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DEVELOPMENT OF MODEL OF A WEB-BASED INFORMATION SYSTEM CONTROL PROBLEM

The object of research is the processes of operation of a web-based information system. The conducted research is based on the application of existing approaches to organizing the operation of IT products, as well as on the previously developed formal model of the problem of managing the operation of an information system. The existing assessment of the satisfaction degree of the requirements for the system was adopted as the main criterion for managing the operation of the information system. The main hypothesis of the study is the assumption that the main criterion for managing the operation of a web-based information system should be considered the efficiency indicator as the ratio of the degree of satisfaction of requests for changes in individual components of the information system and the total costs of operating the system. The analysis of the applicability of the criterion «Satisfaction of the requirements of users of the information system» is carried out and its incomplete objectivity is shown for describing the goals of managing the operation of the information system. The use of the management efficiency indicator is substantiated, the features of the use of this indicator for solving the problem of managing the operation of the information system are considered. The existence of two approaches to determining the efficiency of the operation of an information system is recognized. Based on the results obtained, a concept for managing the operation of a web-based information system is proposed. This concept represents the main task of managing the operation of a web-based information system as a special case of a multicriteria optimization problem, the solution of which will be a Pareto-optimal system. On the basis of the proposed concept, a mathematical model of the problem of effective management of a web-based information system has been developed. To describe the function of the goal in the course of developing the model, it is proposed to move from descriptions of requirements to knowledge-based models of requests for changing the information system. It is also proposed to divide the set of model constraints into two separate complexes – a set of technical management constraints and a set of operating process constraints. Application of the developed model will make it possible to create new information technologies for managing the operation of web-based information systems for enterprise management. In contrast to the existing ones, such technologies will allow formalizing and automating the work on the formation and approval of the most profitable for the participants in the operation of the information system of project plans for fulfilling requests for changes in the operating system.

Keywords: *web-based information system, system operation management, multi-criteria optimization problem, operation efficiency indicator, Pareto-optimal system.*

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1. Introduction

Modern strategies for the development of IT companies consider effective IT products as the main source of profits. Such products are considered effective because the costs of IT companies for their support and maintenance are less than the profits coming from the enterprises that consume these IT products. Therefore, for the successful long-term existence of IT companies, it becomes necessary to formulate and solve global problems of managing the effective operation of IT products. Such a task becomes especially difficult for such a variety of IT products as information systems (IS) for enterprise management. One of the reasons for this is the fundamental difference between enterprise management information systems and other types of IT products. In particular, the main goal of the enterprise management IS is the formation and display of a single integral informational representation of an object or process that is useful for users [1]. This means that the effective operation of the enterprise management IS will be determined not only by the effective implementation of scenarios for the performance of individual functions of this system, but also by the effective implementation of data structures that describe the inputs and outputs of the functions of this system.

Currently, enterprise management ICs are characterized by various architectures, among which the most common should be considered a web-based architecture. There are various models of web-based architecture [2–4]. However, all these models point to the representation of IS as a large number of loosely coupled elements of various nature. Therefore, solving global problems of managing the effective operation of a web-based IS is seriously complicated due to the need to simultaneously manage a large number

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of heterogeneous elements of such a system.

Existing approaches to solving the problem of managing the operation of IT products are focused mainly on finding optimal solutions for managing technical aspects [5–7]. The same orientation is typical for the task of managing the operation of enterprise management information systems. In this case, such aspects include performance, security, reliability, etc. Particular attention is paid to solving the issues of administration and management of the operation of individual IT products within the existing computer networks that form the IT infrastructure of the enterprise. The problem of managing the operation of enterprise management information systems as a set of functions that provide services for the processing and display of data and information does not currently have a general solution. Therefore, research in this area, which makes it possible to assess and improve the efficiency of the enterprise management IS through the development and implementation of a set of measures to improve its economic, technical and technical characteristics, are relevant from the theoretical and applied points of view.

The object of research is the operation processes of the web-based IS. This type of IS has been chosen as the most common in modern enterprises.

The aim of research is to develop a mathematical model for managing the operation of a web-based IS, which would take into account the existing features of the relationship between an enterprise-supplier and an enterprise-consumer of an IS during its operation.

2. Methods of research

Currently, the main theoretical and applied work in the field of management of the exploitation of information systems is based on the provisions of the ISO 20000 standard [5] and sets of best practices ITIL v.3 [6, 7]. These works make it possible to single out a number of basic approaches to the formal description of the problem of managing the operation of IS as a particular case of the problem of managing an IT project. So, in [8], the application of simulation models based on the accumulated data is proposed. In [9], it is proposed to apply a model describing the success of an IS project as a result of the following groups of factors:

– project management process;
– project results;
– contextual factors.

The need to create a general model for assessing the effectiveness of management of life cycle processes of systems is emphasized in [1]. The reason for this need in [1] indicates the additional efforts arising from the coordination of individual models.

However, these studies leave unresolved a number of questions, among which it is necessary to highlight:

a) issues of the relationship between technical and technical and economic indicators characterizing the processes of operating IS;

b) issues of formal technical and technical and economic assessment of the efficiency of IS operation.

The solution of these issues to a large extent depends on the form of organization of work on the management of the IS operation. Currently, the main such form is recognized as IT-projects to improve the operation of web-based IS [6, 7]. However, the formation of integral assessments of the progress and results of operation of individual IS services does not currently involve the use of formal models [8]. At the same time, studies have shown that the success of projects aimed at improving individual processes is not an accident, but a predictable result with clearly defined and measurable characteristics [10].

To solve various problems of IT-services management, in [11], approaches based on solving multi-criteria optimization problems were proposed. However, the difficulties of applying such approaches when controlling real web-based ISs force to look for other options for solving such problems. Thus, in [12], it is proposed to consider a knowledge-based approach to managing web services. However, this approach has not yet been fully developed and needs additional research.

To formally describe the global task of managing the operation of a web-based IS, it is first necessary to determine the main indicator of the attainability of the goals of the supplier organization (hereinafter referred to as the Supplier) and the consumer organization (hereinafter referred to as the Consumer) of IT services. As such an indicator is usually considered an indicator characterizing the degree of satisfaction of the IS requirements put forward by the Consumer and accepted for execution by the Supplier [1]. In this case, the dissimilar requirements put forward by the consumer will be elements of the general set of requirements for a specific information system Tr_{IS}. In the general case, this set will have the form [1]:

$$Tr_{IS} = \left(tr_1, tr_2, ..., tr_i, ..., tr_n\right), \tag{1}$$

where tr_i – generalized description of the i-th requirement for the system, for a separate IT service; i – identifier of the generalized description of the requirement tr_i, $i = \overline{1,n}$; n – the number of requirements for the system, its IT services.

The degree to which each IS requirement tr_i is satisfied can generally be described by an operator $r(tr_i)$ assigned a number in a range [0..1] to the description of the requirement tr_i. To estimate the pay of fulfilling the requirement, in the general case, an operator $\text{pay}(r(tr_i))$ is introduced. In the general case, an operator $t(r(tr_i))$ is introduced to estimate the execution time of a requirement. In the general case, an operator $q(r(tr_i))$ is introduced to assess the quality of fulfillment of the requirement. Ranges of possible values and interpretation of individual values of these operators are discussed in detail in [1].

The introduced generalized descriptions of requirements (1) and operators make it possible to formulate a generalized formalized description of the problem of managing the operation of an IS from the point of view of an IT service provider as follows [13]:

$$F_{\text{Pr}} = \sum_{i=1}^{n} r^{\text{Pr}}\left(tr_i\right) \to \max, \tag{2}$$

$$\begin{cases} \sum\limits_{i=1}^{n} \alpha_i^{\text{Pr}} \text{pay}\left(r^{\text{Pr}}\left(tr_i\right)\right) \geq \text{pay}^*\left(\sum\limits_{i=1}^{n} r^{\text{Pr}}\left(tr_i\right)\right); \\ \sum\limits_{i=1}^{n} \beta_i^{\text{Pr}} t\left(r^{\text{Pr}}\left(tr_i\right)\right) \leq t^*\left(\sum\limits_{i=1}^{n} r^{\text{Pr}}\left(tr_i\right)\right); \\ \sum\limits_{i=1}^{n} \gamma_i^{\text{Pr}} q\left(r^{\text{Pr}}\left(tr_i\right)\right) \geq q^*\left(\sum\limits_{i=1}^{n} r^{\text{Pr}}\left(tr_i\right)\right), \end{cases} \tag{3}$$

where Pr – designation of the Supplier of IT services and

the corresponding IT services; $r^{\Pr}(tr_i)$ – satisfaction degree of the requirement tr_i from the point of view of the Supplier; $\alpha_i^{\Pr}$ – standard coefficient of the cost of fulfilling the requirement tr_i, taking into account the individual characteristics of the Supplier; $\text{pay}^*\left(\sum_{i=1}^{n} r^{\Pr}(tr_i)\right)$ – the minimum allowable for the Supplier value of the pay of meeting a set of requirements; $\beta_i^{\Pr}$ – standard coefficient of the duration of the fulfillment of the requirement tr_i, taking into account the individual characteristics of the Supplier; $t^*\left(\sum_{i=1}^{n} r^{\Pr}(tr_i)\right)$ – maximum time allowed for the Supplier to fulfill a set of requirements; $\gamma_i^{\Pr}$ – standard quality factor for fulfilling the requirement tr_i, taking into account the individual characteristics of the supplier; $q^*\left(\sum_{i=1}^{n} r^{\Pr}(tr_i)\right)$ – the minimum acceptable quality for the Supplier of fulfilling many requirements.

A generalized formalized description of the problem of managing the operation of IS from the point of view of the Consumer of IT services can be presented as follows [13]:

$$F_U = \sum_{i=1}^{n} r^U(tr_i) \to \max, \tag{4}$$

$$\begin{cases} \sum_{i=1}^{n} \alpha_i^U \text{pay}\left(r^U(tr_i)\right) \le \text{pay}^*\left(\sum_{i=1}^{n} r^U(tr_i)\right); \\ \sum_{i=1}^{n} \beta_i^U t\left(r^U(tr_i)\right) \le t^*\left(\sum_{i=1}^{n} r^U(tr_i)\right); \\ \sum_{i=1}^{n} \gamma_i^U q\left(r^U(tr_i)\right) \ge q^*\left(\sum_{i=1}^{n} r^U(tr_i)\right), \end{cases} \tag{5}$$

where U – designation of the Consumer of IT services and the corresponding IT services; $r^U(tr_i)$ – satisfaction degree of the requirement tr_i from the point of view of the Consumer; α_i^U – standard coefficient of the cost of meeting the requirement tr_i, taking into account the individual characteristics of the Consumer; $\text{pay}^*\left(\sum_{i=1}^{n} r^U(tr_i)\right)$ – maximum allowable for the Consumer value of the pay of meeting a set of requirements; β_i^U – standard coefficient of the duration of the fulfillment of the requirement tr_i, taking into account the individual characteristics of the Consumer; $t^*\left(\sum_{i=1}^{n} r^U(tr_i)\right)$ – maximum time allowed for the Consumer to fulfill a set of requirements; γ_i^U – standard quality factor for meeting the requirement tr_i, taking into account the individual characteristics of the Consumer; $q^*\left(\sum_{i=1}^{n} r^U(tr_i)\right)$ – minimum acceptable quality for the Consumer in meeting the set of requirements for S.

3. Research results and discussion

3.1. Development of a concept for a formal description of effective management of an information system

One of the main difficulties in the practical implementation of the provisions regarding the management of the IS operation, set out in [5–7], is the absence of objective quantitative criteria that establish the objectives of the management of the IS operation and allow to evaluate the control actions on the IS during its operation. The criterion «Satisfaction of IS users' requirements» can't be considered objective due to the following reasons:

a) this criterion does not distinguish between different types of IS requirements (for example, those considered in [1]) and, in the overwhelming majority of cases, does not take into account the priority of fulfilling individual requirements;

b) the methods of forming the values of this criterion are based, in the overwhelming majority of cases, on the methods of expert assessment, which to a large extent depend on the subjective points of view of individual experts;

c) this criterion practically does not reflect the features of cost management during the IS operation (in particular, the costs of acquiring supporting complexes and IS services, the costs of supporting logistics and managing its results, etc.).

The latter reason is especially important in modern conditions, when the Consumer is not the IS Provider and its individual IT services. The separation of the IS Providers into independent economic entities has led to the emergence of a number of possible situations that are extremely disadvantageous for the Suppliers. Such situations are characterized by a significant increase in the Supplier's costs in response to a slight increase in the value of the criterion «Satisfaction of the requirements of IS users» for the Consumer.

The most objective characteristic of the management of IS operation should be considered the indicator of management efficiency. This indicator allows to present the management processes of the IS operation as a special case of solving the problem of maximizing the values of the indicator of the management efficiency of the operated IS and its individual elements for a time much less than the total time of operation of such an IS. At the same time, the disturbing influences that bring management processes out of the state of the achieved global maximum values of the management efficiency indicator of the operated IS should be considered changes in the Consumer's business processes or individual requirements put forward by the Consumer's employees for the operated IS and its individual elements.

However, the use of this indicator for the formal description of operational management also depends on the points of view of the Consumer and the Supplier on the assessed IS operation processes. The difference between these points of view is mainly determined by the difference between the global goals of the Consumer and the Supplier, considered in [1].

Let's consider the manifestation of differences in points of view on the indicator of effective management of the IS operation in more detail. For this purpose, here and in the future, let's represent efficiency in accordance with the definition given in ISO 9000:2015 as the ratio between the achieved result and the resources used.

In the overwhelming majority of cases, the degree of customer satisfaction is chosen as the main criterion for the success of any IT event (including the operation of IS). Consequently, the achieved management result can be represented by the criterion «Satisfaction of the needs of IS users». This view does not depend on the points of view of the Supplier and the Consumer on the processes of IS operation, the effectiveness of which is evaluated.

The satisfaction degree of the needs of the Consumer

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is currently characterized by the criterion «Satisfaction of the needs of IS users». In financial terms, this criterion can be expressed in general as the price of any type of contract for the supply by the IS Provider. At the same time, the IS should have such a set of IT services (functions, services, etc.), which is necessary and sufficient to maximize the satisfaction of the consumer's needs.

However, there is no such unity of views on the description of the resources used. For the Consumer, the resources used in the general case can be presented as the sum of the costs for the implementation of those processes and works in which the operated IS is used, as well as the costs for the implementation of the IS functioning process, which is auxiliary for the Consumer. Such a description makes it possible to unify the quantitative representation of heterogeneous resources (people, complexes of technical means, IS elements, etc.) spent in the course of IS operation. For the Supplier, the resources used in the general case can be presented as the sum of the costs of operating and project activities aimed at the implementation of the IS maintenance process. In the worst case – for example, with full outsourcing of IS – the Supplier must additionally take into account the amount of costs for the implementation of operational and project activities aimed at the implementation of the IS functioning process.

This difference in views on the costs associated with the use of different resources makes it necessary to consider the possibility of one of the following two situations:

1) situation of complete coincidence of the Supplier's cost items and the Consumer's cost items;

2) situation in which the set of Supplier's cost items will be a subset of the Consumer's cost items.

It should be recognized that these situations are possible only if the Supplier and its employees are part of the Consumer, and financing of any (operational or project) activities of the Supplier is carried out within the framework of financing the consumer's business processes. Therefore, the values of the quantitative indicator of the operational efficiency of the same IS will differ depending on whether the value of this indicator is calculated from the point of view of the Supplier or the Consumer.

The above allows to assert that there is no objective approach to determining the efficiency of IS operation processes. At the same time, the simultaneous existence of the following two approaches should be recognized:

1) an approach to determining the efficiency of the IS operation processes from the point of view of the Consumer (an approach to determining the efficiency of the IS operation process);

2) an approach to determining the effectiveness of the IS operation processes from the point of view of the Supplier (an approach to determining the effectiveness of the IS maintenance process).

Based on these considerations, it is proposed to formulate the basic concept of managing the operation of a web-based IS and its elements as a set of the following provisions:

a) management of the operation of IS and its elements from the point of view of the Consumer is considered as a set of design and/or operational activities. The result of these activities should be the achievement of the global maximum criterion for satisfying the needs of the Customer's employees. At the same time, the costs of these activities should be maintained at the level desired for the Consumer;

b) management of the exploitation of IS and its elements from the point of view of the Supplier is considered as a set of design and/or operational activities. The result of these activities should be the achievement of the global maximum criterion for satisfying the needs of the Supplier's employees. At the same time, the costs of these activities must be maintained at the level desired by the Supplier;

c) management of the operation of the IS as a whole, while respecting the interests of the Consumer and the Supplier of this IS, should be considered as a special case of the problem of multi-criteria optimization, the solution of which will be the Pareto-optimal IS;

d) management of the operation of individual elements of the IS while respecting the interests of the Consumer and the Supplier of this IS should be considered as a set of design and/or operational activities. These activities are aimed at converting the set of initial values of the performance characteristics of individual elements into the set of desired values of the same characteristics. The desirable characteristics are those under which the IS as a whole will be Pareto-optimal.

The proposed concept makes it possible to develop a mathematical model that formally describes the task of managing the operation of the IS and its components.

3.2. Development of a mathematical model of the problem of effective management of a web-based information system

The above-considered formalized description of the problem of managing the operation of a web-based IS (1)–(5) is overly general and is complicated by the following factors [1]:

– not a single representative of the Consumer, as a rule, has an idea of the entire sequence of operations of all IT services of the system;

– consumer decides on the feasibility of introducing and operating the system, first of all, based on the pragmatic value of the IT services offered by the Supplier;

– the direct executors of the work on the creation of the system on the part of the Supplier are not required to know the features of the business of a particular Consumer, which do not directly affect the development of the relevant IT services;

– supplier decides on the advisability of developing a version of the system, based on its ability to form a set of IT services that meet the many requirements of the Consumer, subject to the fulfillment of the system of constraints (3) as a whole, with the possibility of violating individual inequalities.

In general, functions (2) and (4) determine the decisions of the Supplier and the Consumer in the course of managing the operation of a web-based IS. The action of the factors discussed above allows to consider these functions as a function of choosing the optimal set of IT services for a given system and achieving optimal values of the operational characteristics of the elements of this system. In this case, the Supplier and the Consumer must comply with certain restrictions.

The main difference between the management of the operation of a web-based IS and the management of its design should be recognized as the receipt from the Consumer to the IT Service Provider not of requirements, but

of requests for change (requestforchange, RFC). These RFCs define not only new functional requirements for an exploited web-based IS, but also new non-functional requirements for its software, network and technical elements.

However, the existing approaches to IS management and the models created on their basis leave unresolved the issue of generating RFC elements of an exploited IS based on the results of evaluating the operation of these elements within the system. At the same time, the solution of this very issue leads to a serious waste of time. These costs are due to the following factors:

a) the lack of a generally accepted formal description of RFC elements of the IS, which leads to disagreements in the classification, formation and interpretation of such requests;

b) the lack of connection between the ITIL indicators and the formal description of the RFC, which leads to the need for intuitive formation of specific RFCs.

Based on this, the main goals of service-oriented IS operation management should be considered [14]:

– reducing the number of RFCs received from the Consumer of IT services to the required minimum, which is determined by the influence of factors external to the Consumer or the long-term program for the development of the Consumer's IT infrastructure;

– reducing the number of RFCs that have not been fulfilled by the IT Service Provider or which the IT Service Provider has refused to the IT Service Provider to the required minimum.

Then the goal functions (2) and (4) can be represented as follows [14, 15]:

$$F_{\mathrm{Pr}} = \begin{cases} \sum\limits_{i=c+1}^{e} K_i^{tr_{\mathrm{Pr}}}\left(RFC_i\right) \to \min; \\ \sum\limits_{i=c+1}^{e} \bar{K}_i^{tr_{\mathrm{Pr}}}\left(RFC_i\right) \to 0, \end{cases} \tag{6}$$

$$F_U = \begin{cases} \sum\limits_{i=c+1}^{e} K_i^{tr_U}\left(RFC_i\right) \to \min; \\ \sum\limits_{i=c+1}^{e} \bar{K}_i^{tr_U}\left(RFC_i\right) \to 0, \end{cases} \tag{7}$$

where RFC_i – i-th request to change the operated system; $K_i^{tr_{\mathrm{Pr}}}\left(RFC_i\right)$ – knowledge-based model RFC_i from the point of view of the IT Service Provider; $K_i^{tr_U}\left(RFC_i\right)$ – knowledge-oriented model RFC_i from the point of view of the Consumer of IT services; $\bar{K}_i^{tr_{\mathrm{Pr}}}\left(RFC_i\right)$ – knowledge-based model RFC_i that the IT Service Provider was unable to fulfill; $\bar{K}_i^{tr_U}\left(RFC_i\right)$ – knowledge-based model RFC_i, the implementation of which was denied to the Consumer of IT-services by the Supplier.

It is necessary to highlight such complexes of limitations of the task of managing the operation of a web-based IS:

– a set of restrictions on technical management, determined based on the features of IT projects for the operation and maintenance of an operated web-based IS;

– a set of restrictions on the operation processes, determined based on the RFC features of the operated web-based IS, its software, network and technical elements.

By analogy with the systems of constraints of the task of managing the creation of a service-oriented IS, considered in [1], the complexes of constraints of technical management, from the point of view of the Supplier and the Consumer of IT services, will have the form [15]:

$$\begin{cases} \sum\limits_{i=c+1}^{e} \alpha_i^{\mathrm{Pr}} \mathrm{pay}\left(r^{\mathrm{Pr}}\left(RFC_i\right)\right) \ge \mathrm{pay}^*\left(\sum\limits_{i=c+1}^{e} r^{\mathrm{Pr}}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \beta_i^{\mathrm{Pr}} t\left(r^{\mathrm{Pr}}\left(RFC_i\right)\right) \le t^*\left(\sum\limits_{i=c+1}^{e} r^{\mathrm{Pr}}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \gamma_i^{\mathrm{Pr}} q\left(r^{\mathrm{Pr}}\left(RFC_i\right)\right) \ge q^*\left(\sum\limits_{i=c+1}^{e} r^{\mathrm{Pr}}\left(RFC_i\right)\right); \end{cases} \tag{8}$$

$$\begin{cases} \sum\limits_{i=c+1}^{e} \alpha_i^{U} \mathrm{pay}\left(r^{U}\left(RFC_i\right)\right) \le \mathrm{pay}^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \beta_i^{U} t\left(r^{U}\left(RFC_i\right)\right) \le t^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \gamma_i^{U} q\left(r^{U}\left(RFC_i\right)\right) \ge q^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right). \end{cases} \tag{9}$$

The complexes of operating process restrictions, as mentioned above, are based on the need for the Supplier of the operated web-based IS to perform a certain set of functional and non-functional IT services RFC. Therefore, by analogy with the systems of constraints of the task of managing the creation of a service-oriented IS, considered in [1], the complexes of constraints of the operation processes, from the point of view of the Supplier and the Consumer of IT services, will have the form [15]:

$$\begin{cases} \sum\limits_{i=b+1}^{c} \chi_i^{Pr} r^{Pr}\left(RFC_i^{f}\right) \ge \rho_{Pr}^{f}; \\ \sum\limits_{i=e+1}^{g} \eta_i^{Pr} r^{Pr}\left(RFC_i^{nf}\right) \ge \rho_{Pr}^{nf}; \\ \sum\limits_{i=g+1}^{k} \varsigma_i^{Pr} r^{Pr}\left(RFC_i^{fw}\right) \ge \rho_{Pr}^{fw}; \\ \sum\limits_{i=k+1}^{n} \omega_i^{Pr} r^{Pr}\left(RFC_i^{nfw}\right) \ge \rho_{Pr}^{nfw}, \end{cases} \tag{10}$$

$$\begin{cases} \sum\limits_{i=b+1}^{c} \chi_i^{U} r^{U}\left(RFC_i^{f}\right) \ge \rho_{U}^{f}; \\ \sum\limits_{i=e+1}^{g} \eta_i^{U} r^{U}\left(RFC_i^{nf}\right) \ge \rho_{U}^{nf}; \\ \sum\limits_{i=g+1}^{k} \varsigma_i^{U} r^{U}\left(RFC_i^{fw}\right) \ge \rho_{U}^{fw}; \\ \sum\limits_{i=k+1}^{n} \omega_i^{U} r^{U}\left(RFC_i^{nfw}\right) \ge \rho_{U}^{nfw}, \end{cases} \tag{11}$$

where χ_i^{Pr} – standard coefficient of completeness of the implementation of the functional RFC of the IT service RFC_i^f, taking into account the individual characteristics of the Supplier; ρ_{Pr}^{s} – minimum level of completeness of the implementation of a subset of functional RFC of the IT services, acceptable for the Supplier; η_i^{Pr} – standard

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coefficient of completeness of implementation of non-functional RFC of the IT services RFC_i^{nf}, taking into account the individual characteristics of the Supplier; $\rho_{\Pr}^{nf}$ – minimum level of completeness of the implementation of a subset of non-functional RFC of the IT services RFC_i^{fw}, acceptable for the Supplier; $\varsigma_i^{\Pr}$ – standard factor of completeness of implementation of functional RFC of the IT-services RFC_i^{fw}, taking into account the individual characteristics of the Supplier; $\rho_{\Pr}^{fw}$ – minimum acceptable for the Supplier level of completeness of the implementation of a subset of functional RFC of the IT services that are operated in existing Internet/Intranet networks and other elements of the enterprise IT infrastructure; $\omega_i^{\Pr}$ –- standard completeness coefficient of implementation of non-functional RFC of the IT services RFC_i^{nfw}, taking into account the individual characteristics of the Supplier; $\rho_{\Pr}^{nfw}$ – minimum acceptable for the Supplier level of completeness of the implementation of a subset of non-functional RFC of the IT services that are operated in existing Internet/Intranet networks and other elements of the enterprise IT infrastructure; χ_i^U – standard coefficient of completeness of implementation of functional RFC of the IT-service RFC_i^f, taking into account the individual characteristics of the Consumer; ρ_U^s – minimum level of implementation completeness of the RFC subset of IT services, acceptable for the Consumer; η_i^U – standard coefficient of implementation completeness of non-functional RFC of the IT services RFC_i^{nf}, taking into account the individual characteristics of the Consumer; ρ_U^{nf} – minimum level of completeness of the implementation of a subset of non-functional RFC of the IT services, acceptable for the Consumer; ς_i^U – standard completeness coefficient of implementation of functional RFC of the IT service RFC_i^{fw}, taking into account the individual characteristics of the Consumer; ; ρ_U^{fw} – minimum acceptable for the Consumer level of implementation completeness of functional RFC subset of the IT services, which are operated in existing Internet/Intranet networks and other elements of the enterprise IT infrastructure; ω_i^U – standard coefficient of implementation completeness of non-functional RFC of the IT-service RFC_i^{nfw}, taking into account the individual characteristics of the Consumer; ρ_U^{nfw} – minimum acceptable for the Consumer level of implementation completeness of non-functional RFC subset of the IT services that are operated in existing Internet/Intranet networks and other elements of the enterprise IT infrastructure.

In general, the task of managing the operation of a web-based IS, taking into account expressions (6)–(11), is proposed to be presented as a problem of multi-criteria optimization, which has the form:

$$\begin{cases} \sum\limits_{i=c+1}^{e} K_i^{tr_{\Pr}}\left(RFC_i\right) \to \min; \\ \sum\limits_{i=c+1}^{e} \overline{K}_i^{tr_{\Pr}}\left(RFC_i\right) \to 0; \\ \sum\limits_{i=c+1}^{e} K_i^{tr_U}\left(RFC_i\right) \to \min; \\ \sum\limits_{i=c+1}^{e} \overline{K}_i^{tr_U}\left(RFC_i\right) \to 0; \end{cases} \quad (12)$$

subject to a set of technical management restrictions:

$$\begin{cases} \sum\limits_{i=c+1}^{e} \alpha_i^{\Pr} \operatorname{pay}\left(r^{\Pr}\left(RFC_i\right)\right) \ge \operatorname{pay}^*\left(\sum\limits_{i=c+1}^{e} r^{\Pr}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \beta_i^{\Pr} t\left(r^{\Pr}\left(RFC_i\right)\right) \le t^*\left(\sum\limits_{i=c+1}^{e} r^{\Pr}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \gamma_i^{\Pr} q\left(r^{\Pr}\left(RFC_i\right)\right) \ge q^*\left(\sum\limits_{i=c+1}^{e} r^{\Pr}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \alpha_i^{U} \operatorname{pay}\left(r^{U}\left(RFC_i\right)\right) \le \operatorname{pay}^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \beta_i^{U} t\left(r^{U}\left(RFC_i\right)\right) \le t^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right); \\ \sum\limits_{i=c+1}^{e} \gamma_i^{U} q\left(r^{U}\left(RFC_i\right)\right) \ge q^*\left(\sum\limits_{i=c+1}^{e} r^{U}\left(RFC_i\right)\right); \end{cases} \quad (13)$$

and a set of restrictions on operating processes:

$$\begin{cases} \sum\limits_{i=b+1}^{c} \chi_i^{Pr} r^{Pr}\left(RFC_i^f\right) \ge \rho_{Pr}^f; \\ \sum\limits_{i=e+1}^{g} \eta_i^{Pr} r^{Pr}\left(RFC_i^{nf}\right) \ge \rho_{Pr}^{nf}; \\ \sum\limits_{i=g+1}^{k} \varsigma_i^{Pr} r^{Pr}\left(RFC_i^{fw}\right) \ge \rho_{Pr}^{fw}; \\ \sum\limits_{i=k+1}^{n} \omega_i^{Pr} r^{Pr}\left(RFC_i^{nfw}\right) \ge \rho_{Pr}^{nfw}; \\ \sum\limits_{i=b+1}^{c} \chi_i^{U} r^{U}\left(RFC_i^f\right) \ge \rho_U^f; \\ \sum\limits_{i=e+1}^{g} \eta_i^{U} r^{U}\left(RFC_i^{nf}\right) \ge \rho_U^{nf}; \\ \sum\limits_{i=g+1}^{k} \varsigma_i^{U} r^{U}\left(RFC_i^{fw}\right) \ge \rho_U^{fw}; \\ \sum\limits_{i=k+1}^{n} \omega_i^{U} r^{U}\left(RFC_i^{nfw}\right) \ge \rho_U^{nfw}. \end{cases} \quad (14)$$

The proposed model of the problem of managing the operation of a web-based IS allows to represent the solution of this problem as a Pareto-optimal IS, which has the following properties:

1) minimizes the number of RFCs arising from the activities of the IT Service Provider;

2) reduces to zero the number of RFCs that the IT Service Provider could not comply with;

3) minimizes the number of RFCs arising from the activities of the Consumer of IT services;

4) reduces to a value tending to zero the number of RFCs in the implementation of which the Consumer of IT-services was refused by the Provider;

5) comes to an optimal state as a result of the expenditure of financial resources, if the amount of expenses satisfies the Supplier and the Consumer of IT services;

6) comes to an optimal state for a period of time, the value of which satisfies the Supplier and the Consumer of IT-services;

7) comes to an optimal state with an indicator of the quality of operation, the value of which satisfies the Supplier and the Consumer of IT-services;

8) ensures the completeness of the implementation of a subset of functional and non-functional requirements for

IT services from the point of view of the Supplier, not less than a priori specified level;

9) ensures the completeness of the implementation of a subset of functional and non-functional requirements for IT services from the point of view of the Supplier, not less than a priori specified level;

10) the completeness of the implementation of a subset of functional and non-functional requirements for IT services from the point of view of the Consumer, not less than a priori specified level;

11) ensures the completeness of the implementation of a subset of functional and non-functional requirements for IT services from the point of view of the Consumer, not less than a priori specified level.

4. Conclusions

The issues of developing a model of the task of managing the operation of a web-based IS are considered. The analysis of modern approaches to the organization of IS management as a kind of IT products is carried out. In accordance with the provisions of these approaches, the main goals of the Supplier and the Consumer are formulated in the course of the IS operation. The generalized problem of IS management as maximizing the satisfaction of requirements for the system is stated. The basic concept of managing the operation of a web-based IS and its elements is proposed. The essence of this concept lies in the recognition of the IS management problem as a special case of the multicriteria optimization problem, the solution of which will be the Pareto-optimal IS. In this case, the management of the operation of individual elements of the IS, while respecting the interests of the Consumer and the Supplier of this IS, should be considered as a set of design and/or operational activities. The purpose of these activities is to convert the set of initial values of the performance characteristics of individual elements into a set of desired values for the same characteristics. The desirable characteristics are those under which the IS as a whole will be Pareto-optimal.

On the basis of the proposed concept, a mathematical model of the problem of managing the operation of a web-based IS has been developed. The function of the goal of this problem (12), a set of restrictions of technical management (13) and a set of restrictions of operation processes (14) are determined. The use of this model allows to approach the creation of specialized information technologies for effective management of the operation of web-based enterprise management information systems. The main feature of such technologies is the possibility of formalized formation and approval of the most beneficial for the Supplier and the Consumer plans for IT projects for the implementation of emerging RFCs.

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