Trade-off Optimization in the Problem of Software System Architecture Choice

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Abstract **The problems of multi-criteria choice of software system architecture are discussed, connected with definition of criterion function.**

For this the universal scalar convolution is offered to apply, where the priority of quality criteria depends on its proximity to the limitation. Optimization model application for problem of reengineering or directed choice of software architecture is discussed too.

Keywords – **Software Architecture, Software Quality, Architecture Ranking, Multicriteria Choice.**

I. INTRODUCTION

The component technology is applied widely for design of software systems (SWS). It is grounded on the usage of components taken from earlier executed projects (reused components) [1]. The architecture according to this technology is designed by the frame selection based on the requirements to the SWS and filling it by necessary components taken from the repository or from Internet. The frame is a high-level abstraction of the SWS design; it combines set of interacting objects into some integrated environment [2].

The pattern is an expansion of the component concept. It is an abstraction, which contains the description of interactive objects in generalized cooperative activity where roles of participants and their responsibilities are defined. The great amount of components is developed. They are classified according to the types and kinds of applications, and also the technologies of their usage for SWS architecture design. Since the repository of patters as usual contains several components, which implement the same functionality, so for component technology of design we will obtain the set of alternative SWS architectures. Selection of the most acceptable option of the architecture with respect to the set of quality criteria requires either to range alternatives according to the values of quality criteria or to use some integral index with own value for each alternative

Some methods for SWS architecture evaluation are used on practice. The most popular methods are based on the development of use case scenarios and testing whether certain architecture satisfies to quality criterion. ATAM and SAAM are the most known methods of this type [3].

The common disadvantage of these methods is that their implementation requires to create and analyze rather large quantity of use case scenarios, what makes them laborious, expansive and complicated for formalization. That is the appearance of papers where the Analytical Hierarchic Process (AHP) was proposed for the solution of this problem allowed to improve the procedure of architecture selection considerably and to formalize it for automation of decision making processes [4].

The essential disadvantage of AHP is limited quantity of alternatives for evaluation ($n \le 7 \pm 2$) what is caused by the inconsistency of elements in the matrices of pairwise comparisons. Inconsistency increases as far as quantity of alternatives grows [5].

For the solution of this problem A. Pavlov in [6] offered the modification of AHP where weight indices of alternatives are obtained from the condition of minimization of inconsistency of matrices of pairwise comparisons, what leads initial problem to the problem of mathematical programming. In paper [7] the problems of modified AHP (MAHP) application are discussed in terms of the problem of evaluation of alternative software architectures for large amount of alternatives.

Final selection of architecture option taking into account all the criteria is performed often via replacement of multi-criteria optimization by single criterion one represented by scalar criterion usually expressed as additive convolution of partial quality criteria. Usage of scalar convolution requires to assign weights to partial quality criteria by expert method. This procedure as rule is badly formalized, has subjective nature and is additional source of errors. The trade-offs made between criteria remain hidden when scalar convolution is used. The procedure of trade-offs assignment for partial criteria weighting has to be formalized in order to reduce the subjective influence on the weights of quality criteria selection and to take into account requirements of subject area. The idea of universal scalar convolution can be applied [8], where the target function that depends on the level of situation tension is optimized. The tension level is defined by the proximity between values of criteria to their threshold values. The iterative procedure may be applied for formalization of the process of quality criteria weighting.

II. THE PROBLEMS OF THE MULTI-CRITERIA CHOOSING OF THE SWS

The scheme of the problem of the evaluation and multicriteria SWS architecture selection from the set of alternatives is shown on the Fig. 1.

Here the following denotations are used: $K_j^1,\ j=\overline{1,p}$ are quality criteria of SWS itself, defined according to requirements in terms of standard ISO/IEC 25010; $K_i^2, i=\overline{1,n}$ are architecture quality criteria defined from the set of $K_j^1,\ j=\overline{1,m}$ using SQFD (Software Quality Function Deployment) method or method of pairwise comparisons [7]. K^0 is integral quality criterion of SWS; $R_i, i=\overline{1,n}$ are given limits of architecture quality criteria; $A_i, i=\overline{1,m}$ are alternative architectures. Since the set of criteria $\{K_i^2\}$ is obtained from the set $\{K_j^1\}$ then the level of quality criteria of SWS can be excluded from the discussion.

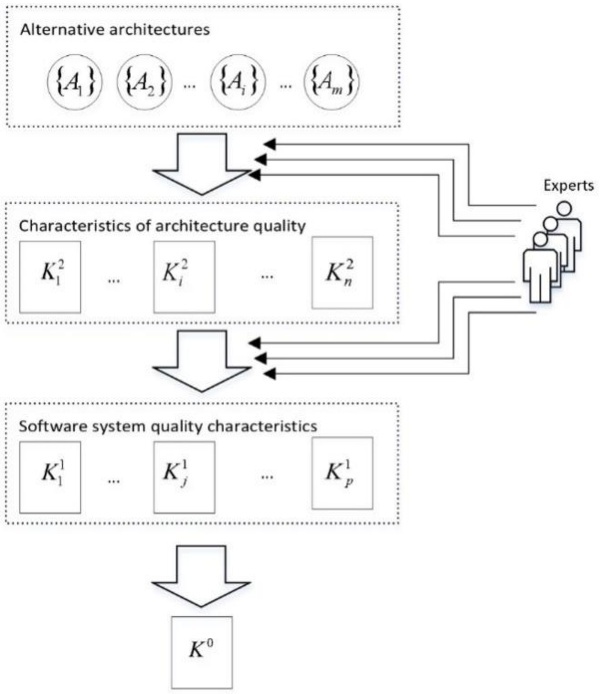

Fig.1. General description of the problem of multi-criteria software architecture evaluation

The comparative assessments of alternatives $\{A_i\}$ for each criterion $K_i^2, i=\overline{1,n}$ can be obtained from the AHP or Modified AHP (MAHP). Their applications are described in details in papers [4], [7]. The difference between MAHP and AHP is that first method determines the assessments of alternatives by quality criteria realization from the condition of minimization of inconsistency measure of the matrices of pairwise comparison. This approach allows to expand limits of the application of AHP for greater quantity of alternatives (criteria) ($n \le 30$) [7]. To evaluate the set of criteria the method of scalar convolution is used most often. In this case vector of criteria $\{K_i^2\}, i=\overline{1,n}$ is replaced with scalar. Its calculation requires the coefficients of criteria weights assignment, what dealt with acquiring and processing of expert information.

As rule, a few groups of professionals, which have different opinions on the level of influence of each quality attribute on general quality of the SWS architecture, take part in expert evaluation. The indices of competency for each group are assigned ($\alpha_1, \alpha_2, \ldots, \alpha_n$) to improve of the authenticity of their assessments and to reach the trade-off.

Then every group forms matrices of pairwise comparisons for quality criteria and calculates the weights of criteria $\{p_i^s\}, i=\overline{1,n}$; using AHP; here s is the number of group of professionals. Compromise decision can be reached as a geometric mean $p_{ij}^* = \sqrt[n]{p_{ij}^1 \cdot p_{ij}^2 \cdot \ldots \cdot p_{ij}^n}$ or as average mean taking into account the indices of the competency of the groups of professionals $p_{ij}^* = p_{ij}^{\alpha_1} \cdot p_{ij}^{\alpha_2} \cdot \ldots \cdot p_{ij}^{\alpha_n}$. But in case of significant differences in assessments such mean can not lead to the trade-off of interests. As follows from data represented in Table 1 the values of criteria weights obtained from the results of assessment of architectures quality acquired from different groups of professional differ more than twice.

TABLE 1

PRIORITIES OF QUALITY CRITERIA

Quality attributes	**Stakeholders**			**Gene-ralized value**
	deve-lopers	**users**	**custo-mers**	
Modify-ability	0,216	0,294	0,184	0,280
Scalability	0,087	0,092	0,038	0,082
Performance	0,052	0,117	0,087	0,097
Cost	0,245	0,019	0,272	0,135
Developmen t effort	0,245	0,019	0,272	0,135
Portability	0,050	0,155	0,053	0,094
Ease of install	0,106	0,304	0,093	0,177

In this case the usage of averaged values for assessments of criteria weights cannot ensure the trade-off, and application of linear convolution for assessment of alternative SWS architectures for choosing the best among them can be not valid. So other approaches for reasoning of solution have to be found.

III. TRADE-OFFS OPTIMIZATION FOR MULTI-CRITERIA ASSESSMENT AND SELECTION OF SWS ARCHITECTURE

As we mentioned above the assessment of alternatives $\{A_i\}$ by the totality of quality criteria most often are determined using calculation of scalar convolution of criteria. The linear additive convolution is used most often:

$$Q(A_i) = \sum_{j=1}^{m} \alpha_j \cdot K_{ij}^2(A_i),\ j = \overline{1,m}. \quad (1)$$

Here α_j is a weight of j[th] criterion; K_{ij}^2 are computed assessments of corresponding components of the criterion for i[th] alternative. The value of α_j from one side expresses the weight, which assigned to given criterion by the decision maker, and from other side it is the partial derivative of criterion function for j[th] criterion in the basic operating point. But it is important to keep in mind that this is only linear approximation of criterion function.

The solution of the problem of vector optimization under the condition of criteria minimization is represented as follows:

$$A_{op} = \arg\min_{A_i} \sum_{j=1}^{m} \alpha_i \cdot K_{ij}^2(A_i),\ i = \overline{1,m}. \quad (2)$$

The assignment of values α_i and their ratio defines accepted trade-off. The selection of the trade-offs scheme is performed by decision maker which has conceptual nature. To formalize this procedure the criteria importance was proposed to define with respect to the tension of current situation in [8].

In different situations the rank of "the most important" can be assigned to different partial criteria. In other words, the scalar convolution of partial criteria must define the scheme of trade-offs, that can adopt to the situation. The concept of the tension of situation is introduced to be a measure of proximity of relative (reduced to 1) partial criteria to their threshold values.

In our case the tension of situation will be defined for each parameter of each alternative. The process of sequential examining of alternatives will simulate the change of situation tension. That is, tension of situation under the examination of alternative A_i by criterion K_j will be defined using the following expression:

$$\vartheta_{ij}\left(K_{ij}^2, A_i\right) = 1 - \overline{K}_{ij}^2(A_i),\ i = \overline{1,m};\ j = \overline{1,n}. \quad (3)$$

Here $\overline{K}_{ij}^2$ is a relative value of the criterion, obtained by dividing it on the threshold value for the case of criterion function minimization.

Let examine nonlinear trade-off scheme, which is relevant to the model of vector optimization, and obviously depends on characteristics of situation tension:

$$A_{op} = \arg\min_{A_i} \sum_{j=1}^{m} \alpha_j \left[1 - \overline{K}_{ij}\right]^{-1},$$
$$\sum_{j=1}^{m} \alpha_j = 1;\ i = \overline{1,m};\ \alpha_j \geq 0. \quad (2)$$

Nonlinear model of trade-offs does not require obligatory reduction to uniform way of extremization, for example, to criteria minimization. If there are both such that have to be minimized and such that have to be maximize among *s* criteria, then the scalar convolution will be as follows

$$Q(A_i) = \sum_{j \in L_1} \alpha_j K_{ij}^2 \left(K_{ij}^2 - R_j\right)^{-1} + \sum_{j \in L_2} \alpha_l K_{il}^2 \left(R_l - K_{il}^2\right)^{-1},$$

$i = \overline{1,m}$, where $K_{ij}^2,\ j \in L_1$ are criteria for minimization, $K_{il}^2, l \in L_2$ are criteria for maximization, R_j and R_l are corresponding threshold values of criteria. For acquiring of criteria's weights in the Eq. (2) the iterative dual procedure is used, what is based on the method of simplex-panning [9].

IV. THE METHOD OF MULTICRITERIA CHOICE OF SWS ARCHITECTURE ON THE BASE OF INFORMATION ABOUT CRITERIA COMPARABILITY

Let set of alternatives $\{A_i\}$ with estimated relative values of quality criteria $\{K_{is}\}$ be considered. In case when some alternative has preferences over others, and is the most acceptable, but its assessments on some criteria are not the best then a problem of optimal correction of those assessments using the "replacement - compensation" procedure will have been arisen. Firstly, the candidate for the best alternative has to be chosen. Then the values of the criteria on which this alternative is not the best are increased, by reducing at the same time the indicators on which it is the best. The optimization model of such substitution is constructed as a model of linear programming, solution of which gives us the necessary decision [10].

Let consider some alternative A_i from set $\{A_i\}$. Let K_r and K_s be r[th] and s[th] components of quality criterion of alternative. Connection between criteria differences in this problem can be represented as $\Delta r, \Delta rs = f(r, s, K, \Delta r)$.

The problem is to make alternative A_i better than alternative A_j (i≠j) using the replacement of its components until each component of A_i is not worse than relevant component of A_j (i≠j) and some components are even better. That is if A_i^p is the

alternative that replace A_i by correction of K_r and compensation of K_s, then their corrected values will be $\overline{K}_r^{ip} = \overline{K}_r^{i} - \Delta_r$, $\overline{K}_s^{ip} = \overline{K}_s^{i} + \Delta_{si}$, $\Delta_{si} = f\left(r, s, \overline{K}, \Delta_r\right)$, where $\overline{K}$ is a vector of criteria values.

The expression for trade-off under replacement for set of components of vector $\overline{K}^i$ of alternative A_i, which we want to make better than A_j can be written as:

$$\Delta\overline{K}_r^{ir_z} = C_r^{ir_z} \cdot \Delta K_r^i,\ r_z \in R_i^2(r),\ r \in R_i^1, \quad (1)$$

where $\Delta\overline{K}_r^{ir_z}$ is possible decreasing of component $\overline{K}_r^i$ in term of increasing $\overline{K}_{r_z}^i$; R_i^1 is a set of indices r, for which $\overline{K}_r^{iz} > \overline{K}_r^j$, $j = \overline{1,n}; i \neq j$; $R_i^2(r)$ is given for R_i^1 set id indices such that the components $\overline{K}_r^i, r \in R_i^1$ can take place in replacement of components $\overline{K}_s^i, s \in R_i^2(r)$; $C_r^{ir_z}$ are given coefficients of proportionality, which in fact define the accepted compromise in assessment of importance of quality criteria.

Components of vector $\overline{K}^i$ after replacement are defined by following expressions:

$$\overline{K}_r^{ip} = \overline{K}_r^{i} - \sum_{r_z \in R_i^2(r)} C_r^{ir_z} \cdot \Delta\overline{K}_{r_z}^{i}, \quad r \in R_i^1;$$

$$\overline{K}_r^{ip} = \overline{K}_{r_z}^{i} + \sum_{r \in R_i^1} \sum_{r_z \in R_i^2(r)} \Delta\overline{K}_{r_z}, \quad (2)$$

$$r_z \in s,\ s \overline{\in} R_i^1,\ r_z \in R_i^2(r).$$

Let consider the procedure of replacement. We will take into account constraints on minimum criteria values, introduced in problem of alternative evaluation:

$$\overline{K}_s^{ic} > S_s^i,\ \left(s = \overline{1,m},\ i = \overline{1,n}\right), \quad (3)$$

where S_s^i defines the minimum possible values of *s*-th component of criteria K_i of alternative A_i.

The optimization of replacement procedure is performed by maximization of following criterion $\max \sum_{s=1}^{p} \beta_s K_s^i$, with constraints (1), (2), (3), where β_s are weight factors of quality criteria.

Accepting Pareto-optimal strategy, we will receive the maximization problem under the constraints (1), (2), (3):

$$\max \left\{ \begin{array}{l} \sum_{l \in L_i'} \beta_l \left(K_l^i - \sum_{l_m \in L_i^2(l)} \Delta K_l^{ilm} \right) + \\ + \sum_{\substack{l_m \cup L_i^2(l) \\ \forall l \in L_i^1}} \beta_{lm} \left(K_{l_m}^i + \sum_{l_m \in L_i^2(l)} \Delta K_l^{ilm} \right) \end{array} \right\}. \quad (4)$$

β_l, ΔK_l^s are unknown here.

Let consider the application of the above models for solution of practical replacement problem. We have three alternative architectures, the quality of which is assessed by five criteria. The problem is to adjust the characteristics of one of the alternatives in order to meke it best. Numerical values of architectures estimates obtained using the modified AHP are given in Table 2.

TABLE 2

NUMERICAL VALUES OF ARCHITECTURE ASSESSMENTS RECEIVED USIND MAHP

Criteria	**Architectures**		
	A_1	**A_2**	**A_3**
K_1	5	2	2
K_2	4	4	4
K_3	3	5	6
K_4	2	4	3
K_5	4	1	2

It is necessary to correct assessments of the alternative A_1 in such a way that it will be not worse for all criteria then two other alternatives, and for some criteria it will be better.

Here the set $L_i^1 \rightarrow \left(\forall l \in L_i^1, \overline{K}_l^i > \overline{K}_l^j, i \neq j \right) \in \{1;5\}$, and correspondently $L_i^2 = \{3;4\}$. The problem is to decrease the assessments of the first and fifth criteria in order to increase third and fourth assessments such that they will be not worse than in two other alternatives.

As a result of solution of optimization problem (1), (2), (3), (4) with introduced constraints we will obtain:

$$\Delta K_{13} = 0{,}12;\ \Delta K_{14} = 1{,}11;$$

$$\Delta K_{53} = 0{,}18;\ \Delta K_{54} = 0;\ y = 0{,}13.$$

The criteria values for alternative architectures taking into account the corrections are given in Table 3.

TABLE 3.

CRITERIA VALUES FOR ALTERNATIVE ARCHITECTURES TAKING INTO ACCOUNT THE CORRECTIONS

Criteria	**Architectures**		
	A_1	**A_2**	**A_3**
K_1	2,04	2	2
K_2	4,00	4	4
K_3	6,44	5	6
K_4	4,53	4	3
K_5	2,71	1	2

Now alternative A_1 is the best by all criteria excepting K_2, for which its assessment is not worse than assessments of other alternatives. Thus in given method of selection the best alternative based on its assessments

corrections trade-off has to be defined just between criteria which participate in replacement but not between all the criteria using assignment of proportionality coefficients $C_r^{ir_z}$. It is much more easier problem than determination of all criteria weights.

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III. Conclusion

When scalar convolution is used for multi-criteria problem of SWS architecture selection the problem of proper determination of weights for partial criteria as a results of expert questioning is appeared.

The universal scalar convolution can be used to solve this problem. It reflects the proximity values of criteria to their threshold values, i.e. the criticality of current situation. Since such convolution is nonlinear with respect to the level of situation criticality for each criterion, so its application from one side allows to take into account technological "limitations" for criteria values. From other side it is more accurate expression of dependence of integral criteria from the level of "criticality".

It is shows as well that application of the procedure of criteria "replacement-compensation" in case when the preference for some alternative is granted, which is not the best for some criteria, allows to correct its indices in such way, that it can be picked for the project implementation.