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RESEARCH ARTICLE

About managing the number of simultaneously functioning software robots of different types

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Abstract
Objectives. The study sets out to justify the relevance and investigate approaches for solving the problem of managing the number of simultaneously functioning software robots of various types under conditions of limited computational resources and changes in sets of executable tasks.
Methods. A proposed solution is based on models and methods of scenario management, linear programming, inventory management, queuing theory, and machine learning. The described methods are valid for different compositions and preconditions for generating initial data, as well as ensuring the relevance horizons of the obtained solutions.
Results. The initial data is obtained via the presented approach for determining the computational resource parameters for operating a single software robot. The resources are determined by analyzing the composition of the software and information services used by an actual software robot. Problem statements and mathematical models are developed for cases involving scenario management and linear programming methods. Methods for real-time management of the number of software robots and their sequential local optimization are proposed based on the abovementioned solution sequences. The developed method for generating statistical data based the results of applying the sequential local optimization method is used to identify deficient and non-deficient computational resources. Some results of working in the multi-functional center of RTU MIREA software robots developed on the Atom.RITA platform are outlined.
Conclusions. The emerging problem of managing the number of simultaneously operating software robots of various types for cases involving scenario control methods and linear programming is formalized. This problem is relevant in the field of automation of business processes of organizations. The use of mathematical methods for solving this problem opens up opportunities for expanding the functional capabilities of robotic process automation platforms, as well as increasing their economic efficiency to create competitive advantages by optimizing the use of IT infrastructure components.

Keywords: software robot, digital employee, robotic process automation, business process automation, software robotization

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НАУЧНАЯ СТАТЬЯ

Об управлении численностью одновременно функционирующих программных роботов различных видов

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Резюме
Цели. Изложение постановки, обоснование актуальности и предложение методов решения задачи управления численностью одновременно функционирующих программных роботов различных видов в условиях ограниченности вычислительных ресурсов и изменений состава совокупностей задач, поступающих на выполнение.
Методы. Задачу предложено решать, применяя модели и методы сценарного управления, линейного программирования, управления запасами, массового обслуживания и машинного обучения, соответствующие различным составам и предпосылкам формирования исходных данных, а также обеспечивающие различные горизонты актуальности получаемых решений.
Результаты. В целях формирования исходных данных задачи авторами предложен подход к определению состава и параметров вычислительных ресурсов, требующихся для функционирования одного программного робота, основанный на анализе состава используемого им программного обеспечения и информационных сервисов. Для случаев применения методов сценарного управления и линейного программирования составлены постановки и математические модели соответствующих задач, а на основе последовательностей их решения предложены метод оперативного управления численностью программных роботов и метод последовательной локальной оптимизации их численности. Предложен основанный на обработке результатов применения метода последовательной локальной оптимизации способ формирования статистических данных, позволяющих идентифицировать дефицитные и недефицитные вычислительные ресурсы. Изложены некоторые результаты применения программных роботов, разрабатываемых на платформе «Атом.РИТА», в интересах многофункционального центра РТУ МИРЭА.
Выводы. Сформулирована и формализована для случаев применения методов сценарного управления и математического аппарата линейного программирования новая и актуальная в сфере автоматизации бизнес-процессов организаций задача управления численностью одновременно функционирующих программных роботов различных видов. Решение данной задачи с применением различных математических методов открывает перспективы расширения функциональных возможностей платформ программной роботизации, а также повышения экономической эффективности их применения и формирования дополнительных конкурентных преимуществ посредством оптимизации использования компонентов ИТ-инфраструктуры.

Ключевые слова: программный робот, цифровой сотрудник, robotic process automation, автоматизация бизнес-процессов, программная роботизация

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INTRODUCTION

Over the last 10 years, one of the main sources of the improved efficiency of legal entities, government and commercial structures, etc., (hereinafter—organizations) consists in the automation of business processes to delegate repetitive, routine and non-analytical tasks and actions from employees to specialized services [1–3]. Various subject-oriented information systems [4, 5], such as electronic document management, personnel management, warehouse logistics, accounting, interaction with target audience and clients, project management, analytical and intelligent systems, etc., can serve as tools for automating business processes. At the same time, the use of application software in the business processes of organizations implies the presence of appropriate personnel, who use this software to perform business tasks included in the business functions assigned to them in accordance with their allocated roles [6].[1] In the present work, a business task is understood as a typical sequence of actions of an employee using a set of software tools to achieve a given result taking into account the changing composition of input data.

A logical and innovative direction having occurred during the development of business process automation consists in software robotization systems known as robotic process automation (RPA) [7, 8]. RPA software, which implements technologies for the development and application of software robots (SR), comprises special applications whose operational scenarios reproduce typical sequences of actions carried out by employees using combinations of software tools.[2] Since December 4, 2023, RPAs are legally defined by the Ministry for Digital Technology, Communication and Mass Media of the Russian Federation.[3]

An important feature of an RPA is the possibility for an SR to work with the totality of information systems and services that are not provided with a means of integration and interoperability in accordance with embedded functional scenarios or algorithms [9]. There are currently several RPA-platforms on the international[4] and Russian[5] software markets that provide tools for development and management of SR functionality.

Software robots partially or fully replace employees of an organization in its business processes in terms of performing typical business tasks, i.e., they either act as "digital employees" functioning in accordance with a specific business role, which is traditionally provided for in the staff schedule [10], or they function as "digital assistants" of real employees [11]. The advantages of a digital employee for an organization are obvious [12, 13]: a 24/7/365 work schedule, no working conditions or salary requirements, elimination of recruiting procedures, training, work control, personnel "turnover", etc.

Business tasks subject to software robotization will be referred to as robotic automation tasks (RAT). We will assume that there is a mutually unambiguous correspondence between RATs and the SRs that perform them, each SR corresponding to a separate RAT. Based on the results of executing the scenario of a particular business task, each of its instances is either considered as successfully completed (which should correspond to the vast majority of cases), or is added to the list of incidents that require additional consideration by an employee, including in cases of unsatisfactory completion of the SR functioning scenario. One of the advantages of using SRs is the ease of scaling their application when changing the intensity of business tasks, which will be further understood as the number of their repetitions or instances requiring execution for some given period of time. Necessary indicators of business processes fulfillment efficiency can be provided as a result of increasing or decreasing the number of simultaneously functioning SR corresponding to these business processes. Under conditions of limited computational resources allocated for their application in compliance with the required performance indicators of the corresponding business processes, the simultaneous application of a set of SR types, each having the possibility of replication in different quantities, the management of the number of simultaneously functioning SRs of different types becomes a relevant problem.

[1] On Amending the Classifier of Programs for Electronic Computing Machines and Databases Approved by Order of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation No. 486 of September 22, 2020. Order of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation No. 974 dated December 22, 2022. http://publication.pravo.gov.ru/Document/View/0001202304200009 (in Russ.). Accessed March 22, 2024.

[2] On Approval of the Classifier of Programs for Electronic Computing Machines and Databases. Order of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation No. 486 dated September 22, 2020. https://digital.gov.ru/ru/documents/7362/ (in Russ.). Accessed March 26, 2024.

[3] On Amending the Classifier of Programs for Electronic Computing Machines and Databases Approved by Order of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation No. 486 dated September 22, 2020. Order of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation No. 1041 dated December 04, 2023. http://publication.pravo.gov.ru/document/0001202403110026 (in Russ.). Accessed March 26, 2024.

[4] Top-31 best robotic process automation software on the market. https://www.zaptest.com/rpa-tools-top-31-best-robotic-process-automation-software-on-the-market. Accessed March 22, 2024.

[5] Russian market of RPA-systems. Tadviser November 8, 2022. https://www.tadviser.ru/index.php/Статья:Российский_рынок_RPA-систем (in Russ.). Accessed March 22, 2024.

1. DESCRIPTION OF SR NUMBER MANAGEMENT TASK

As application software and executed as processes in the operating system, SRs consume computational resources, which should be considered as not only finite, but also subject to optimization. Problems that arise in this connection are relevant both for individual organizations using SRs in terms of minimizing the costs of their operation, as well as for the providers of cloud "factories" of SRs [14, 15] in the context of optimizing the costs of maintaining the corresponding IT infrastructure.

In the IT infrastructure of organizations that use SRs and/or supply services to ensure their operation, the solution of the abovementioned problems requires the development, justification and implementation of both architectural and infrastructural solutions. Architectural solutions can be considered, for example, in the context of ensuring information security, including the operation of SR on physical and virtual machines in open and protected circuits [16, 17]. Infrastructure solutions imply the allocation of physical and/or virtual machines with certain parameters and characteristics that provide computational resources sufficient for the functioning of a certain set of SR of several types in compliance with the required performance indicators of the corresponding business processes of the organization. Computational resources can be understood as:

- number of threads of the central processing unit (CPU);
- amount of random-access memory (RAM);
- amount of the internal data storage device (hard disk drive, HDD and/or solid-state drive, SSD);
- amount of video memory and the number of graphics processing unit (GPU) cores;
- number of simultaneous terminal sessions;
- bandwidth of a wired or wireless transmission network channel, etc.

The information and technological infrastructure of SR functionality is one of the key parameters predetermining the effectiveness of their application. Therefore, its formation should take into account, among other things, the following aspects:

- composition of software and information services with which the SR interacts is determined by the content of the corresponding business task and predetermines the requirements to the operating environment of its functioning to the required computational resources;
- while several SRs from some set of their types can operate simultaneously, the permissible combinations of their numbers are limited by the allocated computational resources;
- in case of a large variety of types of SR, as well as under conditions of their "factory" implementation, the set of applied SR can be decomposed into subsets corresponding to separate business processes and/or structural subdivisions of the organization with allocation of separate (independent) volumes of computational resources;
- due to changes in the intensities of business tasks performed by SRs (the number of their repetitions, instances requiring execution for a given period of time), it becomes rational to vary the number of SRs of corresponding types while limiting the computational resources allocated for the realization of their entire set (the set of types and instances of each type);
- changes in parameter and business processes requirements, including those business tasks solved by SR, may affect the number of SRs and intensity of corresponding tasks.

Considering the abovementioned aspects of the implementation of SR aggregates, the task of managing the number of simultaneously functioning SRs of various types under conditions of limited computational resources, changing intensities of RPAs, as well as varying requirements to the parameters of the corresponding business processes, becomes of practical importance. Such an optimization approach, which involves different statements corresponding to the particular prerequisites for the formalization of the initial data, can be solved using a range of formulations and mathematical instruments [18].

Various RPA-platforms include a component of managing the operation of SRs ("master" or "orchestrator"), which performs the functions of starting and stopping them (including in accordance with the specified schedule), managing licenses, integration, versioning, logs, analytics, accesses, etc. Taking into account a certain composition of formalized constraints and requirements, the dynamic optimization of the number of simultaneously functioning SRs of different types can be considered as an additional functionality of this control component, providing the expansion of competitive advantages of the RPA-platform by optimizing the use of IT-infrastructure components to ensure the functioning of SRs.

Some of the different approaches and methods for solving the formulated problem are compared in Table 1:

- scenario management—available variants of the number of SRs of different types are considered as a set of management scenarios from which the most rational is selected according to the current intensity of forming the business tasks;
- mathematical tool of linear programming—optimal numbers of SRs of various types are determined on

Table 1. Comparison of some methods of solving the task under consideration

Applied mathematical tool	Features of the mathematical tool used	Relevance period of the decision	Application result
Scenario approach to management (described in this article)	Situational response to changing intensities of business tasks is performed	Operational (immediate)	Rationalization in accordance with changes in input data
Machine learning models	Iterative pre-training of the neural network is assumed	Operational (immediate)	
Linear programming (described in this article)	In separate periods of time the previously accumulated business tasks are performed and a new set of business tasks is formed for performance	Short-term	Optimization according to the result of processing of accumulated input data
Inventory management models	Patterns of generation of business tasks with the passage of time are assumed to be known	Medium-term	
queuing theory		Long-term	

the basis of aggregates of corresponding business tasks to be performed over a certain period of time;

- inventory management models—based on formalization of the dynamics of business tasks receipt for processing and their execution by the SRs;
- queuing theory—regularities of change of business task intensities over time are assumed to be known (specified or formalized as a result of a preliminary analysis);
- since SR instances of corresponding types are considered as channels of a queuing theory, their number can be varied to control the characteristics of the considered system;
- machine learning models—the construction and/or training of neural networks is assumed for automating decision-making regarding the number of simultaneously functioning SRs of various types in accordance with the dynamics and/or forecasts of changes in the values of some set of formalized constraints and requirements.

As well as assuming the presence of assumptions corresponding to them concerning the available structure and the results of preliminary formalization of its initial data, the different methods of solving the problem under consideration allow us to provide different horizon of autonomy for the implementation of the obtained solution without requiring further correction.

In the following section, different formulations of the problem under consideration are described for the cases of scenario management and a mathematical linear programming apparatus. A detailed description of its formulations and formalizations using other mathematical apparatuses, including those not listed in Table 1, will be the subject of a future work.

2. APPROACH FOR DETERMINING THE COMPOSITION AND PARAMETERS OF COMPUTATIONAL RESOURCES REQUIRED FOR THE SR

The first stage of forming the initial data of the task under consideration consists in determining the composition and amount of computational resources required for the functioning of one SR of each type. For this purpose, a table similar to Table 2 can be used to form the required data as a result of systematization of software and information services involved in the performance of relevant business tasks. Such computational hardware resources as the number of CPU threads, amount of RAM, number of GPU cores, amount of internal data storage, maximum available number of terminal sessions, bandwidth of the communication channel, etc., can be considered as limited within the organization's IT infrastructure allocated for the purposes of software robotization and additive across the entire set of simultaneously functioning SRs.

3. TASK STATEMENT FOR THE CASE OF SCENARIO MANAGEMENT APPLICATION

In cases of operative (instantaneous) variation of numbers of simultaneously functioning SRs of different types, the application of scenario management becomes expedient. In accordance with a one-step (current) change in the intensity of business tasks (the number of their instances received for processing at a moment in time), it may be necessary to make an instantaneous decision on the transition to a scenario corresponding to the given conditions that involves a combination of the

Table 2. Determination of the computational resources required by the SRs based on the composition of used software

Computational resource	Software used	Resource required by the software	Number of copies of the software required by the SR			
			Robot No. 1	Robot No. 2	…	Robot No. *n*
RAM capacity, MB (resource No. 1)	Software No. 1 (browser)	O_{11}	3	0	…	1
	Software No. 2 (word processor)	O_{12}	1	2	…	0
	…	…	…	…	…	…
	Software No. *k* (mail)	O_{1k}	1	1	…	1
SR needs for resource No. 1		Value	$3O_{11} + O_{12} + \ldots + O_{1k}$	$2O_{12} + \ldots + O_{1k}$	…	$O_{11} + \ldots + O_{1k}$
		Designation	a_{11}	a_{12}	…	a_{1n}
Number of CPU threads (resource No. 2)	Software No. 1 (browser)	P_{21}	3	0	…	1
	Software No. 2 (word processor)	P_{22}	1	2	…	0
	…	…	…	…	…	…
	Software No. *k* (mail)	P_{2k}	1	1	…	1
SR needs for resource No. 2		Value	$3P_{21} + P_{22} + \ldots + P_{2k}$	$2P_{22} + \ldots + P_{2k}$	…	$P_{21} + \ldots + P_{2k}$
		Designation	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…	…	…
Data storage capacity, MB (resource No. *m*)	Software No. 1 (browser)	H_{m1}	3	0	…	1
	Software No. 2 (word processor)	H_{m2}	1	2	…	0
	…	…	…	…	…	…
	Software No. *k* (mail)	H_{mk}	1	1	…	1
SR needs for resource No. *m*		Value	$3H_{m1} + H_{m2} + \ldots + H_{mk}$	$2H_{m2} + \ldots + H_{mk}$	…	$H_{m1} + \ldots + H_{mk}$
		Designation	a_{m1}	a_{m2}	…	a_{mn}

number of simultaneously functioning SRs of different types. Different approaches to the realization of scenario control of the numbers of simultaneously functioning SRs obtained from some set of their species are possible. Two approaches proposed by the authors are outlined below.

Assuming that one SR of type j consumes a_{ij} computational resources of type i when performing its corresponding business task of the same type j, we introduce the following designations:

- b_i are the available (limited) volumes of computational resources of the types $i = \overline{1, m}$, where m is their number;
- x_j are the numbers of simultaneously functioning SR of the types $j = \overline{1, n}$, where n is their number;
- c_j is the performance of one SR of type j, equal to the number of instances of a business task of this type j performed by it during a unit time period;
- $e_j \geq 1$ are the coefficients of relative priority of business tasks of respective types $j = \overline{1, n}$.

We will call scenarios $P_k = (x_{k1}, x_{k2}, ..., x_{kn})$, where $k = \overline{1, p}$, the options of simultaneous use of specific quantities x_{kj}, $j = \overline{1, n}$ SR of each of the types. Here, we consider only the scenarios admissible for realization on the basis of the total amounts of required computational resources.

In order to determine the composition of admissible scenarios, each associated with the maximum use of one or more allocated computational resources, we can use an auxiliary table similar to Table 3 to structure the search of combinations of the number of simultaneously functioning robots of each type. When moving to each subsequent row of the table, the computational resources are redistributed in favor of the SR with a higher order number.

Preliminary formation of the composition of acceptable scenarios allows us not to perform their formation at each solution of the task under consideration, but to determine the rational (not excessive) composition of functioning SRs by selecting a scenario from those contained in scenario tables such as Table 3.

There are 2 possible approaches to the development of scenario tables:

1. Formation of a complete scenario composition including scenarios with incomplete utilization of computational resources. This leads to the inclusion in the scenario table of the results of a complete search of possible combinations of SRs. While increasing computational resources, it reduces the logical complexity of analyzing the scenario table content. For example, formulas (4) and (7) proposed by the authors below can be applied without checking additional relevant conditions (5) and (8). This approach is more appropriate for small amounts of allocated computational resources and/or a small number of SR types.

Table 3. Determination of the composition of scenarios of simultaneous operation of the SR with maximum utilization of one or several allocated computational resources

Scenarios	Number of functioning robots of types j							
	1	2	3	4	5	…	$n-1$	n
P_1	Q	0	0	0	0	…	0	0
P_2	$Q-1$	1	0	0	0	…	0	0
P_3	$Q-1$	0	2	0	0	…	0	0
P_4	$Q-1$	0	1	2	0	…	0	0
P_5	$Q-1$	0	1	1	1	…	0	0
P_6	$Q-1$	0	0	3	1	…	0	0
…	…	…	…	…	…	…	…	…
P_k	$Q-1$	0	0	0	0	…	0	r
P_{k+1}	$Q-2$	2	0	0	0	…	0	0
…	…	…	…	…	…	…	…	…
P_{p-1}	0	0	0	0	0	…	1	$R-1$
P_p	0	0	0	0	0	…	0	R

2. Formation of scenario composition with maximum use of one or several allocated computational resources. While leading to a significant reduction in the number of records in the scenario table, it necessitates checking the possibility of reducing the number of simultaneously functioning SRs. In this regard, the formulas (4) and (7) proposed by the authors below will require verification of additional corresponding conditions (5) and (8). This approach is more appropriate for large amounts of allocated computational resources and/or a large number of types of SRs.

The efficiency of the above-described approaches should be studied for each specific task of managing the number of simultaneously functioning SRs. While the approach that provides the most expected speed of solving the corresponding task will naturally be preferred, each of the approaches forms the initial data for determining the corresponding realizable scenario.

The implemented scenario predetermines the number of business tasks of each type performed by the corresponding set of SRs for a single period of time. A change in the realized scenario leads to a change in the composition of simultaneously functioning SRs. These changes can be determined once with the help of a transition table similar to Table 4 for all possible pairs of considered acceptable scenarios from Table 3 and further used for automatic selection of the most rational scenario, to which it is expedient to switch from the currently used one under the conditions of the observed change in the intensity of receiving the business tasks.

Let us designate the change in the number of simultaneously functioning SRs of species j as a result of the change from scenario x to scenario y through z_j^{xy}. Then T^{xy} (1) is the vector of changes in the numbers of simultaneously functioning SRs during the transition from scenario x to scenario y:

$$T^{xy} = (z_1^{xy}, z_2^{xy}, ..., z_n^{xy}). \quad (1)$$

The vector of corresponding changes in productivity of business tasks of types j can be calculated by the formula:

$$U^{xy} = (c_1 z_1^{xy}, c_2 z_2^{xy}, ..., c_n z_n^{xy}). \quad (2)$$

The first proposed approach to scenario-based management of SR functioning consists in matching scenarios and task sets at a given unit of time to the tasks coming in for implementation.

Let us assume that for a single period of time a pending set of business tasks of types j (taking into account their quantities not executed at previous stages), described by a vector of non-negative integer components F, has been formed:

$$F = (f_1, f_2, ..., f_n), \quad (3)$$

then scenario G, which can be considered as the most rational for realization in the next period of time, can be determined on the basis of Table 3 by the formula:

$$G = \min_{k=\overline{1,p}} G_k, \text{ where } G_k = \sqrt{\sum_{j=1}^{n} e_j (f_j - c_j x_{kj})^2}$$

$$\text{or } G_k = \sum_{j=1}^{n} e_j \left| f_j - c_j x_{kj} \right|, \quad k = \overline{1,p}, \quad (4)$$

at that, if $f_j - c_j x_{kj} \le 0$, then the corresponding summand j is considered to be equal to zero, and the number of robots x_{kj}^* of type j, which does not need to be launched, can be determined by the formula:

Table 4. Example of a transitional table—changes in the numbers of functioning SRs under changing scenarios

Change of scenarios		Change in the number of functioning robots of the types j							
Initial scenario	New scenario	1	2	3	4	5	…	$n-1$	n
P_1	P_1	0	0	0	0	0	…	0	0
P_1	P_2	−1	+1	0	0	0	…	0	0
P_1	P_3	−1	0	+2	0	0	…	0	0
P_1	P_4	−1	0	+1	+2	0	…	0	0
P_1	P_5	−1	0	+1	+1	+1	…	0	0
P_1	P_6	−1	0	0	+3	+1	…	0	0
…	…	…	…	…	…	…	…	…	…
P_1	P_k	−1	0	0	0	0	…	0	$+r$
P_1	P_{k+1}	−2	+2	0	0	0	…	0	0
…	…	…	…	…	…	…	…	…	…
P_1	P_p	$-Q$	0	0	0	0	…	0	$+R$
P_2	P_1	+1	−1	0	0	0	…	0	0
…	…	…	…	…	…	…	…	…	…
P_{p-1}	P_1	$+Q$	0	0	0	0	…	−1	$-R+1$
P_p	P_1	$+Q$	0	0	0	0	…	0	$-R$

Table 5. Input data for Fig. 1 $(e_j = 1, j = \overline{1,n})$

Time period	Set of tasks to perform				Set of tasks completed by the SR				Value according to formula (4)
	f_1	f_2	f_3	Point	c_1x_{k1}	c_2x_{k2}	c_3x_{k3}	Point	
1	2	2	3	B(2; 2; 3)	2	1	2	D(2; 1; 2)	$\sqrt{2}$ or 2
2	3	2 + 1	1 + 1	C(5; 4; 4)	2	2	0	G(4; 3; 2)	$2\sqrt{2}$ or 4
3	1 + 1	3 + 1	2 + 2	A(6; 7; 6)	2	4	2	Z(6; 7; 4)	2 or 2

$$x_{kj}^* = \lfloor c_j x_{kj} - f_j \rfloor. \quad (5)$$

The second proposed approach to scenario-based management of SR functioning consist in comparing the results of scenario changes and changes in the composition of the sets of tasks to be performed in a given unit of time.

Let us assume that for a unit period of time of realization of some scenario t, changes in the numbers of business tasks of types j to be performed (taking into account their numbers not performed at previous stages) are described by a vector of non-negative integer components F^*:

$$F^* = (f_1, f_2, ..., f_n), \quad (6)$$

then the scenario G, which can be considered as most rational for transition to implementation, can be determined on the basis of Table 4 by the formula:

$$G = \min_{k=\overline{1,p}} G_k, \text{ where } G_k = \sqrt{\sum_{j=1}^{n} e_j (f_j - c_j z_j^{tk})^2}$$

$$\text{or } G_k = \sum_{j=1}^{n} e_j \left| f_j - c_j z_j^{tk} \right|, \ k = \overline{1,p}, \quad (7)$$

at that, if $f_j - c_j z_j^{tk} \le 0$, then the corresponding summand j is considered to be equal to zero, and the number of robots x_{kj}^{**} of type j, which does not need to be launched, can be determined by the formula:

$$x_{kj}^{**} = \lfloor c_j z_j^{tk} - f_j \rfloor. \quad (8)$$

Generalization of proposed approaches. Formulas (4) and (7) in the part of calculation of G_k values are made for Euclidean and Minkowski metrics and allow us to choose the vector G of the smallest length among all vectors, which are the result of subtraction of the vector of productivity or change of productivity of performance of business tasks of types j from the vector of pending business tasks or the vector of changes in the number of pending business tasks.

Vector G enables to determine the scenario k, which is the most rational for application, or to which it is most rational to switch from scenario t in accordance with the current intensity of business tasks at the moment of time. That is, the management of the number of simultaneously functioning SR types j is reduced to the maximum possible repetition of the dynamics of intensity or dynamics of change in the intensity of business tasks with a delay of one-unit time interval. The conditional illustration is presented in Fig. 1. The axes f_1, f_2, and f_3 correspond to three types of business tasks and corresponding SRs; the initial data are given in Table 5.

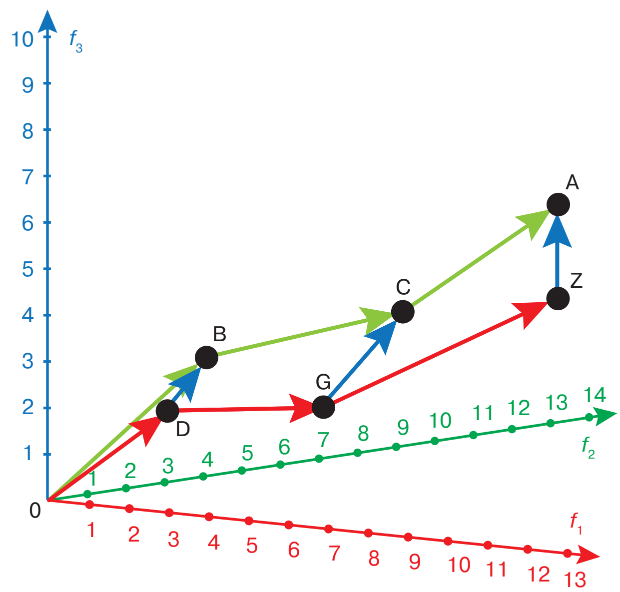

Fig. 1. Examples of vectors illustrating the application of formulas (4) and (7)

Thus, the proposed method of operative management of the number of functioning SRs from some set of their types under the conditions of limited computational resources and dynamic changes in the composition of the business tasks for execution does not require the solution of optimization tasks.

4. TASK STATEMENT FOR THE CASE OF THE LINEAR PROGRAMMING APPLICATION

The application of the mathematical apparatus of integer linear programming becomes expedient in those cases when the content of business processes enables the fulfillment of previously accumulated business tasks to be performed in short-term (single) periods of time and parallel formation of sets of business tasks that should be performed. Thus, not only is a set of business tasks to be performed formed at each small-time interval, which requires optimization of the number of SRs of corresponding types for the next time interval, but also a set of SRs optimized in accordance with the set of tasks formed in the previous time interval functions.

Initial data:

- n is the number of SR types and the corresponding number of types of business tasks to be performed;
- m is the number of types of limited computational resources;
- P_j are the designations (names) of the SR types, $j=\overline{1,n}$;
- Z_j are the designations (names) of the business task types, $j=\overline{1,n}$;
- c_j is the performance of one SR of P_j type, equal to the number of instances of a business task of the corresponding Z_j type performed by them during a unit time period;
- d_j is the number of instances of a business task of the corresponding type Z_j to be performed at the moment of solving the optimization task;
- e_j are the fixed coefficients of relative priority of business tasks of the corresponding Z_j types;
- f_j are the variable coefficients of relative priority of business tasks of the corresponding Z_j types, determined before solving the optimization task on the basis of d_j values by different methods, for example, by the formula:

$$f_j = \frac{d_j}{\sum_{j=1}^{n} d_j},\ j=\overline{1,n}, \qquad (9)$$

- x_j is the number of simultaneously functioning robots of the type P_j;
- S_i are the names of types of limited computational resources, $i=\overline{1,m}$;
- b_i is the available (limited) amount of computational resource of S_i type;
- a_{ij} is the consumption of computational resource of S_i type during the operation of one SR of P_j type, where $i=\overline{1,m}$ and $j=\overline{1,n}$.

Task statement: Such a combination of values x_j, $j=\overline{1,n}$ (the plan of functioning of SR of P_j type) should be determined at which the number of executed instances of corresponding business tasks Z_j will be maximum taking into account their priority coefficients e_j and f_j; the consumed volumes of computational resources of each of S_i types, $i=\overline{1,m}$ will not exceed the corresponding constraints b_i; the number of executed instances of business tasks of all P_j types will not exceed their number d_j to be executed at the moment of solving the optimization task.

Note: in accordance with different conditions of the task statement and prerequisites for solving this task, any variants of combining the presence of coefficients e_j and f_j, $j=\overline{1,n}$ (10) may be taken into account in the composition of the target function.

The mathematical model of the task comprises:

- a target function maximizing the total number of executed instances of business tasks Z_j, $j=\overline{1,n}$, taking into account their priority coefficients e_j and f_j, as well as the performance of SR of P_j types;
- a system of constraints that takes into account: the limited b_i computational resources of S_i types, $i=\overline{1,m}$; the set d_j of business tasks to be performed by Z_j types, $j=\overline{1,n}$, formed at the moment of solving the optimization task; the requirements of non-negativity and integer values of variables x_j, which are a consequence of the fact that they correspond to the number of simultaneously functioning SRs of P_j types;

$$\begin{cases} \sum_{j=1}^{n} a_{ij}x_j \le b_i, i=\overline{1,m}, \\ c_j x_j \le d_j, j=\overline{1,n}, \\ x_j \ge 0, j=\overline{1,n}, \\ x_j - \text{int.}, j=\overline{1,n}, \end{cases} \qquad (10)$$

$$F = \sum_{j=1}^{n} c_j e_j f_j x_j \to \max.$$

The system of constraints of the task under consideration may also include additional conditions describing, for example, a restriction on the total number of simultaneously functioning SRs (simultaneous number of terminal sessions):

$$\sum_{j=1}^{n} x_j \le X.$$

Within the framework of the above task statement (10), the period of operation of a set of SRs is divided into single time segments, within each of which a set of business tasks to be performed is accumulated. After obtaining a solution to the optimization problem for implementation during the next time segment, the optimization problem solution obtained during the previous time segment is directly implemented. The number of business tasks not accepted for execution by the SR based on the results of the optimization task solution can be determined by the following formula:

$$g_j = d_j - c_j x_j,\ j = \overline{1,n}. \qquad (11)$$

The values $g_j, j = \overline{1,n}$, are added to the set of business tasks to be performed in the next single time period; the increase of their values during the consecutive solution of the optimization task under consideration signals the insufficiency of computational resources allocated for the operation of the SR. The duration T of the single time period under consideration can be determined dynamically, e.g., as a result of controlling the maximum allowable accumulated number W_j of the business-task instances $P_j, j = \overline{1,n}$. In this case, it is reasonable to adjust the values of c_j, for example, according to the following formula, taking into account the constants t_j—durations of execution by SR P_j of one task of the type Z_j :

$$c_j = \left\lfloor \frac{T}{t_j} \right\rfloor,\ j = \overline{1,n}. \qquad (12)$$

The initial data for the analysis of the use of the allocated computational resources is formed on the basis of the results of multiple solutions of the considered optimization task. Let the set of tasks V, $|V| = k$ be solved and ordered chronologically for optimum solutions $\mathbf{x}(x_1^p, x_2^p, \ldots, x_n^p), p = \overline{1,k}$, which time series of values of incomplete utilization of computational resources of S_i types can be formed by the following formula:

$$S_i^p = b_i - \sum_{j=1}^{n} a_{ij} x_j^p, i = \overline{1,m}, p = \overline{1,k}. \qquad (13)$$

Each set of values $S_i^p, p = \overline{1,k}$ can be studied using methods of time series analysis and random variables characteristics in order to identify computational resources that are scarce or require increase, as well as non-deficient resources that can be reduced. Future research will be devoted to clarifying this direction.

Thus, the authors propose a method of sequential local optimization based on solving the tasks of integer linear programming for the number of simultaneously functioning SRs from a set of their types under the conditions of limited allocated computational resources and the formation of sets of incoming business tasks. A method for the formation of statistical data based on processing the results of application of the method of sequential local optimization is also proposed to identify deficit and non-deficit computational resources by means of application of known methods of analysis of time series and characteristics of random variables.

5. EXPERIENCE WITH THE USE OF SR IN RTU MIREA

The Institute of Information Technologies (IIT) of MIREA – Russian Technological University (RTU MIREA) uses the software robotization platforms Atom.RITA[6] (Grinatom[7], Russia) and ROBIN (Robin[8], Russia) in the educational process in accordance with the relevant cooperation agreements and license contracts. Within the framework of development of cooperation with Rosatom State Corporation[9] and the Digital University project[10] IIT RTU MIREA has started to implement the project "Roboticization of the multifunctional center" since November 2023 to apply the RPA-platform Atom.RITA for development, implementation and administration of SR in business processes of the multifunctional center of the University:

- the object of the study is a multifunctional center comprising a structural subdivision within the Department of Educational and Social Work, which provides services to students on scholarships, dormitory accommodation, obtaining certificates, and other issues;
- the object of the study is business processes performed by the multifunctional center to enable the possibility of software robotization of their implementation;
- the subject of the study is represented by the project team of the multifunctional center and IIT employees;
- the objective of the study is to reduce the labor intensity of business processes of a multifunctional center by means of singling out business tasks that enable the performance via SR in their composition.

The composition of the studied business processes and corresponding business tasks is presented in Table 6.

Table 7 presents scenarios for some of the SRs listed in Table 6.

Table 8 shows the calculation of computational resources required by the considered SRs to perform

[6] https://greenatom.ru/atom-rita/ (in Russ.). Accessed June 17, 2024.

[7] https://greenatom.ru/ (in Russ.). Accessed June 17, 2024.

[8] https://rpa-robin.ru/ (in Russ.). Accessed June 17, 2024.

[9] https://www.rosatom.ru/index.html (in Russ.). Accessed June 17, 2024.

[10] https://minobrnauki.gov.ru/upload/iblock/e16/dv6edzmr0og5dm57dtm0wyllr6uwtujw.pdf (in Russ.). Accessed June 17, 2024.

their respective business tasks using software and information services:
- robot 1—implementation of requests for certificate of the place of study;
- robot 2—implementation of applications for issuance of income certificates;
- robot 3—ending out alerts to students regarding expired passports.

Table 6. Business processes and business tasks under study

Business process	Business tasks (SR)
Processing of applications received from students	1. Implementation of requests for vacations after the state final attestation. 2. Implementation of applications for the issuance of a certificate of income. 3. Implementation of requests for the confirmation of study letter. 4. Implementation of requests for issuance of a certificate of residence in the dormitory. 5. Transfer of applications to the archive and deletion of certificates with the term of more than 1 month.
Transfer of data on students to the State Unitary Enterprise "Moscow Social Register"	1. Collection of consents for data transfer to the State Unitary Enterprise "Moscow Social Register". 2. Data transfer to the State Unitary Enterprise "Moscow Social Register". 3. Acceptance and processing of the application for the production of a scholarship card.
Informing the students	1. Sending out signed certificates from the educational institution. 2. Sending alerts to students regarding expired passports.

Table 7. General operational scenarios for some of the SRs under consideration

SRs	Operating scenario
Implementation of applications for issuance of a certificate of income	1. Login to the personal account of the employee of RTU MIREA. 2. Going to the Applications section, selecting the appropriate type of application. 3. Processing of data from the application. 4. Classification of applications into processed and rejected. 5. Downloading applications as Excel files. 6. Change of status for each uploaded request in its Excel file. 7. Distribution of Excel files to accounting departments.
Implementation of requests for the issuance of a confirmation of study letter	1. Login to the personal account of the employee of RTU MIREA. 2. Going to the Applications section, selecting the appropriate application type. 3. Processing of data from the application. 4. Logging in to the Tandem.University information system. 5. Classification of applications into processed and rejected. 6. Downloading a Word file with issuance. 7. Logging into the cloud of RTU MIREA. 8. Downloading the help file to the cloud of RTU MIREA.
Sending signed issuances from the place of study	1. Login to the personal account of the staff member of RTU MIREA. 2. Going to the Applications section, selecting the appropriate type of application. 3. Logging in to the RTU MIREA cloud. 4. Forming a link to a file with a signed certificate. 5. Attaching the link to the file to the corresponding application and closing it.
Sending alerts to students regarding expired passports	1. Logging in to Tandem.University. 2. Filling in the report form in Tandem.University. 3. Downloading and processing an Excel file with data on students. 4. Logging in to the personal account of an employee of RTU MIREA. 5. Go to the Announcements Control Panel section. 6. Formation of publication with notification about expired passports with sending by list from the Excel file formed earlier. 7. Mailing to addressees from the publication with notification.

Table 8. Calculation of computational power required by some SRs used in the multifunctional center of RTU MIREA

Computational resource	Software used	Resource required by the software	Resource requirements of the SR			Total demand
			Robot No. 1	Robot No. 2	Robot No. 3	
RAM capacity, MB (resource No. 1)	Browser	$O_{11} = 120$	120 + 60 + 60	120 + 60 + 60	120 + 60 + 60	720
	Word processor	$O_{12} = 85$	0	85 + 60	85 + 60	290
	Tabular processor	$O_{13} = 65$	0	65 + 65	65 + 65	260
	Mail	$O_{14} = 65$	0	65 + 65	65 + 65	260
SR need for resource No. 1			240	645	645	1530
Number of CPU threads (Resource No. 2)	Browser	$P_{21} = 1$	1	1	1	3
	Word processor	$P_{22} = 1$	0	1	1	2
	Tabular processor	$P_{23} = 1$	0	1	1	2
	Mail	$P_{24} = 1$	0	1	1	2
SR need for resource No. 2			1	4	4	9
Data storage capacity, MB (Resource No. 3)	Browser	$H_{31} = 2048$	2048	2048	2048	6144
	Word processor	$H_{32} = 1024$	0	1024	1024	2048
	Tabular processor	$H_{33} = 1024$	0	1024	1024	2048
	Mail	$H_{34} = 512$	0	512	0	512
	File storage	not required	2048	100	100	2248
SR need for resource No. 3			4096	4708	4196	13000

The differences in the formation of Table 8 content from Table 2 confirm that the amount of computational resource (for example, RAM) consumed by a SR can be determined not only by the fact of parallel use of a certain number of versions of some software product or information service, but also by the amount of information being processed in them—open files, tabs, etc.

Since January 10, 2024, the multifunctional center of RTU MIREA has been operating a robot that produces certificates of study in an educational organization (certificates from the place of study) based on electronic applications in the student's personal cabinet. As at July 07, 2024, this robot has successfully processed more than 46800 applications and issued more than 45700 certificates. The time of execution of one application by an employee of the multifunctional center is 155 s. The time of execution of one application by the SR is 100 s, indicating that in this case two thirds of the employee's time is spent waiting for the results of the software and information services used. During 183 days of the SR operation, the saving of the working time fund of the multifunctional center employees exceeded 2015 man-hours or more than 251 man-days.

Figure 2 shows the dynamics of day-by-day receipt of requests for issuance by the SR of the certificate from the place of study specified in Table 7.

Based on the data presented in Fig. 2, we conclude that the task of managing the number of simultaneously functioning SRs of some set of their types considered in this paper under the conditions of limited allocated computational resources and changes in the number of tasks of the corresponding types is relevant both within the framework of the above-described project "Robotization of the multifunctional center" (taking

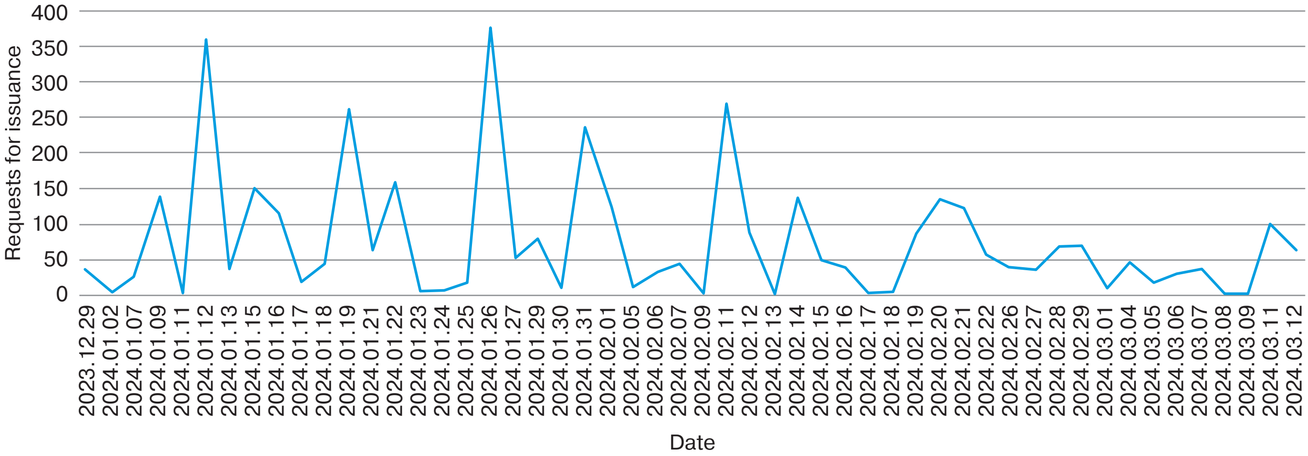

Fig. 2. Dynamics of requests for the issuance of certificates from the place of study

into account the commissioning of SRs from Table 7 in 2024 and 2025), as well as falling within the remit of further software robotization of business processes.

CONCLUSIONS

The automatic optimization of the composition of simultaneously functioning SRs in accordance with the number of incoming business tasks and amount of computational resources allocated for their operation is one of the directions of development of functional capabilities of RPA-platforms, providing their additional competitiveness by minimizing the cost of maintenance (rent) of the required IT infrastructure components.

The material presented in this paper establishes a basis and opens prospects for a new direction of research. This direction is not only universal within the field of software robotization technology, but also in demand both in the context of ensuring import substitution of foreign RPA-platforms and the need to improve the efficiency of organizations (business entities) functioning in the national economy of the Russian Federation.

Authors' contributions. The authors' contributions to this article are consistent with the principles of supervisor–postgraduate student interaction.

A.S. Zuev—task statement, advice on conducting, summarizing and evaluating the results of all stages of the study.

D.A. Leonov—formulation and formalization of the considered tasks, development of the outlined approaches and methods.

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