

# An Optimal Trade-off Solution of the Software Architecture Choice Problem

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**Abstract.** The problems of a multi-criteria decision making model of software system architecture dealing with definition of criterion function and formalization of the trade-off estimation procedure are discussed. Taking into account the domain requirements and criteria values limitations, the universal scalar convolution is proposed where the weights of the quality criterion depends on its proximity to the limitation. An optimization model of "replacement-compensation" was used for solution of reengineering problems and directed selecting of software architecture.

**Keywords:** software system architecture, software architecture quality, quality characteristics, trade-off, decision making.

## 1. Introduction

The component technology based on the usage of components taken from earlier executed projects (reused components) is widely applied for software systems (SWS) design [1]. The design of such an architecture technology starts with the frame selection based on the SWS requirements and filling it with necessary components taken from the repository or Internet. The frame is a high-level abstraction of the SWS design and it combines the set of interacting objects into some integrated environment [2]. The pattern is an expansion of the component concept. It is also an abstraction that contains description of interactive objects in generalized cooperative action 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 patterns usually contains several components that produce the same functionality, the set of alternative SWS could be obtained in the component technology design. Selection of the most acceptable architecture option with the respect to the set of quality criteria requires either arrangement of alternatives according to the quality criteria values or use of some integral index with own value for each alternative.

Only few SWS architecture evaluation methods are used in practice. The most popular methods are based on the development and testing scenarios for certain architecture to satisfy the quality criterion. ATAM and SAAM are the most known methods of this type [3], [4]. The most common disadvantage of these two methods is generation and analysis of rather large quantity of development scenarios upon implementation which makes them laborious, expansive and complicated for formalization. Emergence of Analytical Hierarchic Process (AHP), that was proposed to overcome ATAM and SAAM drawbacks, led to considerable improvement of the architecture selection procedure and its further formalization for automation of decision making processes [5], [6].

In turn, the essential disadvantage of AHP is the limited quantity of alternatives for evaluation ( $n \leq 7 \pm 2$ ) that caused by the inconsistency of elements in the matrices of pairwise comparisons. Inconsistency also increases as quantity of alternatives grows [7]. To solve this problem, Pavlov offered the modification of AHP where weight multipliers alternatives are obtained from the condition to minimize misalignment matrix of paired comparisons [8]. Such a modification would simplify the initial problem to the problem of mathematical programming. The problems of modified AHP (MAHP) application in terms of the task of evaluating alternatives architecture of software systems with a large number of alternatives are described elsewhere [9, 10].

Final selection of architecture option is often performed via replacement of multi-criteria optimization with single criterion usually expressed as additive convolution of partial quality criteria. The weights of partial criteria are determined herewith by expert method of subjective nature that is badly formalized and

could be a source of additional errors. The trade-offs made between criteria are also remain hidden when scalar convolution is used. The acceptable structure of scalar convolution should be first selected. In order to reduce the subjective influence on the weights of quality criteria selection and to take into the account requirements of subject area, formalized methods of partial criteria weighting should be applied. By using universal scalar convolution [11] in this report, the objective function that depends on the measure of situation tension and determined by proximity of criteria values to their limits is optimized. The iterative procedure of simplex planning is used for formalization of criteria weighting process. The other important problem is mathematical formalization of SWS reengineering processes for optimal utilization of required resources. To address this issue, we used "replacement-compensation" procedure and optimization model of software architecture (SWA) alternatives' quality criteria changes definition in this report. These changes can reflect changes of requirements to the architecture.

## 2. Problems of software architecture multi-criteria selection

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

The following denotations are used:  $K_j^1, j = \overline{1, p}$  are quality criteria of SWS itself, defined according to the ISO/IEC 25010 requirements in terms of standard;  $K_i^2, i = \overline{1, n}$  are architecture quality criteria defined from the set of  $K_j^1, j = \overline{1, m}$  using SQFD (Software Quality Function Deployment) method or pairwise comparisons method [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.

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 elsewhere [5], [10]. The difference between MAHP and AHP is that first method determines the alternatives assessments by quality criteria solution from the condition of a minimum degree of consistency of the matrix of pairwise comparison. This approach allows expanding the limits of AHP application for greater quantity of alternatives (criteria) ( $n \leq 30$ ) [10]. The weights of criteria are determined with expert method by calculating the integral criterion of alternatives' quality with applying of scalar convolution.

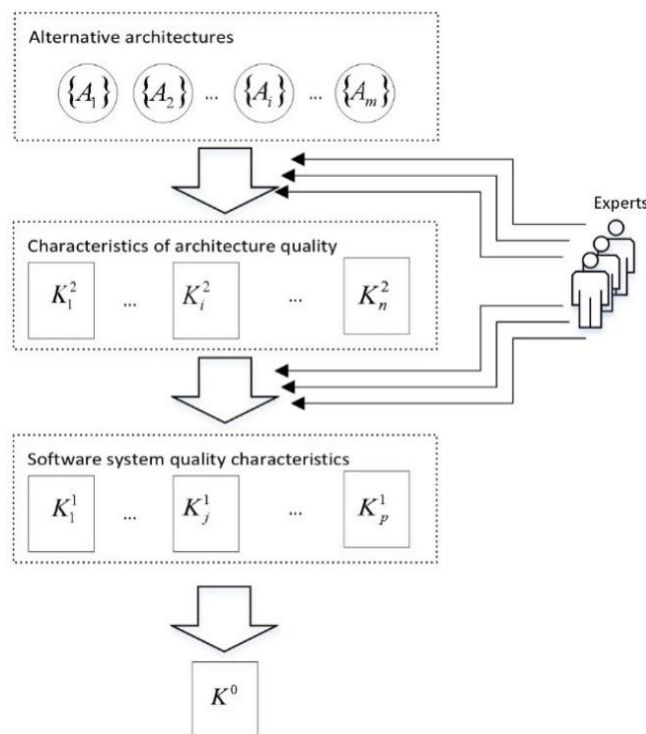


Fig.1. General description of the problem of multi-criteria software architecture evaluation.

Usually an expert evaluation of the SWA general quality is performed by a few groups of professionals, which have different opinions on the level of individual quality influence. The indices of competency  $(\beta_1, \beta_2, \dots, \beta_r)$ ,  $\sum_{i=1}^r \beta_i = 1$ ,  $\beta_i \geq 0$  for each group are assigned to improve the authenticity of their assessments and to reach the trade-off. Every group then forms matrices of pairwise comparisons for quality criteria and calculates the weights of criteria  $\{\alpha_i^s\}$ ,  $i = \overline{1, n}$ ;  $s = \overline{1, r}$  using AHP; where  $r$  is the experts' group number. Compromise decision can be reached as a geometric mean  $\alpha_i = \sqrt[r]{\alpha_i^1 \cdot \alpha_i^2 \cdot \dots \cdot \alpha_i^r}$  or as average mean taking into account the competency indices of the experts groups  $\alpha_i = \sqrt[r]{\alpha_{i1}^{\beta_1} \cdot \alpha_{i2}^{\beta_2} \cdot \dots \cdot \alpha_{ir}^{\beta_r}}$ ,  $i = \overline{1, n}$ . However in the case of significant assessment differences, such a mean cannot lead to the trade-off of interests. According to data represented in Table 1 [10], the values of criteria weights in evaluating alternative architectures differ more than twice when acquired from different groups of professionals.

The usage of averaged values for assessments of criteria weights cannot ensure the trade-off in this case, and application of linear convolution for assessment of alternative SWA for choosing the best among them can be incorrect. Therefore it is necessary to take into account the possibility of requirements change to SWA during the design process and, respectively, change of quality requirements weights during the SWA selection.

Table 1. Weights of quality criteria

Quality attributes	Stakeholders			Generalized value
	developers	users	customers	
Modifiability	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
Development 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

At the same time, the usage of linear additive scalar convolution for approximation of objective function causes a number of problems. It can be treated as linear regression that is approximate representation of criterion function in small neighbourhood of "work points". To ensure more accurate representation of criterion function as well as to take into account the proximity of partial criteria values to their limits it is necessary to use nonlinear function in respect to partial criteria. We propose to use universal scalar convolution [11] to solve above listed problems.

### 3. Analysis of alternatives ranging sensitivity and selection of criterion function for architectures assessment

Most methods for SWA assessment include evaluation of separate quality criteria and integral evaluation of the criteria totality [8], [9], [13]. Moreover, the integral assessment is carried out by calculation of the value function as linear convolution of partial criteria. It is during the decision selection when some problems arise related to complexity of quality criteria weights determination, especially when their values for some criteria are close enough. It is also necessary to take into account the possibility of quality requirements changes during the SWA design that will lead to criteria weights change. The later will cause the reordering of ranged alternatives and as a result changing the decision on alternative architecture selection.

Therefore it is necessary to examine the sensitivity of the decision and probable trade-offs between quality criteria when taking into account possible quality requirements changes and for the selection of most stable for these changes decision on architecture.

The decision sensitivity problem of changes in weights making quality criteria and determination of trade-offs in SWA assessment and selection problem was initially described by L. Zhu et al [13], however there were proposed no methods for the problem analysis. This can be explained by the fact that most used methods for SWA analysis, such as ATAM and others scenario based methods, are not quantitative. At the same time, quantitative methods, such as CBAM [15] and AHP [7] can be used to solve this problem. In the

CBAM method customers can determine dependencies between costs for reaching of given values of quality criteria for certain architecture alternative and quality requirements using the function of the utility and then to carry out calculations for evaluating of alternatives and choosing the best one [5]. But as it denoted in [6] it quite difficult to acquire the function of the utility from customers. Thus using of CBAM for the solution of this problem is challenging.

Another perspective method is AHP that gives possibility to obtain assessments of alternative relatively to all quality criteria and applying scalar convolution of criteria to gather the assessments for their totality. It allows to range alternatives according to values of partial quality criteria and integral quality criterion and to investigate possible changes in the order of ranging.

### 3.1. Sensitivity analysis of alternatives' ranging to changes of the quality criteria weights

Let's discuss the sensitivity of decisions obtained with applying of AHP to changes of the quality criteria weights.

Let's assume that we know the weights of alternatives' quality criteria  $\{\alpha_i\}$ , and architectural alternatives  $\{A_i\}$  are ranged according to the assessments, determined by AHP. The equation for estimating the minimal change of absolute value of quality criterion's weight, such that alternatives  $A_i$  and  $A_j$  will change the order to the opposite, is as follows:

$$D'_{s,i,j} = \frac{|J_i - J_j|}{|K_{js}^2 - K_{is}^2|} \cdot \frac{100}{\alpha_s} \quad (3.1)$$

Here  $D'_{s,i,j}$  ( $s = \overline{1, m2}; i, j = \overline{1, n}, i \neq j$ ) is a minimal change of weight of quality criterion  $K_s$  that changes the order of neighbor alternatives  $A_i$  and  $A_j$  to opposite;  $J_i$  and  $J_j$  are values of integral quality index for  $i^{\text{th}}$  and  $j^{\text{th}}$  alternatives. The smallest value of  $D'_{s,i,j}$  shows that the weight of attribute  $K_s$  is critical to the changes of assessments in pairwise comparisons. This expression can be also used in case of change requirements to the SWS during the design process that can lead to changes of weights relatively quality criteria.

Some values of  $D'_{s,i,j}$  that can change the order of ranged neighbor alternatives may be available for each quality attribute. Most sensitive and most critical decision corresponds to the smallest value of  $D'_{s,i,j}$ . Thus, it is more advisable to select not the best quality criterion decision when making decision but that, for which  $D'_{s,i,j}$  will not be critical to change of criterion's weight.

The smallest values of  $D'_{s,i,j}$  that can cause the change of assessments of alternatives obtained according to Eq. (3.1) are shown in the Table 2.

Table 2. The smallest change of quality criteria's weights for change in the order of ranging

Quality attribute	Alternative $i$	Alternative $j$	Smallest change
Performance	A1	A2	9,4
Cost	A1	A2	5,1
Development effort	A1	A2	3,1
Portability	A1	A2	2,4
Ease to install	A1	A2	13,5
Scalability	A2	A1	5,7
Modifiability	A2	A1	3,9

The numbers in the table 2 are in percents from the absolute value of quality attribute's weight. As we can see, the portability has second smallest weight among quality attributes and simultaneously this attribute is most sensitive to the changes. Thus the analysis of sensitivity allows determination of the quality attributes' weights limits when the requirements of subject area are changed. The change of requirements can occur both during SWS design and during reengineering process. In case these changes are within of defined limits the current order of ranged alternatives will not change.

### 3.2. Selection of criterion function and determination of trade-offs schemes

The criterion function should be selected with taking into account the problem's specific principle that individual decision makers guided by and accepted schema of trade-offs.

It is known that multi-criteria decision must be made in the Pareto region (which is the region of trade-offs) because the improvement of one criterion in it can be made via decline of others. Most often Pareto region for convex set of criteria values will be determined by the following equation.

$$X = \bigcup_{x \in X_\alpha} \arg \min_{x \in X} \sum_{j=1}^m \alpha_j K_j(x) \tag{2.2}$$

where  $X_\alpha$  is the domain of solutions,  $K_j$  are values of partial criteria,  $\alpha = \{\alpha_j\}_{j=1}^m$  is a parameter defined on the set:

$$X_\alpha = \left\{ \alpha \mid \sum_{j=1}^m \alpha_j = 1, \alpha_j \geq 0 \right\} \tag{2.3}$$

Multi-criteria solution can be obtained from (2.2) for certain values of  $\alpha_j$ , defined by individual decision maker on the base of made trade-offs.

For taking into account limits for criteria values lets write down the criterion function (2.2) for the case of minimization as follows:  $Q(A) = \sum_{j=1}^m \alpha_j (R_j - K_j(A))$ .

For the possibility to compare partial criteria of different nature we will number them with values of limits:

$$Q(A) = \sum_{j=1}^m \alpha_j (1 - \bar{K}_j(A)) \tag{2.4}$$

This transformation is monotonous and according to Hermeier theorem any monotonous transformation does not change the results of comparison [11]. Thus we can represent the model of optimal architecture choice as follows:

$$A_{opt} = \arg \min_{A_i \in A} \sum_{j=1}^m \alpha_j (1 - \bar{K}_j(A_i)), i = \overline{1, n} \tag{2.5}$$

where A is a set of alternative architectures  $A = \{A_i\}, i = \overline{1, n}$ .

Criterion function (2.5) has a number of disadvantages. Firstly, it is only linear approximation in small neighborhood while parameters  $\{\alpha_j\}$  have content of partial derivatives of criterion function at criteria. Application the criterion function (2.4) can lead to significant errors in decisions when expanding the domain of definition. Thus we propose using nonlinear criterion function taking into account the principle "further from limits":

$$Q(A_i) = \sum_{j=1}^m \alpha_j (1 - \bar{K}_j(A_i))^{-1}, i = \overline{1, n} \tag{2.6}$$

This function is nonlinear relatively quality criteria and when values of some criteria are close to their limits the minimax model of decision making will be implemented:  $A_{opt} = \arg \min_{A_i \in A} \max_{j=1, m} K_j(A_i)$ .

The model of integrational optimality is used:  $A_{opt} = \arg \min_{A_i \in A} \sum_{j=1}^m \alpha_j (1 - \bar{K}_j(A_i))^{-1}$  for the situations when the criteria's values are far from limits.

If some criteria that can be both minimized and maximized, then (2.6) will appear as follows:

$Q(A_i) = \sum_{j \in L_1} \alpha_j (1 - \bar{K}_j(A_i))^{-1} + \sum_{j \in L_2} \alpha_j (\bar{K}_j(A_i) - 1)^{-1}, i = \overline{1, n}$ , where  $L_1$  is the set of criteria's indices for minimization and  $L_2$  set of criteria's indices for maximization.

To make optimal Pareto solution of choice for the problem of SWA selection on the set of criteria it is needed to determine  $\alpha_j$ , then substitute them into (2.6) and select the best alternative. As it was mentioned above, the use of expert technologies for criteria weights determination does not ensure acceptable compromise decision and could be a cause of extra errors. Thus for decision making we will apply dual iterative procedure where the individual decision maker obtains the solution from (2.6) for selected values of  $\alpha_j$ , analyzes obtained decision and, if needed, corrects values of  $\alpha_j$  in such a way, that obtained sequence of Pareto decisions will fall to its optimum. If the individual decision maker does not have any information about correlations between criteria, then initial value  $\alpha_j^0 = 1/m$ ,  $j = \overline{1, m}$  will be set and the equation (2.6) will be solved. On the next iteration we will build the regular simplex in the neighborhood of the point  $\alpha_j^0$ ; coordinates of the simplex's vertexes in m-dimensional space will be values of criteria weights  $\alpha_j^{1k} = S_j^k$ , where  $k = \overline{1, m}$  is a number of simplex's vertex,  $j$  is a number of a criterion. We will calculate the value of criterion  $Q_i$  then for each value of weights  $\alpha_j^{1k}$ ,  $k = \overline{1, m}$ . The vertex of the worst result simplex will be changed by its mirror reflection relatively to the middle of simplex opposite sites. Value of the criterion will be calculated in new vertex of simplex and the worst vertex will be determined again. This iteration procedure will be repeated until meeting the results set by the individual decision maker.

#### 4. The method of multi-criteria choice of SWS architecture on the base of information about criteria comparability

##### 4.1. Comparability under replacement during alternatives' assessments correction

Some alternative can be preferable for multi-criteria choice of SWA despite the fact it is not the best for all quality criteria. The problem arises when characteristics of such SWA must be correlated in order to introduce the best alternative during system's reengineering, and when requirements of subject area are changed. In this case the modification of selected architecture alternative is carried out in such a way that that it was the best for all criteria. The method of SWA multi-criteria choice based on the data about criteria comparability is one of these methods [14].

When using SWA method during the first step, based on the additional information about supremacies on the set of criteria  $K = \{K_i\}$ ,  $i = \overline{1, n}$ , the relation of criteria comparability by importance of  $S$  will be built. Based on assumed concept of comparability the rule T will be deducted then, which allows building the relation of supremacy  $R(P, T)$  on the set of criteria's assessments  $E^m$  and its further narrowing. The resulting relation includes introduced relations of pairwise comparability and belongs to the class of rational transitive relations. The final structure of the result relation of supremacy  $R$  in the space of criteria's assessments is defined by the structure of the relation of comparability.

Let's discuss the method of comparison by replacement.

The relations of supremacy are based on the local information about the criteria's importance. When building these relations the axiomatic approach offered by V. Podinovskiy is applied [12].

The concept of comparability under replacement is not reduced to any structuring benefits of supremacies for all set of alternatives  $\{A^n\}$  but only shows for any alternative  $t$  the possibility of compensation (by supremacy) of any change of criteria  $K_r$  by some change of criteria  $K_s$ .

The concept of comparability under replacement of criteria  $K_r$  and  $K_s$  is defined by the essence of these criteria and made trade-off relatively to their importance. The following definition of comparability by replacement is introduced in the paper [12]. If for the alternative  $A_i$  and for any  $\Delta s$  exists equipollent alternative  $A_{ic}$  such that  $\overline{K}_r^{ic} = \overline{K}_r^i - \Delta r$ ,  $\overline{K}_s^{ic} = \overline{K}_s^i + \Delta r s$ ,  $\Delta r s = f(r, s, \overline{K}, \Delta r)$ ,  $\frac{\Delta r}{\Delta r s} > 0$ , then criteria  $K_r$  and  $K_s$  are comparable by replacement  $K_r C K_s$ . Here  $\overline{K}_i$  are the values of criteria and in the function  $f(r, s, \overline{K}, \Delta r)$  made trade-offs are accounted relatively to the criteria weights. It is also assumed that for  $\Delta r \neq 0$ ,  $\Delta r s \neq 0$  and for  $\Delta r = 0$  it is true that  $\Delta r s = 0$ ,  $A_{ic} = A_i$ . Notably, the relation of comparability by

replacement is symmetrical but is not transitive in general case. That is  $K_r C K_s, K_s C K_r$ , however  $K_r \bar{C} K_s$ .

### 4.2. Case study of the described approach

Let's consider a set of alternatives  $\{A_i\}$  with the estimated relative values of the qualitative criteria  $\{K_{is}\}$ . In case when some alternative has preferences over others while been 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 emerge. 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 [14].

Let's consider the alternative  $A_i$  from the set  $\{A_i\}$ . Let  $K_r$  and  $K_s$  be  $r^{th}$  and  $s^{th}$  components of the quality criterion for such alternative. In this problem the correlation between the criteria differences can be represented as  $\Delta r, \Delta r_s = f(r, s, K, \Delta r)$ .

The goal is to make the alternative  $A_i$  more acceptable than the alternative  $A_j$  ( $i \neq j$ ) by replacing its components so that each component of  $A_i$  is not worse than the corresponding component of  $A_j$  ( $i \neq j$ ) and some components are even better. Thus if  $A_i^p$  is an alternative that replaces  $A_i$  by correcting  $K_r$  and compensation of  $K_s$ , then the corresponding corrected values will be

$$\bar{K}_r^{ip} = \bar{K}_r^i - \Delta_r, \bar{K}_s^{ip} = \bar{K}_s^i + \Delta_{si}, \Delta_{si} = f(r, s, \bar{K}, \Delta_r), \tag{4.1}$$

where  $\bar{K}$  is a vector of criteria values.

The equation for the compensation replacement of the vector components  $\bar{K}^i$  for the alternative  $A_i$ , which we want to make more acceptable than  $A_j$  can be written as:

$$\Delta \bar{K}_r^{ir_z} = C_r^{ir_z} \cdot \Delta K_r^i, r_z \in R_i^2(r), r \in R_i^1, \tag{4.2}$$

where  $\Delta \bar{K}_r^{ir_z}$  is a possible decrease of the component  $\bar{K}_r^i$  for the sake of increase  $\bar{K}_{r_z}^i$ ;

$R_i^1$  is a set of indices  $r$ , for which  $\bar{K}_r^i > \bar{K}_r^j, j = \overline{1, n}; i \neq j$ ;

$R_i^2(r)$  is a set of indexes for  $R_i^1$  so that the components  $\bar{K}_r^i, r \in R_i^1$  can be used for the components replacement  $\bar{K}_s^i, s \in R_i^2(r)$ ;

$C_r^{ir_z}$  are set proportionality coefficients, which in fact define the accepted compromise in assessment of the quality criteria importance.

Vector components of  $\bar{K}^i$  after the replacement are defined by the following expressions:

$$\begin{aligned} \bar{K}_r^{ip} &= \bar{K}_r^i - \sum_{r_z \in R_i^2(r)} C_r^{ir_z} \cdot \Delta \bar{K}_{r_z}^i, \quad r \in R_i^1; \\ \bar{K}_r^{ip} &= \bar{K}_{r_z}^i + \sum_{r \in R_i^1} \sum_{r_z \in R_i^2(r)} \Delta \bar{K}_{r_z}^i, \quad r_z \in s, s \in R_i^1, r_z \in R_i^2(r). \end{aligned} \tag{4.3}$$

Let's consider the following replacement optimization procedure. The minimum criteria values constraints introduced in the alternatives' evaluation should be taken into account:

$$\bar{K}_s^{ic} > S_s^i, (s = \overline{1, m}, i = \overline{1, n}), \tag{4.4}$$

where  $S_s^i$  defines the minimum possible values of  $s^{th}$  component for the criteria  $K_i$ , alternative  $A_i$ .

The replacement procedure optimization is performed by maximizing the following criterion

$$\max \sum_{s=1}^p \beta_s K_s^i, \tag{4.5}$$

applying constraints (4.2), (4.3), (4.4), where  $\beta_s$  are weight indexes of the quality criteria.

As the result the following linear programing problem will be obtained:

$$\max \left\{ \sum_{l \in L_l^1} \beta_l \left( K_l^i - \sum_{l_m \in L_l^2(l)} \Delta K_l^{ilm} \right) + \sum_{\substack{l_m \in L_l^2(l) \\ \forall l \in L_l^1}} \beta_{l_m} \left( K_{l_m}^i + \sum_{l_m \in L_l^2(l)} \Delta K_l^{ilm} \right) \right\}. \quad (4.6)$$

Here unknowns are  $\beta_l, \Delta K_l^s$

Let's consider the application of the described models for solving the practical replacement problem. We have three alternative architectures, the quality of which are assessed using five criteria. The alternate goal is to adjust the characteristics of one of the alternatives in order to make it the most acceptable. The numerical values of the architecture assessments are obtained using the modified AHP and are presented in Table 3.

Table 3: Numerical values of the architecture assessments using MAHP

Criterion	Architectures		
	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>
K <sub>1</sub>	5	2	2
K <sub>2</sub>	4	4	4
K <sub>3</sub>	3	5	6
K <sub>4</sub>	2	4	3
K <sub>5</sub>	4	1	2

It is necessary to correct the assessments for the alternative A<sub>1</sub> in such a way that it will not be worse for all criteria than the other two alternatives, and for some criteria it will be better.

Here the set is  $L_l^1 \rightarrow (\forall l \in L_l^1, \bar{K}_l^i > \bar{K}_l^j, i \neq j) \in \{1;5\}$ , and correspondently  $L_l^2 = \{3;4\}$ . The goal is to apply the assessments decrease of the first and fifth criteria in order to increase the third and the fourth assessments is such a way that they will be not worse than in other two alternatives. Since the maximum assessment of first criterion for the second and third alternatives is 2 and for the fifth one is 2 too, these limitations are set as following:

$$5 - (\Delta \bar{K}_{13} + \Delta \bar{K}_{14}) \geq 2 \pm 1 \cdot y;$$

$$4 - (\Delta \bar{K}_{53} + \Delta \bar{K}_{54}) \geq 2 \pm 0,8 \cdot y.$$

In order for the assessments of the third and fourth criteria that are applied in the correction were not worse than for the other two alternatives, the limitations are set as following:

$$3 + (1,6 \cdot \Delta \bar{K}_{13} + 1,3 \cdot \Delta \bar{K}_{53}) \geq 6 + 0,5 \cdot y;$$

$$2 + (2,5 \cdot \Delta \bar{K}_{14} + 2 \cdot \Delta \bar{K}_{54}) \geq 4 + 0,6 \cdot y.$$

The replacement coefficients  $C_l^{ilm}$  are introduced by the experts based on the criteria importance.

Table 4. Architecture assessments with corrections

Criterion	Architecture		
	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>
K <sub>1</sub>	2,04	2	2
K <sub>2</sub>	4,00	4	4
K <sub>3</sub>	6,44	5	6
K <sub>4</sub>	4,53	4	3
K <sub>5</sub>	2,71	1	2

The limitations of the maximum adjustment of the assessment for the first and fifth criteria are represented as follows:

$$\Delta \bar{K}_{13} + \Delta \bar{K}_{14} \leq 3;$$

$$\Delta \bar{K}_{53} + \Delta \bar{K}_{54} \leq 2.$$

As a result of the optimization problem, the solution with the introduced limitations will be set the following way:



$$\begin{aligned} \Delta K_{13} &= 0,12; \Delta K_{14} = 1,11; \\ \Delta K_{53} &= 0,18; \Delta K_{54} = 0; y = 0,13. \end{aligned} \quad (4.7)$$

The architecture assessments taking into account the calculated corrections are shown in the Table 4.

Now the alternative  $A_1$  is the most acceptable for all criteria except  $K_2$ , which assessment is not lower than the assessments of other alternatives. Thus in the described above selection method of the best alternative based on the assessment corrections, the trade-off should be defined based solely on the replacement criteria as apposed to using all criteria by assigning the proportional coefficients  $C_i^{ix}$ . For this reason such problem is easier than the problem of determination of all criteria weights. However, the disadvantage of such an approach is that this method cannot be applied in cases when criteria are not comparable.

## 5. Conclusion

The problem of proper determination of weights for partial criteria as a results of expert questioning is emerging when scalar convolution is used for multi-criteria problem of SWS architecture selection. 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 the other side it is more accurate expression of integral criteria dependence from the level of "criticality".

In case when the preference for some alternative is granted, application of the procedure of criteria "replacement-compensation" allows to correct its indices in such way, that it can be selected for the project implementation.

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