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MODELS AND METHODS FOR FORMING SERVICE PACKAGES FOR SOLVING OF THE PROBLEM OF DESIGNING SERVICES IN INFORMATION SYSTEMS OF PROVIDERS

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Today, in the telecommunications industry, service is one of the fundamental concepts. Building a service architecture is a key stage in the service life cycle. Information systems of telecommunications providers are designed, implemented and supported by IT companies based on the End-to-End model. This requires the IT company to solve a number of complex problems. In these conditions, building a service architecture, implementing and providing a service are divided into subproblems. Solutions to subproblems must be integrated to determine the coordinated activities of both the IT company and the provider. In this case, it is necessary to take into account the goals of IT companies, providers and their customers in such a way that it is beneficial to all parties. One of such subproblems is the formation of service packages that the IT company offers to providers. The article proposes formal models for the subproblem of forming service packages that allow taking into account the interests of the IT company and providers. These are multi-criteria nonlinear mathematical programming models. To solve the subproblem of forming service packages, a two-stage algorithm and a modified version of the guided genetic algorithm are proposed. The use of these methods allows us to take into account the interests of the IT company and providers. Also, such important factors that affect the formation of packages as the base price of the service, service dependency, discount system, resource and other constraints of the IT company and providers are taken into account.

The two-stage algorithm at the first stage uses classical algorithms for solving the knapsack problem, and at the second stage implements a compromise scheme to improve the solution. The second of the proposed methods uses three types of tools in combination. The first tool controls the convergence of the genetic algorithm. The second tool determines the choice of the best solutions taking into account the features of the multi-criteria problem. The third tool allows to obtain the best solutions to the optimization problem with the simultaneous choice of a discount strategy. Experimental studies have confirmed the effectiveness of the proposed methods. Their ability to form the basis of the technology of forming service packages as a component of the platform for supporting the life cycle of services is also confirmed.

Key words: service design, service package; service architecture; genetic algorithm; value of service

1. Introduction

The service approach dominates the telecommunications industry. Information Systems (IS) of telecommunications service providers support business process systems aimed at achieving business goals. The architecture of IS of providers usually includes levels of business processes, applications and technologies. A feature of the telecommunications industry today is the provision of IS to providers by companies operating in the Information Technology (IT) industry according to the End-to-End (E2E) model. This requires the IT company to solve a number of complex problems.

A tool for solving these problems can be a platform for supporting the life cycle of services in IS of telecommunications service providers, the concept of which the authors proposed in the work [1]. To support the generally accepted stages of the life cycle of services, it is necessary to develop models, methods and technologies for the implementation of each of the group of relevant interrelated processes.

In conditions of fierce competition, telecommunications providers are forced to provide customers with a certain level of service quality quickly, at a price that is beneficial to both parties. It is the stage of service design, taking into account the characteristic features of the telecommunications industry, that is decisive for the provision of such services.

The complex problem of service design is decomposed into several interrelated subproblems. The article is devoted to solving the subproblem of forming service packages. The development of models and methods for forming service packages is based on mathematical programming approaches. An attempt has been made to bring together business analysts, service architects and applications by providing tools designed to quickly assess business objectives, requirements of telecommunications service providers and define appropriate mutually beneficial service packages. These tools will form the basis for the implementation of provider IS capable of supporting the business process system.

2. Literature review and problem statement

In the service life cycle, the design stage occupies an important place, combining business, functional and technological aspects. This is a complex problem, the solution of which requires taking into account the following factors and concepts:

1) the variety of services that information and communication service providers provide to their customers; the concept of a service catalog is used to represent services: the IT company's service catalog contains descriptions of services that the company provides to providers; the provider's service catalog contains descriptions of services that the provider provides to its customers;

2) a system of business processes for managing the activities of providers, customer business processes and third-party business processes supported by third-party products;

3) service configuration portfolios that combine subsets of services from the service catalog into a single whole based on technological dependence, traditions, business benefits, etc.;

4) processing of commercial offers by customers based on the collection, classification and analysis of information about products;

5) building a service architecture based on agreed commercial offers;

6) implementing a service based on the architecture and agreed commercial offers within the framework of order management.

Based on the need to take into account the above factors and concepts, service design support today is most often carried out through the implementation of the following popular processes:

1) *Formation of service portfolios*. Formation of service portfolios is based on the service catalog, the IT company's pricing policy, and all collected data about the provider. It is necessary to

determine a set of service portfolios formed to meet the needs of specific providers.

2) *Configuration of the provider's business process system*. Configuration of the provider's business process system requires support from the IT company's products. This process is based on the service portfolio, the library of business process descriptions, and all collected data about the provider. It is necessary to describe the business processes that form the provider's business process system and require automation of activities by the IT company.

3) *Development of a functional design (pre-configuration)*. Development of a functional design is based on the results of business analysis, requirements engineering, and descriptions of the provider's business process system. It also relies on the IT company's product catalog with descriptions of their components. It is necessary to develop a preliminary configuration that links business processes, functions, and operations supported by the designed service, products and their components, as well as identifies the need for changes to products, their components, and expansion of the product catalog.

4) *Validation of the preliminary configuration and formation of the final configuration with products*. Validation of the preliminary configuration and formation of the final configuration with products is based on the preliminary configuration and the provider's decisions regarding each product and component. All data collected by the IT company about the provider is also taken into account. It is necessary to develop a final configuration with product components capable of supporting the provider's business process system, based on analysis and the provider's corresponding decisions.

5) *Architecture construction*. Architecture construction is based on the final configuration and involves building a service architecture, considering the variety of telecommunication services, Business Support System (BSS), and Operations Support System (OSS). A microservice architecture can be applied, incorporating functional microservices, structural elements of the architectural style, technological elements, and their connections. These elements determine the interaction within the service architecture, its behavior, and its ability to support business processes, based on the descriptions used to design the service.

6) *Service implementation in the chain "portfolio – business processes – products – components – functions"* – based on the service architecture, it is necessary to define products, microservices, settings.

Effective implementation of these processes requires effective technologies based on appropriate models and methods. This should be done within the framework of a new scientific direction designed to form theoretical foundations and create practical technologies for supporting the life cycle of services. There are several variants of the names of this direction, for example, Service Science [2]. The development of service science is facilitated by the transition from commodity- and product-oriented thinking to service-oriented thinking, which occurs within the framework of the service approach.

This approach, based on modern scientific, technical, and managerial concepts, should develop comprehensive methodologies for creating, supporting, and developing service systems. These methodologies should include implementation tools built on mathematical models and methods that ensure services are provided with optimal efficiency, productivity, and sustainability.

In the article, this approach is demonstrated on the example of the subproblem of forming service portfolios within the framework of service design in IS of telecommunication service providers. It will allow to form the environment envisaged by the authors of the work [3] in which globally coordinated resources are economically used to provide necessary and profitable services to customers, while the services are continuously updated, and their provision is improved, and the user is moved to the focus of attention.

Let us proceed to the analysis of publications devoted to service design, paying main attention to models and methods of service design.

The current state of the infocommunications industry is characterized by the development of technologies focused on user needs in order to maintain a sufficient level of profitability in the face of growing competition and strict customer requirements [4].

In the activities of IT companies engaged in the automation of the activities of telecommunications service providers, the concept of providing services according to the E2E model is systematically implemented [5]. In the process of adapting to new conditions, the implementation of the service approach requires models, methods and technologies for tracking industry trends, market analysis, service interaction, determining Service-Level Agreement (SLA) parameters, ensuring a certain level of Quality of Service (QoS), security and trust, providing the ability to self-manage and self-organize, etc. [6].

Supporting business activities through services requires technologies for managing the service life cycle, implementing inter-service interaction taking into account SLA, ensuring the level of user service defined in terms of business needs, providing and managing the resources necessary for providing services, etc. Solving these problems is based on adequate methods of analysis, assessment, forecasting, generation, selection and justification of the most acceptable technologies and network equipment, and optimization of parameters. Literature sources devoted to the service approach can be divided into several groups.

Firstly, sources that offer general concepts for the development of the service approach regardless of the industry. Since processes in the service sector today affect all areas of human activity, there is a transition from a product-oriented business model to a service-oriented business model, which is called servitization [7]. Servitization is widespread among all companies, both product and service [8]. In the transition to a service business model, servitization is accompanied by digitalization, allowing product companies to radically transform their business model [9, 10]. The authors of [11] identified priorities related to service management and delivery and outlined a service ecosystem capable of influencing critical social and environmental processes. A hybrid approach to developing an intelligent Product-Service System (PSS) is presented in [12]. User orientation requires constant evolution of product and service components. The authors successfully use artificial intelligence models for evolutionary design of PSS.

Secondly, sources that offer general concepts for the development of a service approach in the IT industry and other high-tech industries. IT services, their role in supporting the business process system, processes that are critical to ensuring the use, improvement and development of IT services, advantages, problems, opportunities and practices for implementing IT Service Management (ITSM) in available literary sources are defined in sufficient detail [13 – 15].

Thirdly, sources that develop models and methods for supporting individual stages of the service life cycle, primarily design, implementation, provision and others. In [16], the authors proposed a service design method based on the concept of Information-Technology-enabled Services (ITeS). An approach to continuous improvement of IT services based on maturity assessments using Information Technology Infrastructure Library (ITIL) v3 best practices is described in [17]. The models used, primarily Fuzzy ITIL, allow for an increase in the maturity level in each ITIL cycle. In [18], the authors develop an approach to modeling ITSM frameworks, such as ITIL, ISO/IEC 20000, Microsoft Operations Framework (MOF), and Federated information technologies Service Management (FitSM), using a standardized set of models and their elements, which allows customization for various processes.

Much attention is paid to the problem of service design. Service design and development are positioned as a complex problem of high priority in the information systems of telecommunications service providers, as it consists in creating an environment for achieving business goals and supporting the life cycle of services. The total cost of ownership is recommended to be reduced by effectively developing services, processes and technologies, while improving the quality of service and operational quality by aligning service, performance and management using the concepts of service catalog, service level, bandwidth, security, supplier selection, service continuity and availability management [19].

A model and method for designing services in the telecommunications industry based on the concept of a catalog are proposed in [20]. Optimization of IT service performance is ensured by the correct selection and establishment of relationships between services using formal mathematical methods. An important aspect of the approach is the consideration of criticality, value, and downtime parameters, the requirements for which are defined in agreements concluded with the provider's customers.

Fourth, the sources are devoted to the development of platforms, technologies, and other tools to support the service life cycle and individual stages. The authors of [21] outline the possibilities of digital transformation as the basis for providing innovative digital services that allow businesses to create and receive new values, as well as ensure the readiness of the enterprise to implement digital changes. The problems, opportunities, models of digital transformation of services, and its impact on the customer experience are described.

In [22], the impact of digital transformation on the sustainability of companies is analyzed and a framework is proposed that considers digital transformation as a driving force for ensuring sustainability. By expanding digital capabilities, the positive impact of integrating digital and sustainable transformations on increasing the efficiency and productivity of business is ensured, while balancing economic, environmental and social consequences.

Fifth, sources that consider models, methods and algorithms for solving important tasks for individual processes of the service life cycle.

Now regarding the formation of service packages. The literature emphasizes that their use systematizes and improves the process of providing services. Mainly, combining services into packages is carried out on the basis of analyzing input data and establishing hidden dependencies between them using statistical methods and methods of intellectual analysis. In addition, to obtain business-oriented packages, the business goals and strategies of the service provider and recipient are taken into account.

Unfortunately, the entire range of listed problems has not yet been fully resolved. In particular, there is a need for a comprehensive approach to the design, implementation and provision of services and the development of relevant tools – platforms, information technologies, products and components. Equal attention should be paid to the models and methods that should form the basis for the creation of these tools. In this regard, the integration of neural networks with fuzzy logic and mathematical programming models is promising.

3. The aim and objectives of the study

The complex nature of the problems of analysis, assessment, forecasting, accounting, planning, implementation of services, resource management and others is determined, first of all, by the fact that the platform for supporting the life cycle of services must cover all stages, all processes of each stage. The problem of service design is no exception.

In ITSM and other generally accepted regulatory documents of the industry, the problem of service design is associated with the concept of a Service Design Package (SDPac). In these documents, the prerequisites for the widespread use of service design tools in practice are the needs of real-time service management, coverage of all stages of the service life cycle, orientation on client requirements, proper consideration of business, technical and organizational aspects [23].

To evaluate SDPac and determine the requirements for this package, it is recommended to use the alignment of services with business needs, manageability of life cycle processes, improvement of service quality, facilitation of provision of new or changed services, improvement of economic indicators (for example, reduction of total cost of ownership), increase in efficiency of service provision.

To solve the problem of implementation, transition to service provision, operation, and continuous improvement of the service based on the SDPac concept, ITIL recommends using several key elements. These include agreed business requirements, functional and non-functional requirements for services, and a plan for transition, implementation, and operation of the service. ITIL also highlights the need for new skills, competencies, and capabilities to assess benefits, financial, technical, and resource aspects, as well as business processes, a communication and reporting plan, timeframes, and quality targets for each stage [24].

The introduction of a service approach into the activities of infocommunication service providers necessitates the formulation of the problem of service design in a broad sense. The discussion focuses on service design through the development of a holistic platform to support the service life cycle. Taking into account the need to implement scenarios of operations for creating IS of providers according to the E2E model, the accumulated experience of implementing individual processes of the service life cycle is utilized. Based on the need for models and methods to form decision chains within the scenarios "business processes – requirements – products" and "components – architecture – implementation," the problem of service design in a broad sense is decomposed into subproblems:

1) standardization of scenarios of operations for the creation of information systems of providers according to the E2E model;
2) formation of service portfolios;
3) configuration of the provider's business process system;
4) development of a functional project (pre-configuration);
5) development of the final configuration;
6) construction of the service architecture.

Solving the service design problem involves developing tools for some of the subproblems listed above. The article proposes models and methods for solving the subproblem of forming service portfolios:

Input:
– catalog of IT company services;
– pricing policy of IT company;
– data about the provider accumulated by the IT company.

Output:
– a set of service portfolios formed for the needs of specific providers.

The subproblem of forming service portfolios that the IT company will offer to providers of infocommunication services is essentially a subproblem of forming service packages. But in such a high-tech industry, it has its own characteristics related to taking into account the nature of services and their relationships.

The aim of this study to explore the process of forming service packages. The usage of formal models and methods of forming service packages may lead to improvements in activities of both IT companies and telecommunications providers.

The objective of the study is the development and evaluation of models and methods for forming service packages that will form the basis for the effective implementation of a service lifecycle support platform.

To achieve this goal, the following tasks are set:
– to develop a general approach to solving the formulated problem within the framework of the service life cycle support platform;
– to develop appropriate mathematical models and methods for forming service packages;
– to assess the effectiveness of the developed methods and provide recommendations for their application in IS of IT companies and providers to support business processes in various conditions.

4. The study materials and methods of summarization model development

4.1. General description of the proposed solution

The implementation of business processes as the basis for designing services support in IS of infocommunication service providers created according to the E2E model involves creating a solution in the form of an intelligent engine that transforms business processes and user business requirements into product platform settings in such a way as to support services with product components and technologies on which they are based.

The specified intelligent engine uses specialized models and methods to implement individual subprocesses and operations, guided by the general model of supporting the provider's activities based on a neural network with deep learning. Models and methods for individual subprocesses and operations can be based on traditional methods of mathematical programming, decision theory, discrete mathematics. For some business processes and subprocesses, artificial intelligence models can also be used, which the intelligent engine will integrate with other models in such a way as to ensure rational behavior of the IT company and the provider.

In particular, when designing and developing services in IS of providers, from several classes of framework templates developed in advance for services, an appropriate framework template is selected based on functional requirements and/or the purpose of the service, and then, using a neural network, based on non-functional requirements, additional elements and connections are selected that are added to the service structure.

Two processes occur in a neural network that require appropriate solutions taking into account the specific features of the problem:

– learning, during which the network selects new, more suitable framework templates and typical services;

– classification, the network selects a framework template and a typical service based on functional requirements and/or the purpose of the service and non-functional requirements.

For the first process, it is important that the deep learning neural network includes elements, connections, basic templates, typical services, requirements. At the output, the network can produce a new service structure. The basic principle of training is to teach the system to use the most successful constituent elements and connections to form the necessary architectures, based on the requirements. In other words, in training, the basic approach should be based on identifying common elements, relationships, behavior patterns, etc. in the architecture of these services, in the requirements for them and other components, and to form a new service architecture on this basis.

A system with an intelligent engine, in fact, at the top level models a decision tree based on functional requirements for services and determines a set of products and their components that will be used to provide services to the provider, and at the second level selects and applies neural networks and other models, methods and technologies for configuration and parameter determination. At the top level, the logic for solving the problem of supporting activities related to organizing the interaction of processes of all stages of the service life cycle is implemented (this article is about design and development, but in general it is necessary to take into account all stages). At the bottom level, the logic for executing individual processes, subprocesses, or even operations based on the input data defined at the top level and the selected appropriate technologies is implemented.

To implement such a system, it is necessary to use several important data sources – the type and parameters of the service, functional requirements for the service, customer features (size, complexity, domain...), non-functional requirements, and others, which will allow you to choose the basic architecture of the service for the client, which is then expanded by adding new elements, relationships, templates, typical services. That is, the system regularly analyzes already known services, calculates the ratings of these services, and determines acceptable, common requirements for services. Thus, each service in the system is evaluated in the process of its provision in real time, and in addition, statistical assessments of efficiency and other parameters important for decision-making at the stage of business analysis are calculated for each service. It is important to have these assessments for each service as a whole and for the same service in relation to each client. To do this, it is necessary to implement a detailed description of services, architecture, structural elements, relationships, functional and non-functional requirements, and implement an appropriate system for collecting information, evaluating efficiency, and other indicators important for business for the IT company, provider, and client. It is also important to get ratings directly from users, for example through social media.

When implementing such a system, various problems will arise, such as managing cloud resources for the effective functioning of the intelligent engine, platform, neural networks and other technologies. To obtain samples of architectures and estimates from IT companies, providers and customers, it is necessary to develop a standard form for submitting architectures and estimates, for example in vector form.

All solutions proposed in the second stage are corrected by the service architect.

4.2. Mathematical models of the problem of forming service portfolios

Consider an IT company that provides services from the set: $S = \{S_1, S_2, \dots, S_m\}$, and a set of providers $P=\{P_1,P_2,\ldots,P_k\}$ that are interested in obtaining the opportunity to provide services from the set S to their clients.

Services are not independent. The following options for connections between them are possible.

Option 1. To provide service S_i a set R_i of services is known that are necessary to ensure its provision:

$$R_i=\{S_1^i,\ldots,S_{n_i}^i\}, i=1,\ldots,k, \quad (1)$$

where n_i is the number of services necessary to support the provision of service S_i.

In this case, services from the set R_i must be located at providers simultaneously.

Option 2. All services are divided into q subsets (hereinafter referred to as groups) of interdependent services: $V_1,V_2,\ldots,V_q$, such that the following condition is met:

$$\cup_{l=1}^{q} V_l=\{S_1,S_2,\ldots,S_m\}, \quad (2)$$

$$R_i=\{S_1^i,\ldots,S_{n_i}^i\}, i=1,\ldots,k. \quad (3)$$

In this case, services should be placed in groups with providers. The formation of these groups occurs as follows. First, a relationship graph is constructed, where each edge indicates the dependence of one service on another. Then, connectivity components are identified, each of which forms a separate group. This article focuses on option 2.

In addition, the following values are also known.

Option A. The base price c_{ij} of service S_i, which provider j pays to the IT company for its provision during the planning period $(i=1,\ldots,k; j=1,\ldots,m)$. Here and below, all cost values are tied to the selected planning period (month, year, etc.).

Option B. The value v_{ij} of service S_i for an IT company, if this service is ordered by provider j $(i=1,\ldots,k; j=1,\ldots,m)$), sometimes this value can be taken as the IT company's income from providing service S_i to provider j. To estimate this value, you can also use a statistical approach or methods of assessing potential opportunities, for example, forecasting.

This article focuses on option A.

Variables

An IT company faces the question of how to form service portfolios for each provider. Accordingly, the variables sought are:

$$y_{lj}=\begin{cases}1, \text{if service group } V_l \text{ is included in the portfolio of provider } j,\\0, \text{if service group } V_l \text{ is not included in the portfolio of provider } j,\end{cases} \quad (4)$$
$$l=1,\ldots,q, j=1,\ldots,m;$$

$$x_{ij}=\begin{cases}1, \text{if service } S_i \text{ is included in the portfolio of provider } j,\\0, \text{if service } S_i \text{ is not included in the portfolio of provider } j,\end{cases} \quad (5)$$
$$i=1,\ldots,k, j=1,\ldots,m.$$

Constraints

Services included in the group V_l, $l=1,\ldots,q$, must simultaneously be included/not included in the portfolio of provider j. Therefore, for each service S_i from the set V_l $(l=1,\ldots,q)$ the condition must be satisfied:

$$x_{ij}=y_{lj}, \qquad j=1,\ldots,m. \quad (6)$$

Constraints from the IT company

A constraint that takes into account the limited human resources of the IT company intended to support all its services:

$$\sum_{i=1}^{k}\sum_{j=1}^{m}\beta_{ij}x_{ij}\le B, \quad (7)$$

where, β_{ij} – the amount of human resources used to provide service S_i to provider j, human resource units for the planning period (hereinafter referred to as the labor intensity of the service); B – the total available amount of human resources of the IT company, human resource units for the planning period.

Constraints from providers

Various constraints may apply from the providers' side, the most common are constraints on the relative value of services and constraints on the values of quantitative SLA indicators.

Let:

d_{ij} – income of provider j from providing service S_i, cost units ($i = 1, \dots, k,\ j = 1, \dots, m$);

b_{ij} – costs of provider j when providing service S_i, cost units ($i = 1, \dots, k,\ j = 1, \dots, m$);

γ_{ij} – minimum relative value of service S_i, provided by provider j ($i = 1, \dots, k,\ j = 1, \dots, m$);

S – set of SLA indicators by which services are evaluated, $|S| = r$;

$S^{min} \subseteq S$ – set of SLA indicators for which minimum threshold values are set (i.e. actual values of indicators cannot be less than these threshold values);

$S^{max} \subseteq S$ – set of SLA indicators for which maximum threshold values are set (i.e. actual indicator values cannot be greater than these threshold values);

p_i^z – value of SLA indicator z of service S_i in the IT company's service catalog ($i = 1, \dots, k$, $z = 1, \dots, r$) (threshold values of indicators are set);

$S_j \subseteq S$ – subset of SLA indicators by which provider j evaluates services included in its portfolio ($j = 1, \dots, m$);

$S_j^{min}, S_j^{max} \subseteq S_j$ – subsets of SLA indicators by which provider j evaluates services and for which minimum/maximum threshold values are set;

p_{ij}^z – value of SLA indicator z of service S_i in the service catalog of provider j ($i = 1, \dots, k$, $j = 1, \dots, m,\ z \in S_j$).

Taking into account the introduced notations, the constraint on the relative value of each service of the provider's portfolio j, has the form:

$$\gamma_{ij} x_{ij} \le \frac{d_{ij}}{b_{ij}},\ i = 1, \dots, k, j = 1, \dots, m. \tag{8}$$

The constraints on the values of SLA indicators have the form:

$$p_i^z \ge p_{ij}^z x_{ij}\,,\ i = 1, \dots, k,\ j = 1, \dots, m,\ z \in S_j^{max}, \tag{9}$$

$$p_i^z x_{ij} \le p_{ij}^z\,,\ i = 1, \dots, k,\ j = 1, \dots, m,\ z \in S_j^{min}. \tag{10}$$

Taking into account the introduced notations, the constraint on the relative value of each service of the provider's portfolio j, has the form:

Objective functions

Each of the parties (IT company and providers) pursues its own economic goals, so it makes sense to consider this situation from the perspective of both those who receive services and those who provide them.

Objective function (IT company)

The IT company needs to determine the most profitable way of providing services to a set of existing providers, which will use them to ensure the provision of relevant services to their clients, i.e., it is advisable for the IT company to form the portfolios of provider services in such a way as to maximize the total revenue from providing them to a set of existing providers:

$$F = \sum_{j=1}^{k} \sum_{i=1}^{m} c_{ij} (1 - \omega_{ij}) x_{ij} \to max, \tag{11}$$

where, ω_{ij} – is the discount to the base price c_{ij} for service S_i provided to provider j, $i = 1, \dots, k$, $j = 1, \dots, m$, $0 \le \omega_{ij} < 1$.

Objective function (providers)

In general, providers may be given discounts, for example: discounts on specific services;

discounts on each additional service (group) added to the provider's portfolio; discounts depending on the number of services in the portfolio, etc.

The following system of discounts for providers is used in the work: ω_{ij} – discount on service S_i, when providing it to provider j, $i = 1, \dots, k$, $j = 1, \dots, m$, $0 \leq \omega_{ij} < 1$.

Therefore, the criterion for assessing the profitability of the service portfolio from the point of view of provider $j, j = 1, \dots, m$ will be as follows:

$$\Phi_j = \sum_{i=1}^{k}(d_{ij} - c_{ij}(1 - \omega_{ij}))x_{ij} \to max. \qquad (12)$$

Problem (4) – (12) belongs to the class of multi-criteria Boolean programming problems.

In this model, the variables (unknown quantities) can include not only y_{lj} $(l = 1, \dots, q, j = 1, \dots, m)$ and x_{ij} $(i = 1, \dots, k, j = 1, \dots, m)$, but also the discount values ω_{ij} $(i = 1, \dots, k; j = 1, \dots, m)$. In this case, the problem belongs to the class of nonlinear problems.

The basic research model in this work is a simplified mathematical model of the problem situation, which does not take into account the constraints (8) – (10) and the objective functions (12), hereinafter referred to as the problem $T(\omega)$), in which the values ω of discounts are conditionally constant and the goal is to maximize the objective function (11).

Problem $T(\omega)$

Given: c_{ij}, $i = 1, \dots, k; j = 1, \dots, m$; V_l, $l = 1, \dots, q$; β_{ij} $i = 1, \dots, k; j = 1, \dots, m$; B; ω_{ij} $i = 1, \dots, k; j = 1, \dots, m$.

Find: y_{lj} $(l = 1, \dots, q, j = 1, \dots, m)$ and x_{ij} $(i = 1, \dots, k, j = 1, \dots, m)$ such that satisfy the constraint

$$x_{ij} = y_{lj}, \ i \in V_l, \ l = 1, \dots, q, j = 1, \dots, m, \qquad (13)$$

$$y_{lj} \in \{0; 1\}, \ l = 1, \dots, q, j = 1, \dots, m, \qquad (14)$$

$$x_{ij} \in \{0; 1\}, \ i = 1, \dots, k, j = 1, \dots, m, \qquad (15)$$

$$\sum_{i=1}^{k} \sum_{j=1}^{m} \beta_{ij} x_{ij} \leq B, \qquad (16)$$

and maximize the functional

$$F = \sum_{i=1}^{k} \sum_{j=1}^{m} c_{ij}(1 - \omega_{ij})x_{ij} \to max. \qquad (17)$$

4.3. Methods for solving the problem of forming service portfolios

The specificity of the problem (5) – (10), in particular the nonlinear nature of the objective function and constraints, high dimensionality, suggests the use of heuristic algorithms. Genetic algorithms and the bee swarm algorithm are traditionally used in the case of search spaces with many extrema, the presence of noise, and high dimensionality of the search space. In other cases, brute force search and gradient methods can be effective.

The paper proposes the Combined Two-Stage Exact-Approximate Method (CT-SE-AM) and the author's version of the genetic algorithm – the Modified Version of Guided Genetic Algorithm (MVGGA). The first of them uses at the first stage classical methods for solving the knapsack problem or the Heuristic Method (HM) specially developed taking into account the specifics of the problem, and at the second stage implements a compromise scheme to improve the solution. The second uses specially developed tools for managing the convergence of the genetic algorithm in combination with tools for selecting the best solutions taking into account the features of the multi-criteria problem.

The GA was chosen due to the requirement for more than just a method to solve an optimization problem. In fact, the problem of choosing a portfolio of services requires an approach that involves solving not one problem, but solving problems of several classes with the choice of the best solution.

Here it is necessary to take into account both variables and parameters of a certain behavior.

Therefore, the choice of GA for our problem is justified. It has important advantages over other approximate methods. These advantages consist in the possibility of simultaneous combination of variables in the solution structure and the parameters of the problem when searching for a solution.

4.3.1. Combined two-stage exact-approximate method

Description and justification of the combined two-stage exact-approximate method

As mentioned in subsection 4.2, the basic model of the study is the problem $T(\omega)$.

The solution to the problem $T(\mathbf{0})$ is optimal for the situation corresponding to zero discount values for all providers ($\omega = \mathbf{0}$). It is quite possible that providing discounts on certain/all services to the provider(s) will lead to an improvement in the situation in the sense that the revenues of the IT company and/or providers will increase.

The purpose of further research is to determine the so-called effective discount system ω, which will be to some extent beneficial for both parties. Here, profitability is understood in the sense that one of the conditions is met:

1) there is an improvement in the objective functions (OF) F and all criteria for the profitability of the service portfolio from the provider's Φ_j point of view;

2) the total relative deterioration of these functions is less than the total relative improvement of the others.

To determine an effective discount system, the process of solving the problem is proposed to be divided into two stages:

Stage 1. At this stage, the optimization problem $T(\omega = 0)$ is solved using HM. In this case, such portfolios of services for providers will be determined, under which the IT company will receive maximum income at zero discounts.

Stage 2. At this stage, for the selected provider(s) or group of services, discounts that are mutually beneficial to the parties are selected using a certain iterative procedure, while for each new set of discounts ω the optimization problem $T(\omega)$ is solved.

In the process of searching, the relative changes in the OF values are monitored.

Heuristic method for solving the problem T(ω)

The idea of HM is based on the use of the so-called "value" of a unit of labor intensity of a group of services, which is equal to the ratio of the total price of a group of services to their total labor intensity.

Pseudocode of HM

Input k
q
m
$V_l,\ \ l = 1, \dots, q$
$c_{ij},\ \ i = 1, \dots, k; j = 1, \dots, m$
$\beta_{ij},\ i = 1, \dots, k; j = 1, \dots, m$
B
Parameter $\omega_{ij}\ i = 1, \dots, k; j = 1, \dots, m$
Output $y_{lj},\ \ l = 1, \dots, q; j = 1, \dots, m$
$x_{ij},\ \ i = 1, \dots, k; j = 1, \dots, m$
F
$\Phi_j,\ \ j = 1, \dots, m$
for l **from** 1 **to** q
  for j **from** 1 **to** m
    $C_{lj} \leftarrow \sum_{S_i \in V_l} c_{ij}(1 - \omega_{ij})$ // Total price of services of group V_l for provider j, taking into account discounts

$H_{lj} \leftarrow \sum_{s_i \in V_l} \beta_{ij}$ // Total labor intensity of support of all services of group V_l for provider j

$\eta_{lj} \leftarrow \frac{c_{lj}}{H_{lj}}$ // "Value" of a unit of labor intensity of services of group V_l for provider j

Endfor

Endfor

Order pairs by non-increasing values η_{lj}

$y \leftarrow \mathbf{0}$

$D(y) \leftarrow 0$

for g **from** 1 **to** $q \cdot m$

if $(B - D(y) \geq H_{lj})$ **then**

$y_{ij} \leftarrow 1$

$D(y) \leftarrow D(y) + H_{lj}$

Endif

Endfor

Calculate the corresponding values of all OFs

At Stage 2, the following strategies for selecting a provider or group of providers can be applied:

a) gradually, with a certain step, the discount on the most used services is increased;

b) gradually, with a certain step, the discount on the least used services is increased;

c) gradually, with a certain step, the discount on providing services to the provider with the smallest value of Φ_j is increased;

d) gradually, with a certain step, the discount on providing services to the provider with the largest value of Φ_j is increased;

e) gradually, with a certain step, the discount on providing services to the provider with the largest number of service groups is increased;

f) gradually, with a certain step, the discount on providing services to the provider with the smallest number of service groups is increased;

It is worth noting that usually the provider with the largest (smallest) value of Φ_j usually has the largest (smallest) number of service groups, although in rare cases this may not be the case.

4.3.2. A modified version of the guided genetic algorithm

Description and justification of a modified version of the guided genetic algorithm

As mentioned earlier, the aim of the study is to determine the so-called efficient discount system ω, which will be to some extent beneficial for both parties. This means that it is necessary to find a solution to the following $(m + 1)$-criteria mixed programming problem.

The problem

Given: c_{ij}, $i = 1, \ldots, k; j = 1, \ldots, m$; V_l, $l = 1, \ldots, q$; β_{ij} $i = 1, \ldots, k; j = 1, \ldots, m$; B.

Find: ω_{ij} $i = 1, \ldots, k; j = 1, \ldots, m$ and y_{lj} $(l = 1, \ldots, q, j = 1, \ldots, m)$ and x_{ij} $(i = 1, \ldots, k, j = 1, \ldots, m)$, such that satisfy the constraint

$$x_{ij} = y_{lj}, \qquad i \in V_l, l = 1, \ldots, q, j = 1, \ldots, m, \tag{18}$$

$$y_{lj} \in \{0; 1\}, \qquad l = 1, \ldots, q, j = 1, \ldots, m, \tag{19}$$

$$x_{ij} \in \{0; 1\}, \qquad i = 1, \ldots, k, j = 1, \ldots, m, \tag{20}$$

$$0 \leq \omega_{ij} \leq 0.99, \qquad i = 1, \ldots, k, j = 1, \ldots, m, \tag{21}$$

$$\sum_{j=1}^{k}\sum_{i=1}^{m}\beta_{ij}x_{ij} \le B, \tag{22}$$

and maximize the functionals

$$F = \sum_{j=1}^{k}\sum_{i=1}^{m} c_{ij}(1-\omega_{ij})x_{ij} \to max, \tag{23}$$

$$\Phi_j = \sum_{i=1}^{k}(d_{ij} - c_{ij}(1-\omega_{ij}))x_{ij} \to max,\ j = 1,\dots,m. \tag{24}$$

Since services must be placed in groups with providers, this task can be simplified by removing the variables x_{ij}, because the variables y_{lj} uniquely determine the values of the variables x_{ij}.

The problem *T*

Given:

$$C_{lj} = \sum_{S_i \in V_l} c_{ij},\ \ l = 1,\dots,q; j = 1,\dots,m, \tag{25}$$

$$H_{lj} = \sum_{S_i \in V_l} \beta_{ij},\ l = 1,\dots,q; j = 1,\dots,m, \tag{26}$$

$$D_{lj} = \sum_{S_i \in V_l} d_{ij},\ \ l = 1,\dots,q; j = 1,\dots,m. \tag{27}$$

Find: w_{lj} $(l = 1,\dots,q; j = 1,\dots,m)$ and y_{lj} $(l = 1,\dots,q, j = 1,\dots,m)$, such that satisfy the constraint

$$y_{lj} \in \{0;1\},\ l = 1,\dots,q;\ j = 1,\dots,m, \tag{28}$$

$$0 \le \omega_{lj} \le 0.99, l = 1,\dots,q;\ j = 1,\dots,m, \tag{29}$$

$$\sum_{l=1}^{q}\sum_{i=1}^{m} H_{lj}y_{lj} \le B, \tag{30}$$

and maximize the functionals

$$F = \sum_{l=1}^{q}\sum_{i=1}^{m} C_{lj}(1-w_{lj})y_{lj} \to max, \tag{31}$$

$$\Phi_j = \sum_{l=1}^{q}(D_{lj} - C_{lj}(1-\omega_{lj}))y_{lj} \to max,\ j = 1,\dots,m. \tag{32}$$

Thus, a multi-criteria nonlinear Boolean programming problem T arises, the solution of which will be represented by two components:

– component 1 is a Boolean matrix of genes, the values (0 or 1) of which correspond to the corresponding values of Boolean variables of the matrix Y of size $q \times m$, which is an admissible solution to the problem;

– component 2 is a discount matrix w of size $q \times m$, the values of which belong to the continuous interval [0,1).

The developed MVGGA is based on the Holland genetic algorithm [25], which was modified taking into account the specifics of the problem being solved.

Traditional concepts of genetic algorithms include population creation, selection of parent individuals, implementation of crossover, mutation, population restoration and update. Consider the features of the developed genetic algorithm operators.

Creating the initial population

The initial population contains a given number of randomly generated individuals and does not contain repetitions.

As is customary, each individual will be evaluated by the measure of “adaptability to the conditions of existence”. The adaptability of an individual y is defined as the total value of the revenue functions of the IT company and all providers on the matrix Y of solution variables corresponding to the individual:

$$f(y) = F(y) + \sum_{j=1}^{m} \Phi_j(y). \quad (33)$$

Parents' choice

It occurs according to the Goldberg roulette rule [26], according to which the probability of selecting an individual y^i as a parent is directly proportional to the value of its fitness:

$$p(y^i) = \frac{f(y^i)}{\sum_{i=1}^{N} f(y^i)}, \quad (34)$$

where, $f(y^i)$ – the adaptability of individual y^i, N is the number of individuals in the population.

At each step, $\frac{N}{4}$ pairs of individuals are selected according to this rule.

Crossover

A single-point crossover is performed for a pair of selected parent individuals. For this, a breakpoint is randomly selected and two genotypes of the offspring are formed.

Mutation

The mutation of an individual is carried out according to a probabilistic scheme by changing each bit to the opposite with a probability of 1/10000.

Since the matrix Y has dimensions $q \times m$, the probability of mutation of an individual is $(q \times m)/10000$ and for small values of the product $q \times m$, the mutation of the individual may not occur. In this case, the attempt to mutate this individual is repeated.

Algorithm convergence control

To control the approximation of the result to the best solution, a system of rules based on the principle of mode switching has been developed – the search is accelerated if the approximation steps during the algorithm are large enough, the algorithm switches to expanding the use of useful chromosomes if the approximation steps decrease.

The system of rules (described below) maintains a balance between expanding the search space for the optimum and effectively using all chromosomes useful for obtaining the best solution.

In this case, obtaining a new population of individuals based on representatives of the past era is not carried out by sequentially executing the crossover and mutation operators, but by balancing between the search for:

– new promising areas for obtaining effective solutions that may contain the desired optimum, which are not included in the studied space of mutations of the best representatives of the current population (using mutation);

– the best solutions, which can be both local and global, in new areas (using crossover).

Which operator (crossover or mutation) will be used to obtain the population of the next epoch is determined based on a system of rules (rules 2 and 3). In general, the algorithm focuses on crossover until the current solution is significantly improved. When the growth of the local optimum slows down, a transition occurs to search for new regions with better solutions.

Recovery

During the process of crossing over and mutation, unacceptable solutions may be obtained. In order to ensure that only solutions that are permissible under constraint (28) are used, an individual repair operator has been developed, which is based on the rule "remove the worst".

Determining the record solution

Since this is a multi-criteria problem, to determine the record solution, the rules of the advantages of the solution over others in terms of the values of the criteria are defined, provided that the constraints are met. The concept of determining the record solution uses the presence of two objective functions – for the IT company (F) and providers ($\Phi = \sum_{j=1}^{m} \Phi_j$), taking into account the possibility of discounts. It is required that in the process of solving the problem, the values of both functions improve or the deterioration of the value of one function is compensated by a significant improvement in the other (rule 5).

Population update

An individual is added to the population provided that it is more adapted than the worst individual, and (to avoid repetitions) is not contained in the current population.

Generalized scheme of the method

1 **Input** q
m
$C_{lj},\ l = 1, \dots, q; j = 1, \dots, m$
$H_{lj},\ l = 1, \dots, q; j = 1, \dots, m$
B
2 **Output** $w_{lj},\ l = 1, \dots, q; j = 1, \dots, m$
$y_{lj},\ l = 1, \dots, q; j = 1, \dots, m$
F
$\Phi_j, j = 1, \dots, m$
3 $p = 1$ // if $p = 1$, then the crossover is implemented
// if $p = 0$, then the mutation is implemented
4 $w \leftarrow \mathbf{0}$
5 **while** *condition 2* not met **do**
6 **Create** an initial population
7 **Determine** the record solution
8 **while** *condition 1* not met **do**
9 **Choose** $N/2$ individuals
10 **if** $\boldsymbol{p = 1}$ **then**
11 **Split** the selected individuals into pairs
12 **Cross** selected pairs
13 **else**
14 **Mutate** each selected individual
14 **endif**
16 **Update** population
17 **Update** the record solution if necessary
18 **Recalculate** the value of p
19 **end while**
20 **Change** w
21 **Reevaluate** the population's individuals
22 **Update** the record solution if necessary
23 **end while**

Guided Genetic Algorithm (steps 6–19)

Steps 6–19 implement MVGGA for solving the Boolean programming problem $\boldsymbol{T}(w)$ for a specific value of the discount matrix w. *Condition 1* of the MVGGA termination is given by rule 1.

The outer while loop 5–23 of the method controls the discount values w according to a certain strategy. *Condition 2* of MVGGA termination is given by rule 6.

As a discount setting strategy, it is proposed to take the strategies described in subsection 4.3.1, generalized in a certain way. For example, according to strategy a) the most used services can be determined:

– by the current record solution;

– by the top solutions of the current population.

Description of the developed system of rules

The modified version of the guided genetic algorithm uses the well-known idea of controlling the convergence of the algorithm and introduces a new concept of selecting solutions taking into account the multi-criteria nature of the problem.

The control of the convergence of the algorithm is aimed at achieving a reasonable compromise between the number of algorithm steps and the accuracy of the solutions. For this purpose, a system of rules for controlling the selection, crossover and mutation operators in the process of solving the problem is used based on the current results, history and values of a number of additional parameters [27]. New additional parameters take into account the peculiarities of the problem and give the genetic algorithm the ability to quickly converge to a result that is close enough to the optimum.

The steps of controlling the convergence will also be important for the modified guided genetic algorithm as a whole:

To formulate the modified version of the guided genetic algorithm, it is necessary to change the system of parameters.

In this case, it is advisable to leave the traditional population growth rate

$$k_g = \frac{l}{N}, \quad (35)$$

where, l is the number of descendants obtained in the current iteration of the genetic algorithm, N is the population size;

It is suggested to enter the following additional parameters.

1) To assess the degree to which the current population is approaching the optimum, the *two-sided selection pressure* ρ is introduced:

$$\rho = \frac{F_{max} + \Phi_{max}}{\bar{F} + \bar{\Phi}}, \quad (36)$$

where, F_{max} is the maximum value of the objective function F for the current population, Φ_{max} is the maximum value of the objective function Φ for the current population, $\bar{F}$ is the average value of the objective function of the IT company for the current population, $\bar{\Phi}$ is the average value of the objective function of providers for the current population.

In essence, the new parameter is defined as the ratio of the maximum sum of the values of both OF to the average sum of the values of both OF in the population of the current epoch. In this case, the optimality criterion is assumed to be the maximization of the value of the fitness function. Traditionally, genetic algorithms have used for this purpose selection pressure $\rho = \frac{f_{max}}{\bar{f}}$, where, f is the search OF, f_{max} is the maximum value of the OF for the current population, and $\bar{f}$ is the average value of the OF of the current population.

It is worth remembering that by definition, the traditional selection pressure cannot be less than the value 1. The same applies to the proposed two-way selection pressure.

2) To assess the trend of change in the convergence of the genetic algorithm when moving from epoch to epoch, the relative rate of approach to the optimum is used:

$$\hat{\Delta}_{i-1,i} = \frac{\rho_{i-1} - \rho_i}{\rho_i}, \quad (37)$$

where ρ_{i-1} and ρ_i are the two-sided selection pressures calculated from the results of iterations $i-1$ and i respectively. The relative rate is defined as the weighted difference between the values of the two-sided selection pressures of the populations of the previous and current epochs. Previously, the pressure change rate $\Delta_{i-1,i} = \rho_{i-1} - \rho_i$was used for this.

Based on them, the set of rules is expanded to determine the operators for obtaining the population of the next epoch during the algorithm operation.

Rule 1. There are two traditional options for completing the GGA:

– if $k_g > k_{max}$, where k_{max} is the limiting (maximum) possible number of generated individuals;

– if the number of consecutive iterations, during which the record solution does not change, reaches the established limit value.

Rule 2. The rule for forming the population of the next epoch using the crossover operator when finding the best solution to the problem using the entered parameters takes the form

$$\textbf{if } \hat{\Delta}_{i-1,i} > 0 \textbf{ then } p = 1. \quad (38)$$

The logic of using the rule has not changed – it is worth preserving the best solution by moving from the "research" strategy to the "use" strategy.

Rule 3. The rule for forming the population of the next epoch using the crossover operator under uncertainty using the entered parameters takes the form

$$\textbf{if } ((\widehat{\Delta}_{i-1,i} \geq \widehat{\Delta}_{\text{гр}}) \textbf{ and } (\rho_i \geq \rho_{\text{гр}})) \textbf{ then } p = 1, \quad (39)$$

where, $\widehat{\Delta}_{\text{гр}}$ is the limiting value of the relative speed of approach to the optimum, $\rho_{\text{гр}}$ is the limiting value of the two-sided selection pressure.

The rule implements traditional logic in conditions when the nature of the convergence of processes is still uncertain, there is no convergence to the “local” optimum.

Rule 4. The rule for forming the population of the next epoch using the mutation operator in the absence of real progress in finding a better solution to the problem using the entered parameters takes the form

$$\textbf{if } ((\widehat{\Delta}_{i-1,i} < \widehat{\Delta}_{\text{гр}}) \textbf{ or } (\rho_i < \rho_{\text{гр}})) \textbf{ then } p = 0. \quad (40)$$

This rule implements traditional logic – when the process of improving the solution significantly slows down, mutation is used to obtain the population of the next epoch, i.e., a transition is made from the "use" strategy to the "research" strategy.

Rule 5. A rule for determining the current record solution is added. This does not require improving the solution simultaneously for the IT company (function F) and for providers (function Φ). The logic of this rule is to use the improvement of the sum of the values of both functions in the process of solving the problem, when the deterioration of the value of one function is compensated by a more significant improvement in the other.

Rule 6. The traditional for the guided genetic algorithm rule of stopping the algorithm and determining the solution is preserved.

However, the termination condition is changed so that the relative speed must be less than the specified value for a certain number of iterations.

The logic is traditional – if the adaptability function of the best individual of the current epoch deteriorates relative to the previous epoch, then before stopping the process it is worth making several attempts to search for a potentially effective solution region, and in case of failure, record the correct epoch with its search result.

To organize process control in a modified version of the controlled genetic algorithm, the user must specify the initial values of the traditional and new parameters $k_{\text{гр}}$, $\widehat{\Delta}_{\text{гр}}$, $\rho_{\text{гр}}$. The traditional recommendations for the guided genetic algorithm can be applied to the selection and modification of the values of these coefficients.

5. Results of investigating summarization effectiveness

5.1. Experimental results of the combined two-stage exact-approximate method

Here are some results of the experiments.

Results of an experimental study of the proposed strategies for effectiveness

Experimental study of strategy a)

The results of applying a two-stage algorithm using strategy a) are shown in Figures 1 – 3. These results were obtained when solving the problem with the following parameters: the number of services $k = 20$; the number of providers $m = 3$; the number of service groups $q = 6$; the available human resource $\text{B} = 68$; the value of services $c_{ij} \in [1, 20]$; the labor intensity of services $\beta_{ij} \in [1, 20]$. How the amount of discount on the most used services, obtained as a result of solving the problem $T(\mathbf{0})$, affects the change in the revenues of providers and IT companies is shown in Fig. 1.

The dependence of the relative changes in the total revenues of all providers, the revenue of the IT company, and the sum of these values on the discount value is presented in Fig. 2 (the discount change step was 5%). As can be seen from the graph, there is a range of discount values at which the relative improvement of one objective function is greater than the relative deterioration of the other.

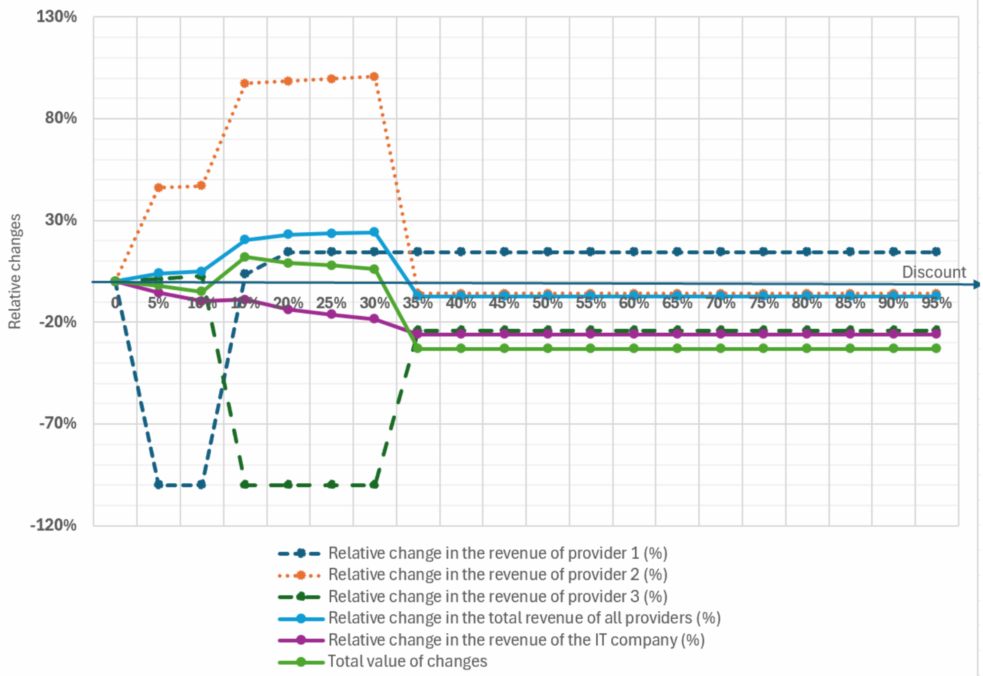

Fig 1. The impact of the size of the discount on the most used services on the change in the revenues of providers and IT companies

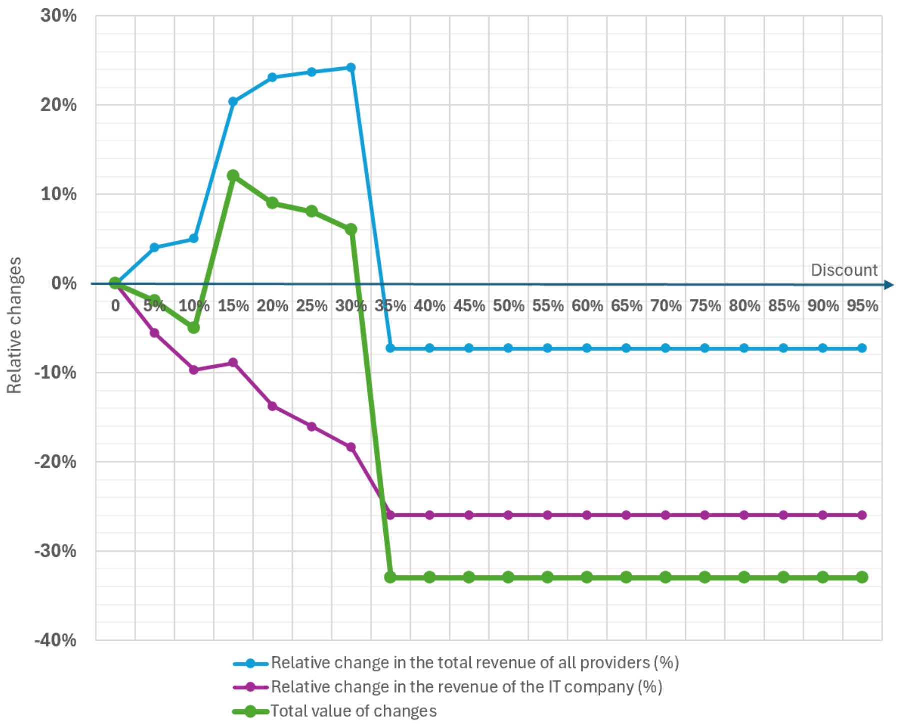

Fig 2. Dependence of relative changes in the total revenues of all providers, IT companies and the sum of these values on the discount amount

To identify the most advantageous discount value at stage 2, the discount value was varied from 10% to 30% in 1% increments. The corresponding results are shown in Fig. 3.

The best results correspond to a 13% discount on the most used services.

The results of applying CT-SE-AM using strategy a) to solve the problem, which differs from the previous one only in the amount of available human resources $B = 60$, are shown in Fig. 4. As can be observed, an improvement in the values of both objective functions occurs for all discount values.

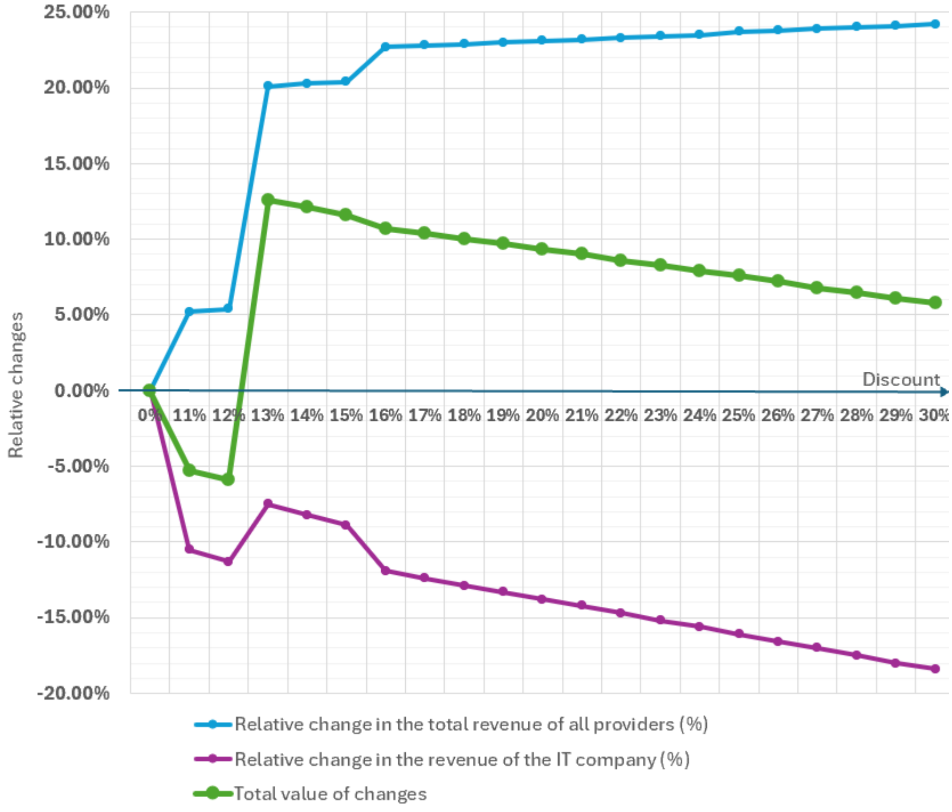

Fig 3. Identifying the most advantageous discount value at stage 2 by changing the discount value from 10% to 30% in 1% increments

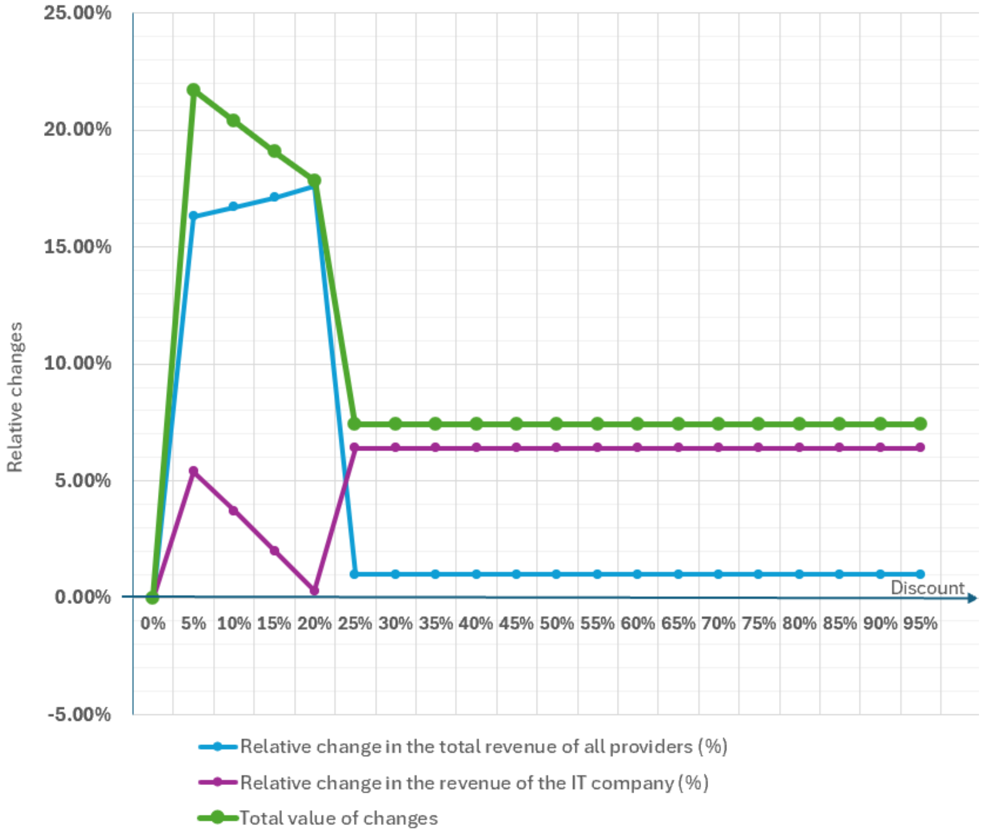

Fig 4. Results of applying strategy a) CT-SE-AM for solving the problem with the amount of available human resource $B = 60$

The results of applying CT-SE-AM using strategy a) to solve the problem, which differs from the previous one only in the amount of available human resource *B*=50, are shown in Fig. 5.

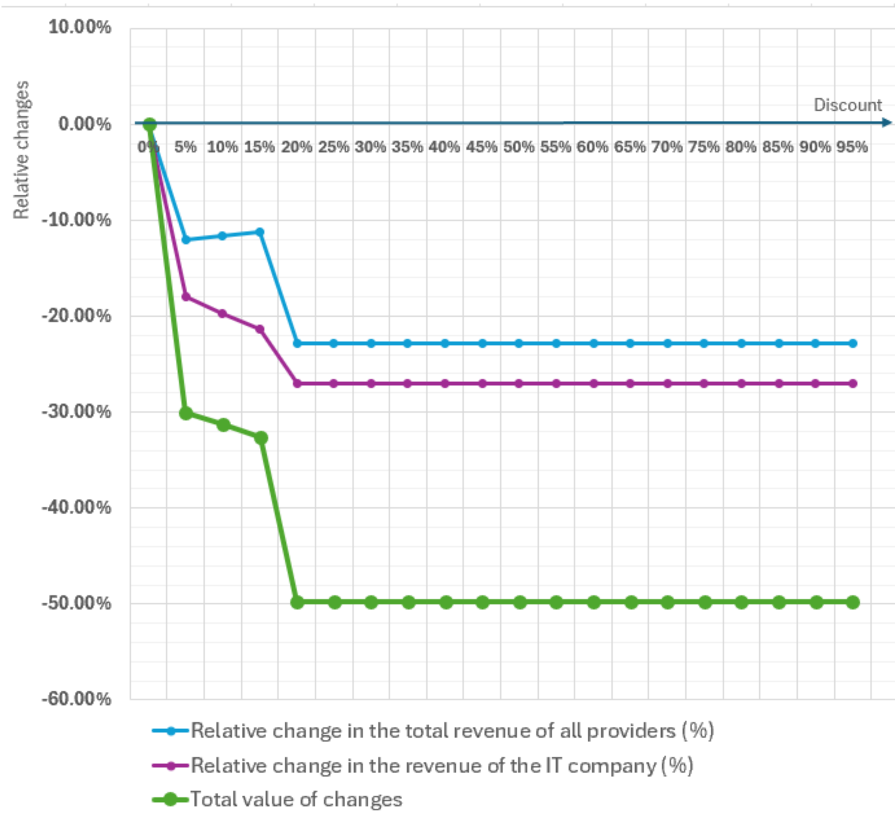

Fig 5. Results of applying strategy a) CT-SE-AM for solving the problem with the amount of available human resource *B*=50

Experimental study of strategy b)

Strategy b) using CT-SE-AM for solving the problem $T(\omega)$ does not allow obtaining a solution that is more advantageous than the solution to the improvement problem $T(\mathbf{0})$.

Experimental study of strategy c)

The results of applying CT-SE-AM using strategy c) to solve the original problem (*B*=68) are shown in Fig. 6.

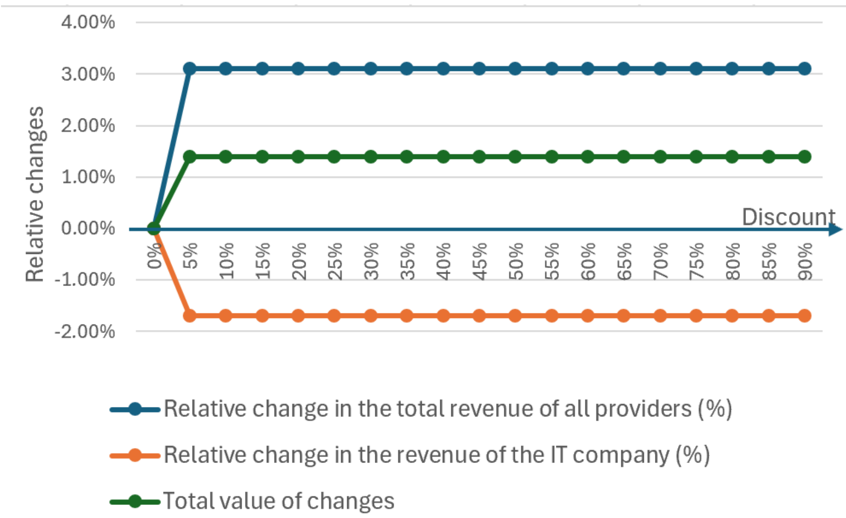

Fig 6. Results of applying strategy c) of CT-SE-AM for solving a problem with the amount of available human resource *B*=68

The results of the study of other proposed strategies for effectiveness confirmed their practical significance, but due to lack of space, they will be considered in subsequent articles by the authors.

Results of an experimental study of the proposed strategies for sensitivity

The results of the research also showed that the model is sensitive to the values of the value B. Therefore, a post-optimal analysis of the model for the feasibility of changing this parameter of the problem seems useful. The results of applying CT-SE-AM using strategy a) are shown on Fig. 7. These results were obtained when solving the problem with the following parameters: the number of services $k = 70$; the number of providers $m = 14$; the number of service groups $q = 8$; the value of services $c_{ij} \in [1, 30]$; the labor intensity of services $\beta_{ij} \in [1, 10]$; the available human resource B varied from 100 to 120. At the same time, for each value of B, 100 problems were solved, which differed in discounts (from 0% to 99%). For each value of B, the number of discount values was calculated, at which there was an improvement in the solution compared to the solution with zero discount.

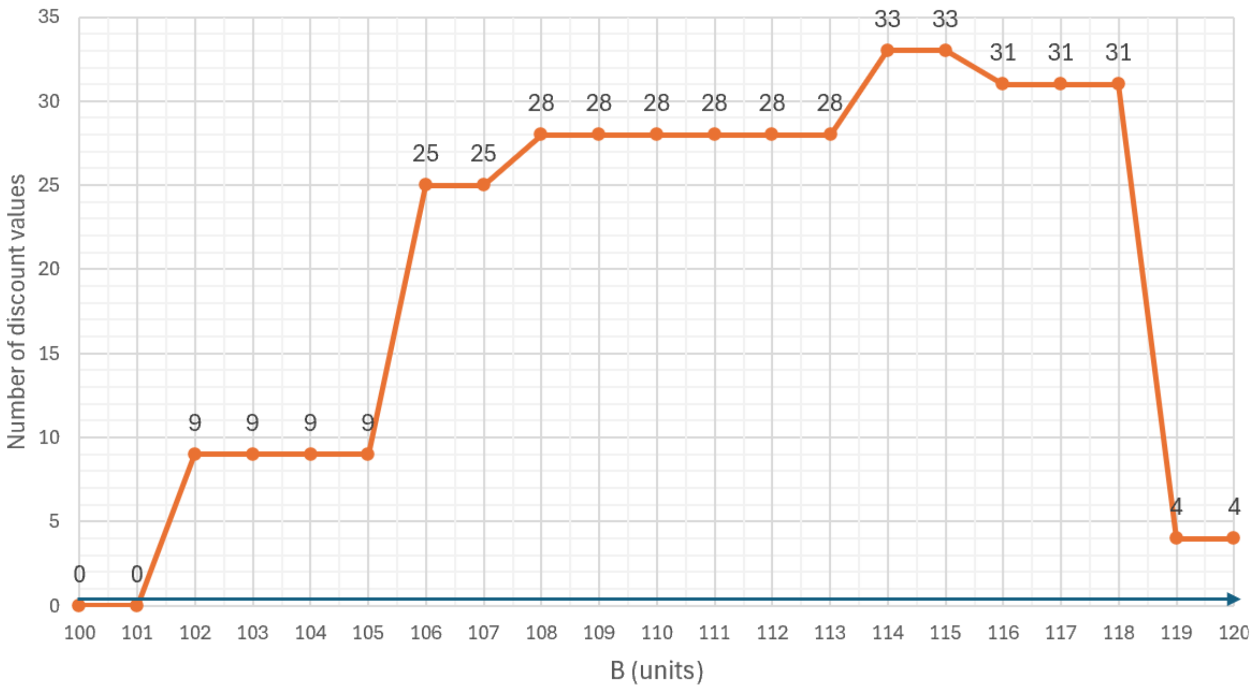

Fig 7. Results of applying strategy a) CT-SE-AM for solving a series of problems with the values of available human resources $B \in [100, 120]$

The results of the study on the sensitivity of other proposed strategies turned out to be quite interesting and will also be considered in the next articles of the authors.

In general, the results of experimental application of various strategies of CT-SE-AM have demonstrated that it can be very useful in conditions of constant market changes. Indeed, for businesses, this provides an opportunity to choose an appropriate pricing strategy and obtain a mutually beneficial solution for the IT company and providers.

In addition, the proposed method can form the basis for the implementation of modern IS tools to provide business managers with solutions that they expect in the new conditions of cooperation with IT departments.

5.2. Experimental results of the application of MVGGA

The experimental study of MVGGA was carried out with a dual purpose. First, according to tradition, the effectiveness of the method was assessed. Second, it was important to determine the conditions under which the application of this method gives the best results.

The most convenient form of conducting the experiment in this case turned out to be a comparative study of the effectiveness of the two methods proposed in the article.

The specific features of the two-stage CT-SE-AM method, in which the second stage consists of applying discount strategies, and MVGGA, in which the choice of discounts is part of the general system of rules, led to the conduct of an experiment to compare the effectiveness of the two methods in solving the $\boldsymbol{T}(0)$ problem.

Thus, the experiment was conducted to compare the effectiveness of the developed methods. In essence, the experiment was reduced to a comparison of HM and MVGGA effectiveness for solving problems $\boldsymbol{T}$ of various dimensions in which $\omega = 0$.

The results of the comparative analysis of the effectiveness of HM and MVGGA with an extended set of rules are given in Table 1.

Experimental results indicate that both algorithms are viable, but their effective application depends on the parameters of the problem.

Table 1. The comparative analysis of HM and MVGGA

Task type number	**Task parameters/ MVGGA parameters**	**Number of tasks generated**	**% when the best result is obtained by the algorithm**	
			MVGGA	**HM**
1	$m = 5, q = 5$, $c_{ij} \in [1, 20], d_{ij} \in [50, 80]$, $B = 450, N = 50$	50	98%	2%
2	$m = 10, q = 10$, $c_{ij} \in [1, 20], d_{ij} \in [50, 80]$, $B = 1350, N = 100$	50	92%	8%
3	$m = 15, q = 20$, $c_{ij} \in [1, 20], d_{ij} \in [50, 80]$, $B = 2500, N = 150$	20	6%	94%
4	$m = 15, q = 20$, $c_{ij} \in [1, 20], d_{ij} \in [21, 30]$, $B = 2500, N = 150$	20	90%	10%

In addition, the experimental results of the developed methods effectiveness confirm that, based on the proposed models and methods, it is possible to supplement the work methods supported in the IS of IT companies and providers with new tools for optimizing, decision-making and using discounts.

6. Analysis of the obtained results

The obtained "not good" results of the guided genetic algorithm for problems of type 3 are explained by the fact that in these problems, for each solution, the value $\sum_{l=1}^{q} \Phi_l$ significantly exceeds the value of F, therefore, according to the principle of compromise selection of the record solution, the solution obtained by the CT-SE-AM (the goal of which is to maximize the function F) will usually be the best. A completely various situation occurs when the values of the values of F and $\sum_{l=1}^{q} \Phi_l$ are close or do not differ much, which is demonstrated by the results for problems of type 4.

Increasing the number of individuals in the guided genetic algorithm population increases its efficiency, but leads to a significant increase in the time for solving problems.

The obtained results show, the MVGGA can take into account both the structure of the solution of the problem and the features of changing the parameters of behavior that determine the classes of problems. This means that we can solve a more complex problem. Indeed, we need not just to find a solution to a certain problem, but to choose the best of the behavior strategies. Those strategies that generate a set of problems. And it is among the solutions to these problems that we are looking for the best. Thus, the GA has advantages over other methods. Like other methods, it allows you to choose the values of variables that give a good approximation to the optimal solution. But it also allows you to change the parameters of the problem in the process of solving.

The general trend that the experimental results allow us to see suggests that the best results are mainly provided by the modified version of the guided genetic algorithm. But with an increase in the dimensionality of the problem, the application of the guided genetic algorithm requires more and more time. This suggests a direction for further research aimed at determining the critical dimensionality of problems for which the application of the guided genetic algorithm is justified.

Another direction of further research is related to the integration of the algorithms proposed in the article. This integration will be based on the multi-stage nature of these algorithms. For example, taking into account the results obtained, it is possible to significantly increase the efficiency of the developed MVGGA by obtaining one of the solutions of the initial population using heuristic algorithm.

7. Conclusion

A model and methods for solving the subproblem of forming service portfolios within the framework of the complex problem of designing complex infocommunication services are proposed, based on the ideas of mathematical programming and artificial intelligence. The model of forming service packages is a classic Boolean programming problem with two criteria that are related to the benefit of both parties. The constraints allow us to take into account the interrelationships of services, the availability of human resources, the value of each service in the portfolio, and the requirements for SLA indicators.

The combined two-stage exact-approximate method and the modified version of guided genetic algorithm are proposed to solve the problem. Multi-criteria, the presence of continuous, integer and Boolean variables, and various constraints in the constructed models determined the complex nature of the developed methods, combining exact and approximate approaches. The study of the results of the application of the developed methods allowed us to determine the areas of their effective application.

The models and methods proposed in the article are notable for their ability to expand the working approaches used by IT companies and providers under modern business conditions in this industry. By enhancing the arsenal of tools for optimizing decisions made by managers of IT companies and providers, the proposed models and methods enable more effective use of discount systems. It is important to emphasize that both the interests of IT companies and the interests of providers are taken into account.

Further research is related to the development of methods for training a neural network with a change in its structure, which is very important for the development of a methodology for analyzing real platforms supporting the life cycle of services.

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МОДЕЛІ ТА МЕТОДИ ФОРМУВАННЯ ПАКЕТІВ СЕРВІСІВ У РАМКАХ ПРОБЛЕМИ ПРОЄКТУВАННЯ СЕРВІСІВ У ІНФОРМАЦІЙНИХ СИСТЕМАХ ПРОВАЙДЕРІВ

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Сьогодні в телекомунікаційній галузі сервіс є одним із фундаментальних понять. Побудова архітектури сервісу є ключовим етапом його життєвого циклу. Інформаційні системи провайдерів телекомунікацій проектуються реалізуються та підтримуються IT-компаніями на основі моделі End-to-End. Це вимагає вирішення низки складних завдань. У цих умовах побудова архітектури, реалізація та надання сервісу поділяються на підпроблеми, рішення яких повинні бути інтегровані для визначення скоординованої діяльності як IT-компанії так і провайдера. При цьому необхідно враховувати цілі IT-компаній, провайдерів та їх клієнтів таким чином, щоб це було вигідно всім сторонам. Однією з таких підпроблем є формування пакетів послуг, які IT-компанія пропонує провайдерам. У статті запропоновано формальні моделі для формування пакетів послуг, які дозволяють врахувати інтереси IT-компанії та провайдерів. Це багатокритеріальні нелінійні моделі математичного програмування. Запропоновано двоетапний алгоритм та модифікований варіант керованого генетичного алгоритму. Використання запропонованих методів дозволяє врахувати інтереси IT-компанії та провайдерів. Також враховуються такі важливі фактори, що впливають на формування пакетів, як базова ціна послуги, сервісна залежність, система знижок, ресурсні та інші обмеження IT-компанії та провайдерів.

Двоетапний алгоритм на першому етапі використовує класичні алгоритми розв'язання задачі про рюкзак, а на другому – реалізує компромісну схему для покращення розв'язку. Другий із запропонованих методів використовує три типи інструментів у поєднанні. Перший інструмент контролює збіжність генетичного алгоритму. Другий інструмент визначає вибір найкращих рішень з урахуванням особливостей багатокритеріальної задачі. Третій інструмент дозволяє отримати найкращі рішення задачі оптимізації з одночасним вибором цінової стратегії. Проведені експериментальні дослідження підтвердили ефективність запропонованих методів. Також підтверджено їх здатність лягти в основу технології формування пакетів послуг як складової платформи підтримки життєвого циклу послуг.

Ключові слова: проектування сервісів, пакети сервісів, архітектура сервісів, генетичний алгоритм, цінність сервісу.