various departments, taking into consideration (a) the market share controlled by the division, (b) the market growth rate (Boston Consulting Group, BCG-approach).

Considering the defect significance as an analogue of the market growth rate, and the defect knowledge as an analogue relative to market share, one can adapt the BCG approach to making decisions on the feasibility of spending resources on eliminating defects. Note that the expediency of adapting approaches that are well-proven in solving complex systems, in the field of software engineering is noted in [6].

The structure of the matrix corresponding to the problem of eliminating defects, similar to the matrix used in the BCG approach, is shown in Fig. 2.

Selected blocks of the matrix can be given the following interpretation. If defects correlate with the area {“High Significance”, “High knowledge”}, then such defects should be eliminated first of all, since this creates a basis for investing resources in improving the IS consumer properties.

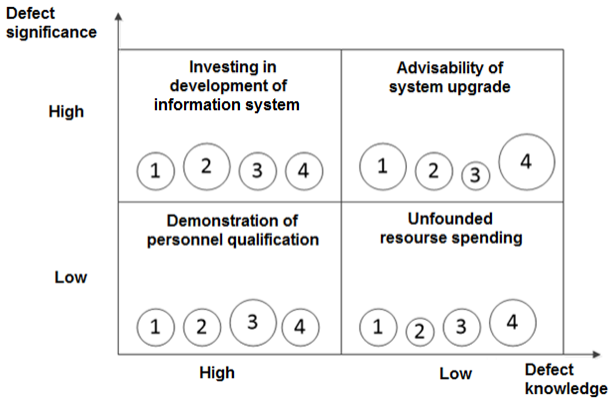

Fig. 2. BCG-matrix analogue for defects description with terms «Defect knowledge», «Defect significance»

In order to illustrate such defects we would mention the improvement of a system function widely accepted which was already incorporated, successfully implemented and debugged in other projects, that are being supervised by a development group at the same time. The effect of such improvement will be significant with minimal expenses for its implementing.

If defects correlate with the area {“Low significance”, “High knowledge”}, then such defects can be eliminated even without additional direct investment of resources by developers, since this type of activity contributes to improving the reputation of developers (service personnel) in the eyes of users. This will create prerequisites for the appearance of future orders.

As an example, we would mention a case similar to the example for the region {“High Significance”, “High Knowledge”}. However, it is not widely accepted, but a private function, which is insignificant for the system as a whole, will be subject to updating.

Defects correlated with the area {“High Significance”, “Low Knowledge”} correspond to the connection to the system of new functions. Allocation of investments to eliminate defects is advisable, since the connection of new functions is due to the problems solution of developing of IS capabilities.

In contrast to the functions given as examples for the regions {“High Significance”, “High Knowledge”}, {“Low Significance”, “High Knowledge”}, for the region {“High Significance”, “Low Knowledge”} it is a completely new function that the development group has never implemented before.

If the defects align with the area {“Low significance”, “Low knowledge”}, then it is useless to spend resources on their elimination.

An example of such defects are functions rarely used, originally developed for the interests of the specific users category, as well as outdated functions that became irrelevant or have been replaced with alternatives.

The diameter of the circles shown in Fig. 2, corresponds to the number of fixed defects correlated with each of the above defined classes. The numbers inside the circles correspond to the defect classes. The availability of this information and expert estimates of the resources amount are spending on eliminating defects of different classes, and forming the basis for planning the total amount of resources needed to eliminate defects in general.

A model accounting for the IS use by different target user groups can be represented by a series of TUG matrices (Fig. 3).

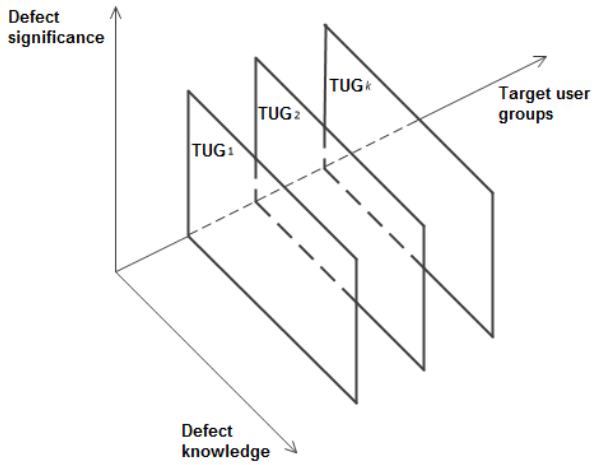

Fig. 3. Series of TUG-matrices

This series account for the various possibilities of the influence of different TUGs on investing in the IS maintenance and development. The need to rank users according to the degree of their influence on projects and processes is discussed in the works [15, 17–23 etc.].

VI. Conclusion

This paper describes a systematic decision support procedure for eliminating defects identified at the information system exploitation stage. The basis of the procedure is a combination of the models “Defect Profile”, “Interval Probability Assessment”, “Boston Consulting Group – BCG”. These models have been used in different science and engineering areas successfully.

The example of resources’ distribution based on BCG-matrix analogue for defects description with terms “Defect knowledge”, “Defect significance” has been shown. The proposed approach can be useful for analysis of system quality at the exploitation stage. The series of proposed matrices allow taking into account interests of different user groups. Also the proposed approach can be extended to the other stages of the lifecycle by applying another criteria of quality evaluation. These issues may be the subjects of separate researches.

The proposed approach increases the reasonableness of making decisions on investing resources in improving the quality of information systems through the joint use of formal methods of structural modeling, methods of mathematical statistics and expert knowledge.

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