# A Decision Making Method for Reconfiguration of Adaptive Info-communications Systems

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# A Decision Making Method for Reconfiguration of Adaptive Info-communications Systems

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**ABSTRACT**

The adaptation both information and communication systems to variable external factors is implemented through the modernization activities. In this paper the problem of decision-making for adaptive system reconfiguration under uncertainty is considered. The decision-making method is used to detect a need for reconfiguration, built a set of reconfigurations plans and choose the preferable one based on data collection from diagnostic sensor network. Integral decision-making criterion combines the criterion for selecting a suitable reconfiguration moment and alternative. The main idea of the proposed method is to combine the multifactor active diagnostic model, weighted utility and preference theory, decision-making technique under uncertainty with comparison methods for fuzzy trees with incomplete requirement. The general result is achieved by reducing the uncertainty of diagnostic data. It is expected that the proposed decision-making method will help to improve the systems' suitability in the case of uncertainty.

Keywords: IT System, Adaptation, Decision-Making, Criterion, Uncertainty, Suitability, Reconfiguration

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## 1. INTRODUCTION

The development of large information and communication systems for organizations and enterprises has led to a significant increase in their structural and functional complexity. Management information systems, distributed computing systems, distributed networks of situation centers, cloud storage and data centers, telecommunications systems include dozens of subsystems with hundreds of heterogeneous components. They combine technology equipment, communication networks, computing and information systems, analytical resources. The purpose of distributed information and communication environments is to automate the execu-

tion of technological processes at extended enterprises by providing a set of information and communication services: automation, computerization, information and telecommunications.

The development of such complex systems is implemented through the modernization activities. For info-communications environments we need to simultaneously implement a significant number of IT projects with increased system's efficiency.

The decision-making problem in IT system reconfiguration is currently being solved by multicriterial methods with experts and optimization techniques. However the situation of system development characterized by the uncertainty of internal and external factors such as goas of enterprise informatization, IT components using intensity, resources flow, IT services request flow and so on. This situation requires not only decision-making within selection a variant of modernization but also combined selection of modernization moment and variant. Thus, the proposal of a decision-making method for choosing the directions within the reconfiguration of adaptive infocommunication system under the conditions of system function uncertainty is relevant now.

## 1.1 The Review of Decision Making Approaches for Infocommunication System Reconfiguration

The development of complex info-communicational systems due to changes in external and internal factors determines effective decision-making for a rational choice of modernization alternatives. With the development of information and communication technologies such as Internet of Things, social media, 3D printing and with the increased enterprise diversification and distributing, a new methods of decision-making under conditions of uncertainly are required. The control method to reconfigure the systems is crucial for the total performance of based enterprise (Renna, 2017; Derevinsky, 2012). The base goal of decision-making in reconfigurable system is to save reconfiguration time, cost, and effort (Kurniadi and Ryu, 2017).

The problem of infocommunication system reconfiguration and particularly decision-making problem are very important in fast developing extended enterprises. There are many known approaches to reconfiguration including methods and techniques of management development (Derevinsky, 2012; Sokolov *et al.*, 2006; Myshenkov and Belyashov, 2013). The review of the main approaches used in the analysis, design and modernization of complex systems is given in (Myshenkov and Belyashov, 2013). The theory of complex systems structural dynamics is used for IT system reconfiguration (Sokolov *et al.*, 2006). In hierarchical systems the

modernization problem are considered with complex effects. Synthesis of the optimal reconfiguration plan may be realized by hierarchical systems of heterogeneous network structure (Gurman *et al.*, 2014) and linking the objectives between the strategic and operational level (Graeca and Ponomareva, 2012).

There are many kinds of reconfiguration systems decision-making approach: flexible and reconfigurable manufacturing systems (Han *et al.*, 2020; Hsieh, 2017), distribution network (Masucci *et al.*, 2016), dynamic cell formation (Niakan *et al.*, 2015), information fusion systems (Benoit *et al.*, 2009), cognitive radios (Colson *et al.*, 2008). A special decision making support is widely used. For example, a generic case-based reasoning decision support system for reconfiguration purpose based on past experience to facilitate the reconfiguration decision making process was proposed in the (Lejri and Tagina, 2012).

Different mathematical mechanisms are used to solve the decision-making reconfiguration problem. The Bellman-Zadeh method with Pareto objective space was adopted in the fuzzy resolution methodology proposed in (Bernardon *et al.*, 2019) to solve fuzzy multicriteria decision making problem. The Tabu Search algorithm (TS) is used to solve reconfiguration problem in the (Huang *et al.*, 2019) due to its excellent search ability. In (Masucci *et al.*, 2016) the multi-criteria decision making based on the ELECTRE II method was applied to distributed network reconfiguration in case of cascading effects of faults, cyber attacks and natural disasters. In the (Mabkhot *et al.*, 2019) a decision support system was proposed to create candidate configurations and select a suitable configuration considering a knowledge-based multi-criteria decision making approach based on ontology and TOPSIS. In (Shin *et al.*, 2018) a dynamic reconfiguration algorithm based on SVM method for the cyber-physical system environment was proposed. In (Niakan *et al.*, 2015) a bi-objective mathematical model based on Non-dominated Sorting Genetic Algorithm of Dynamic Cell Formation Problem with uncertainty conditions and social criteria between the minimization of the total costs and the maximization of social issues with the minimization of potential machine hazards and maximizing job opportunities was developed. A reconfiguration decision-making method based on a Game-Theory algorithm and on the Gale-Shapley model is proposed in (Renna, 2017).

The one of the main conditions of system reconfiguration decision-making is a change in the requirements of alternatives (Akchurin and Rodionov, 2010; de Gouveia and Magadanz, 2008; Wallin and Leijon, 2007). To solve this problem there are dynamic preferences considered within the uncertainty of temporal changes of requirements (Gerber and Rohde, 2013). The time dependences constrains in decision-making for reconfi-

rable systems are widely viewed in the literature. The model of discounted integral effect are considered in (Frederick *et al.*, 2002) based on the discounting and time preferences between alternatives. The papers (Dshemuchadse *et al.*, 2013; Zuberman *et al.*, 2009) view the base framework of decision-making in the conditions of dynamic change of alternatives' preferences. The preferences of active subjects changing over time is using for the temporal approach accounting of alternatives (Gigliotti and Sopher, 2003) for dynamic nature of decision-making. The approach of net discounting is used for the implementation of a complex system.

There are many discounting functions such as hyperbolic, quasi-hyperbolic, exponential, linear (Mishin, 2012; Gigliotti and Sopher, 2003) which describe the preferences between alternatives. The information about both uncertainties of the factors' values and the change of uncertainty depending on the conditions of decision-making under risk (Gerber and Rohde, 2013) are used for creating discounting function. They allow creating decision-making mechanism in the conditions of non-stationary system behavior. Also different time-dependent criterion functions are used to solve the problems of alternatives selection and ranking: fuzzy temporal utility to search necessary information in databases in (Pillai *et al.*, 2010), weighted utility functions for scheduling in distributed computing (Loginov, 2010), the base questions of a probabilistic dynamic method of a consumer choice (Ivanov and Kukushkin, 2010).

Other problem in the complex system reconfiguration is to determinate the moment of control action. To decide this problem the effective monitoring system is needed. Distributed info-communicational environments include diagnostic system based on sensor network. It can include special sensors and data acquisition system based on IoT technology (Han *et al.*, 2020; Kurniadi and Ryu, 2017). In (Han *et al.*, 2020) the decision-making system with the data acquisition system based on IoT technology combined with flexible and reconfigurable manufacturing systems were proposed. The planning of IoT data by reconfigurable system for manufacturing (RMS) was applied in (Scholz *et al.*, 2016). A modular reconfigure system based on 3D printing and the concept of SMARTLAM was proposed in (Scholz *et al.*, 2016).

For a complex reconfiguration problem multistage methods are proposed. For example (Renna and Ambrico, 2014) concerns mathematical models to support the design, reconfiguration and scheduling of the reconfigurable system: optimization model allows to manage the reconfiguration at fixed periods and allocation model uses to allocate the jobs into the components.

The purpose of paper (Wang and Tang, 2018) is to formulate a robust production system with minimal cost and maximum service level that can respond efficiently to the stochastic input demand.

Problem of reconfiguration the autonomous IT system has some distinctions. The method for autonomous decision making with multiple conflicting and operational objectives with a time-varying propagation environment was proposed in (Colson *et al.*, 2008).

Many viewed methods are preventive and off-line reconfiguration planning approaches, thus missing updated accurate data about system components activities and task flow. This may result to non-optimal and non-suitable decision especially in the conditions of environments and goal uncertainty. Thus, the problem to develop a new decision-making method of selection the modernization alternatives is relevant now.

## 2. METHOD

### 2.1 Decision Making Problem Under System Reconfiguration

Adaptive info-communicational systems are characterized by the fact that over time the composition, structure, and the functions list ceases to satisfy users' requirements, and also changing regulations and external factors. Thus, the suitability of technical systems decreases over time. The solution of such a problem is achieved by controlled targeted reconfiguration that is, changing the composition, structure and functions of the system through modernization and structural-parametric optimization. The decision-making for suitable alternative of modernization cycle is immediate reconfiguration.

Decision-making via modernization of an infocommunicational adaptive system is implemented by chosen moment of modernization and alternative plan through a set of alternatines. The goal of a decision-making system is to develop manageable adaptive infocommunicational system with the aim to maximize modernization IT components' positive effect and minimize the cost of reconfigurations activities.

The problem may be described by the following objectives:

1) the infocommunication system S includes several IT components $S_i$ that can be upgraded by the management system $MS$: $\{S_i\}, i = (1, I)$.

2) there are many alternatives to IT components modernization $A_i = \{A_{ij}\} : S_i \xrightarrow{A_{ij}} S_{ij}^*$, that can be used to improve the IT system.

3) the external conditions are characterized by:
   - reducing the duration of components' activity by its life cycle processes (and accordingly increasing the frequency of modernization);
   - increasing the structural and functional complexity of the IT system;

– increasing the level of automation and the num-
ber of alternatives to its implementation;
– increasing the external dynamics.
4) the current situation on reconfiguration process
leads to the following consequences:
– longer time to detect the need for reconfigura-
tion;
– increasing intensity of modernization requests;
– reducing the effect from reconfiguration actions.
5) modernization requests of IT component $S_i$ into
the uncertainty flow $\lambda_{ITreq}(t)$.
6) there are system requirements $RS = \{rs_i\}$ for the
ranking alternatives problem, determining the
characteristics of the modernized IT component.
7) the moment of modernization activity is unknown.
8) for reconfiguration of the system S, resources $R_S$
are used: $R_S = \sum_{i=0} R_i$. The amount of resources
used for the decision-making is under limit.

The problem is to find the modernization alternatives
from the set $A_{ij} \in A_i$ and an optimal reconfiguration mo-
ment $T_{ij}$:
$A_j(T_j) \succ A_k(t) \forall k \neq j$, to maximize the effect of moderni-
zation $E(A_{ij}(T_i)) = \max_{A_j \in A} E$.

## 2.2 Adaptive Infocommunication System Model

The reconfigurable infocommunication system S in-
cludes several IT components $S_i$:
$S = \{s_1, ..., s_I\}$. Due to a change in external conditions,
the suitability of the IT components $S_i$ decreases (Figure
1). If a drop in IT components suitability is detected
above the critical value $k_i(t) < k^{critical}$, the suitability level
is restored $k_i \rightarrow k^{restore}$ in duration of time $t^{modernization}$ by
means of reconfiguration (modernization) measures for
alternative $A_{ij} \in A_i$. Nonsuitable alternative $A_{ik} \in A_i$ cha-
racterized by other moment of reconfiguration $T_{ik}$ or
metrics of reconfiguration activities. For one IT compo-
nent, an alternative $A_k$ may be more preferable than
optimal $A_{ik} \in A_i$, $A_k(T_k) \succ A_j(T_k)$, but for overall system
optimal alternative and reconfiguration moment
$\langle A_{ik}, T_{ik} \rangle$ are more preference than any others.

The effect of the reconfigurable system may be de-
termined by sum of IT components effects calculated
through the service availability quotient:

$$E(S) = \sum_{i=1}^{I} \alpha_i \overline{k}_i \qquad (1)$$

where $\alpha$ – importance (significance) factor of IT compo-
nent, it depends on time; $\overline{k}$ – average value of service
availability quotient for IT components

$$\overline{k} = \int_{t_{create}}^{t_{utilize}} k(t) \approx k^{restore} + k^{min}/2 \qquad (2)$$

The identified effects are enhanced in the typical
system conditions:
– limited capacity to manage the modernization of
samples due to different affiliation and subordina-
tion relationships (interacting samples within an
adaptive multi-component system are usually op-
erated by different departments);
– heterogeneity of used components (wide range of
technical and software tools);
– uncertainties of external conditions (sources and
time points of modernization requests reception
are not determined);
– absence of standard design solutions (due to no-
velty of objects);
– the risks of modernization projects and creating
new components.

Known approaches to reconfiguration management
lead to:
– a decrease in the suitability of the systems;
– an increase of resource requirements for reconfi-
guration (life cycle support).

At the same time, the development of administrative
procedures for supporting the life cycle (reducing the
design, development, implementation, resource consump-
tion, labor intensity) does not compensate for the decrease
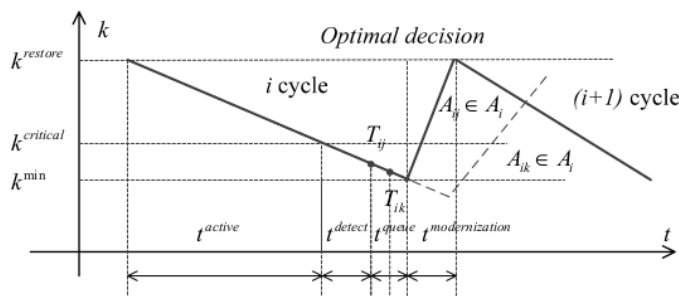in the suitability of the system within the framework of



**Figure 1.** Graph of service availability quotient for IT components as a function of time.

the model under consideration.

## 2.3 Integral Decision-Making Criteria for Information System Reconfiguration

The non-linearity determines system reconfiguration it as a class of complex organizational and technical problems. The multicriteria analysis methods allow searching the optimal solution for problem in the case of system uncertainty.

To solve the problem of systems reconfiguration, an integrated approach to decision making for reconfiguration in conditions of uncertainty are proposed in this article. It is based on an integral decision making reconfiguration criterion, combining a multifactor diagnostic model and maximization of the integral expected utility.

The main features of the proposed criteria are:
- multifactor active diagnostic model based on the data from sensor network-type system;
- theory of the weighted utility and preference for reconfiguration alternatives ranking;
- decision-making under uncertainty with incomplete requirements;
- fuzzy comparison of functional trees based on feature-structural similarity.

The decision-making for reconfiguration bases on the diagnostic data from information sensor network.

The key concepts of proposed method are:
- the effect from reconfiguration actions (usually made via modernization projects) are depending on time $t$ and moment of action $t_{rcfg}$;
- the preference between alternatives $A_j$ and $A_k$ is mean that total effect of system $S$ is more with alternative $A_j$ than with $A_k$.
- the uncertainty of reconfiguration process data may be decreased by adding new accounting data from special sensor network.

The integral decision-making method for system reconfiguration is divided into four base stages.

*Stage I:* In this stage the need of IT components modernization and optimal moments $T_{ik}$ of it is determined.

The main idea of the stage is identifying the state of reconfigurable infocommunication system based on retrospective and current information. It is based on methods and techniques for estimating a weighted state graph, characterized by a complex decision criterion based on fuzzy production rules for combining diagnostic data in conditions of uncertainty.

The main achieved results are:
- reducing the time to detect the need for reconfigu-

ration;
- estimating changes in the utility function for IT components over time $\xi(t, t_{rcfg})$.

This stage includes the following sequential operations:
1) the network $ms_i^{sn}$ monitors the system state $S_i$ (where i – reconfiguration cycle).
2) based on the results of monitoring, an operational diagnostic model $\hat{S}_i$ is being built.
3) based on the diagnostic model $\hat{S}_i$, the utility function over time $\xi_{ij}(t, t_{rcfg})$ is estimated.
4) based on the weighted utility function, an importance (significance) factor $\alpha_{ij}(t)$ of IT component is calculated.
5) optimal moments of reconfiguration $T_{ik}$ for all potential reconfigurable IT components are determined.

*Stage II:* In this stage the set of alternatives is generated.

The main idea of the stage is forming a set of alternatives of IT components modernization actions (plans or projects). It is based on morphology designing methods for generating a base set of alternatives for all potentially modernized IT components and Pareto-optimal based method to reduce a number of alternatives.

The main achieved result here is to generate initial set of alternatives to enable decision-making process.

This stage includes the following sequential operations:
1) for all potentially modernized IT components $S_{ij}$, a set of modernization plans $S_{ij} \rightarrow \{A_{ijk}\}$ is generated.
2) for all components $S_{ij}$ only Pareto-optimal ones remain, all others are deleted from the components alternatives set.
3) a unified set of alternatives from all components is generated.

*Stage III:* In this stage the new requirement system $RS_i$ and the effective criteria are determined.

The main idea of the stage is to form new more suitable requirements from incomplete conflicting needs and predict service availability quotient for IT components $k_{ij}(RS_{ij})$. It is based on multivariable evaluation with inconsistent heterogeneous requirements to a state of components, which takes into account uncertainty of decision-making reconfiguration moments.

The main achieved results are:
- reducing the uncertainty of requirements for the reconfigurable system;

− improving the accuracy of forecasts by using additional information on the qualitative characteristics of alternatives.

This stage includes the following sequential operations:

1) based on basic system requirements $RS$ with the functionality tree template $\overline{FS}$, alternatives functionality trees $\{FS_i\}$ are created.
2) uniting a set of the functionality trees $FS_i^+$ into one extended tree of alternatives $\overline{FS}^+$.
3) determining requirements $RS_i$ based on an extended tree of alternatives $\overline{FS}^+$.
4) estimating positive effect $\hat{S}_{ij} \in \hat{S}_i$ for all alternatives $A_i = \{A_{ij}\} : S_i \xrightarrow{A_{ij}} S_{ij}^*$ based on new requirements $RS_i$.

*Stage IV:* At this stage modernization alternatives are determined from the set $A_{ij} \in A_i$ by multi-criteria decision.

The main idea of the stage is ranking the alternatives by value of expected utility for reconfiguration plan. It is bases on stochastic optimization preprocessing of alternatives characteristics to consider the expected utility by a features tree and decision-making technique under uncertainty.

The basic achieved result is an increased effect of modernization plan. Thus, the suitability of reconfigurable system is increasing by a proposed method.

This stage includes the following sequential operations:

1) calculate the conditions value of the functional parameters $(t)$.
2) calculate the quality indicator value $qs_{ij}(t)$ for all alternatives.
3) estimate the expected utility on features tree with quality indicator.
4) find the ideal object $A^* \Rightarrow FS^*$ from a set of alternatives $A_{ij} \in A_i$ and requirements $RS_i$.
5) calculate the decision tree $\Phi^+$.
6) find the ranks $R = \{r_i\}$ of reconfiguration action alternatives.
7) select the modernization alternatives from a set $A_{ij} \in A_i$ with the minimal rank.

There are several decision trees $\Phi^+$ used for decision-making in special conditions:

− under the uncertainty of implementation time, criteria in (Mabkhot *et al.*, 2019) for condition values of the functional parameters is used;
− under the incomplete requirements, method in (Shin *et al.*, 2018) may be used, which implies restructuring of the requirements system tree by accounting values of additional functional characte-

ristics of the alternatives.

− under the uncertain intensity of components' use, method in (Gurman *et al.*, 2014) is suitable, which minimizes the total cost of modernization resources for the system by a stochastic programming method.

## 2.4 The Implementation of Decision-Making Criteria for Information System Reconfiguration

For implementation of the proposed decision-making method we consider a typical situation: a number of IT components of the reconfigurable system are increased several times. This situation leads to an increase of the number of required resources $R_S$ for the system's operation.

Modeled situation:

The decision-making is done assuming the resource limits: $R_S = \sum_{i=0}^{j} R_i \le R_{\lim}$. We expect that resource limits are growing proportionally with the number of IT components but in practice resources are limited, and also we have an external consumer factor and decreasing component lifetime. The ratio between required resources and limits is shown in the Figure 2, where $\nu = \frac{R_{\lim}}{R_S}$. The graphs show that with increase of the number of IT components and decrease of the active lifecycle, the ratio of
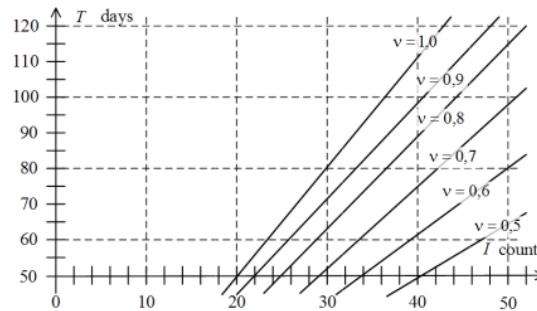


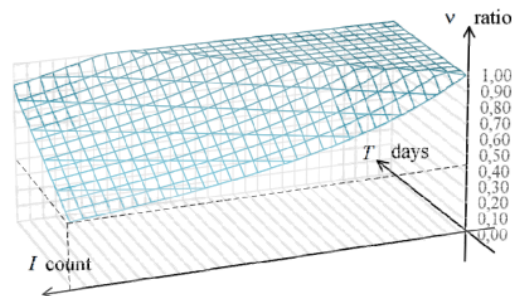**Figure 2.** Graphs of limits-to-required resources ratio.
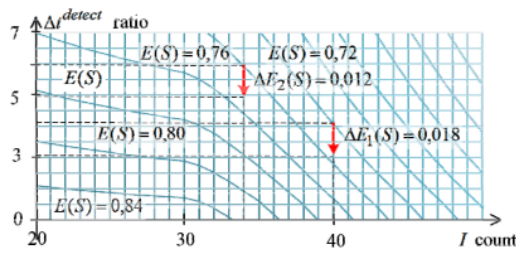


**Figure 3.** 3D-plot of limits-to-required resources ratio.

**Figure 4.** 2D-plot of system effect changing with a number of IT components and moments of reconfiguration $T_{ik}$.
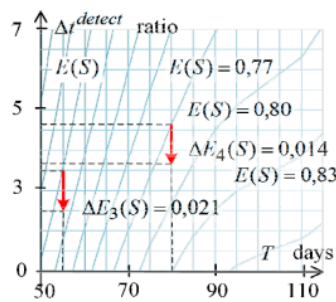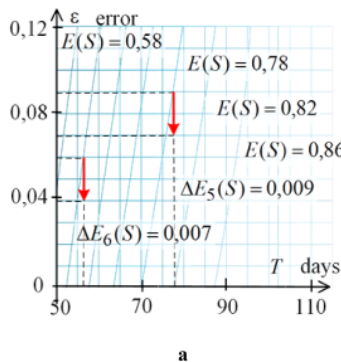


**Figure 5.** 2D-plot of system effect changing with IT components' active lifecycle and moments of reconfiguration $T_{ik}$.
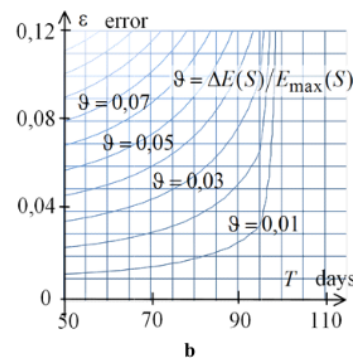
limited to required resources is decreasing (Figure 3). Figure 3 shows 3D-plot of limits to required resources ratio.

A proposed adaptive reconfiguration decision-making method is intended to improve the suitability of the systems by two main effects:
– determine the optimal moments of reconfiguration $T_{ik}$ for all potential reconfigurable IT components via decreasing detection time $t^{detect}$;
– select the modernization alternatives from a set

$A_{ij} \in A_i$.

There are two main factors influencing the experiments:
– a number of IT components – $I$ (we analyze multi-component IT system with 20-50 active IT services);
– the time of IT components active lifecycle and modernization – $T$ (we analyze medium length of IT components lifecycle ~ 2-3 months between modernizations).

Some experiments showed that depending on the external conditions, the use of a sensor network and an adaptive diagnostic model allows reducing the detection time $t^{detect}$ by 10-15 percent compared to typical technological solutions used in infocommunication systems. The result of decision-making is a suitable moment of reconfiguration $T_{ik}$ as a control action.

The impact of the detection time $t^{detect}$ on the system's suitability is shown in Figure 4 (dependence on number of IT components) and Figure 5 (dependence on IT components' active lifecycle).

Figures 4-6 show the changes in system effect $E(S)$ as characteristics of IT system suitability. It is noted that the different values of initial system suitability (points 1 and 2 in Figure 4, and points 3 and 4 in Figure 5) leads to a different total effect (with the same decrease in detection time). As we can see, the total effect may be up to 1-3%.

The proposed method and relevant integral criteria assume change in significance of functional components over time and thereby provide an increase in effect compared with the method of dynamic priorities by 15-20% (reduced total planning error). As we can see in Figure 6a, this method allows to increase the suitability factor by 0,5% to 4%. But if resources are not limited the effect of proposed method is minimal. Figure 6b illustrates the suitable factor change $\vartheta = \Delta E(S)/E_{max}(S)$.

Figure 6 shows that intelligent decision-making me-



**Figure 6.** a – 2D-plot of system effect changing with IT components' active lifecycle; b – 2D-plot of relative system effect.

thods can improve system reconfiguration by reducing the uncertainty of system data and increase its suitability. The effect is the most when resources are significantly limited, and IT components' values change unpredictably over time.

## 3. CONCLUSION

The problem of decision-making for the reconfiguration of adaptive infocommunication system under uncertainty is relevant. To solve this problem, an integrated approach to decision-making for reconfiguration is proposed. It is based on an integral decision-making criterion, selecting a suitable reconfiguration moment and a proper reconfiguration alternative maximizing the integral expected utility.

The main idea of the proposed method is to combine the multifactor active diagnostic model, weighted utility and preference theory, decision-making technique under uncertainty and comparison methods for fuzzy trees with incomplete requirements. The proposed method calculates the decision in four main stages. There are several decision trees proposed for decision-making in special conditions under the uncertainty of implementation time, incomplete requirements, and the uncertain intensity of components' use. The general result is achieved by reducing the uncertainty of diagnostic data.

Results of experiments show that the proposed decision-making methods can generally improve selecting of alternatives for reconfiguration and increase system's suitability. The effect is the most when resources are significantly limited, and IT components' values change unpredictably over time.

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## Submitted!

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Your article A Decision Making Method for Reconfiguration of Adaptive Info communications Systems in Industrial Engineering & Management Systems has the following publication status: Submitted and Review Process

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# A Decision Making Method for Reconfiguration of Adaptive Info-communications Systems