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A SET OF SIMULATION MODELS OF WORKFLOW ELEMENTS FOR TRANSACTIONAL SERVICES OF INFOCOMMUNICATION SYSTEMS

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Abstract. This article describes the development of a set of simulation models for workflow elements related to transactional services in infocommunication systems. The article presents modeling methods used to calculate, analyze and predict various indicators of the quality of infocommunication services, such as delays, service delivery time and productivity. The necessity of using this method is due to the reduction of labor costs for modeling complex systems and the evaluation of the rationality of the developed mathematical models. The article presents the results of the study in the form of a library of components for simulation modeling, which can be used to improve the quality of transactional services in the development of modern high-load infocommunication systems. The approach described in the article is an effective tool for research and optimization of the quality of transactional services. It can be applied in various areas where analysis and improvement of the performance of data processing systems are required, including for the development of integrated solutions for big data processing, cloud computing or the development of digital counterparts of infocommunication infrastructure.

Keywords: simulation modeling, transactions, work-flow, infocommunication systems, fork-join, parallel processing

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КОМПЛЕКС ИМИТАЦИОННЫХ МОДЕЛЕЙ ЭЛЕМЕНТОВ РАБОЧИХ ПРОЦЕССОВ ДЛЯ ТРАНЗАКЦИОННЫХ УСЛУГ ИНФОКОММУНИКАЦИОННЫХ СИСТЕМ

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Аннотация. Данная статья описывает разработку комплекса имитационных моделей элементов рабочих процессов, связанных с транзакционными услугами в инфокоммуникационных системах. В статье представлены методы моделирования, используемые для расчета, анализа и прогнозирования различных показателей качества инфокоммуникационных услуг, таких как задержки, время предоставления услуги и производительность. Необходимость применения данного метода обусловлена снижением трудозатрат на моделирование сложных систем и оценкой рациональности разработанных математических моделей. В статье представлены результаты исследования в виде библиотеки компонент для имитационного моделирования, которые могут быть использованы для повышения качества обслуживания транзакционных услуг при разработке современных высоконагруженных инфокоммуникационных систем. Описанный в статье подход является эффективным инструментом для исследования и оптимизации качества предоставления транзакционных услуг, и может быть применен в различных областях, где требуется анализ и улучшение производительности систем обработки данных, в том числе для разработки комплексных решений обработки больших данных, облачных вычислений или при разработке цифровых двойников инфокоммуникационной инфраструктуры.

Ключевые слова: имитационное моделирование, транзакции, work-flow, инфокоммуникационные системы, fork-join, параллельная обработка

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Introduction

The purpose of the study is to develop models for calculating and determining the qualitative characteristics of infocommunication services in general and their elements. The works [1–2] describe the reasons why it is irrational to collect statistics and analyze the behavior of the system under the influence of various external and internal factors on the functioning system, which led to the need for their modeling. In [3–6], a comparative analysis of modeling methods and their differentiation, as well as the synthesis of results, is carried out.

In the case of high labor costs for mathematical modeling of systems with complex architecture, when introducing complex distributions into the model (for example, long-tailed distributions: Weibull or Pareto), or if it is necessary to calculate error correlation, it is advisable to use simulation models, a comparative analysis of software tools for the development of which is presented in [7–8].

The goal set within the framework of this work is to develop a family of simulation models for calculating the qualitative characteristics of infocommunication loosely coupled transaction services, including the development of a library of components of the *workflow* for servicing tasks within transactional services.

To achieve this goal, the following tasks are proposed:

1. Study of the main technologies and methods of implementing transaction servicing in loosely coupled services. Including using the queuing theory apparatus.
2. Development of a workflow component Library: Creating a library that contains ready-made components used in task maintenance workflows within transactional services.
3. Implementation of simulation models: Development of software code for the implementation of simulation models based on a specific architecture and components from the library.
4. Evaluation of simulation results with a combination of components in the workflow.

The research carried out within the framework of this work will allow develop simulation models of architectures of varying complexity for infocommunication networks and systems, to assess and predict the characteristics of the service being developed. This will shorten the development and implementation time, verify and verify the results obtained by using a mathematical apparatus, as well as obtain qualitative characteristics of systems that are complex enough for mathematical modeling. Thus, the approach to software development based on Model-Driven Architecture models allows you to use models as a set of recommendations for structuring specifications used in software design.

The authors of works on simulation modeling of infocommunication services [9-10], simulate specific services in order to obtain their characteristics, which does not allow using the proposed models for the analysis of other systems. Separately, it should be noted the work of the author [11] in the framework of which an analysis of a particular service was presented with a detailed description of the approach to its modeling, however, the lack of a description of the implementation of structural elements does not allow to accurately reproduce the study.

1. Approach to the development of simulation models of systems.

The research methods used in this work include empirical studies using mathematical and simulation models to analyze qualitative characteristics. As well as analytical methods for formalizing processes, applying statistical methods to extract information from data. Designing a library of workflow components, which includes defining the functionality of each component, their interaction and interfaces for information exchange.

To create a simulation model of an infocommunication service, the following steps must be performed [12–13]:

1) Definition of the purpose of modeling. This will help determine the required level of detail, quantitative characteristics and other parameters of the model.

2) Collecting data that will be used as input characteristics of the system. This can be data on the flow of applications processed in the system, the characteristics of the network infrastructure, the number of users, and others.

3) Definition of the model structure – based on the data and modeling goals, the structure of the model, the processes occurring in the system, and the parameters of each block are determined.

4) Creating a program for the implementation of the model, using special software tools, such as AnyLogic.

5) Run the simulation and analyze the results. As a result of the analysis, it is possible to determine the efficiency of the system, optimize processes and suggest possible improvements.

There are many different types of simulation models, each of which has its own characteristics and applications. Within the framework of this work, it is advisable to use discrete event modeling methods. These models are quite flexible in the implementation of the necessary functionality and can be used to model a large number of different processes. Examples of the implementation of a transactional service [14–15] and a session service [16–18]. In this paper, simulation modeling of infocommunication services and their elements is carried out in the Anylogic development environment [19].

The main element of the model is a queuing system (QS), which can be part of a network of queuing systems implementing a complex service of applications, data blocks, users depending on the purpose of the system being modelled.

The quality of the system functioning is determined by many factors such as:

– Response time: This is the mathematical expectation and variance of the time it takes the system to process a request and send a response. For most transactional systems, the response time should be minimal.

– Lead time: this is the time it takes the system to perform the operation. For transactional systems, the execution time should also be minimal.

– Downtime: this is the time when the system does not work and does not process requests. The less downtime, the better for users.

– System reliability: this is the probability that the system will be able to process the request.

– Throughput: This is the number of requests the system can handle per unit of time. For transactional systems, throughput should be high enough to meet the needs of users.

– The system's node utilisation factor is a measure of the extent to which a particular node's resources are utilised within a distributed system.

For the latter, the expression for the mathematical calculation of the load factor is as follows:

$$\rho_i = \frac{\lambda_i \times t_i}{v_i} = \frac{\lambda_i}{\mu_i \times v_i}. \tag{1}$$

To obtain this parameter in the system, the following algorithm is required at the "Queue" input:

count= count+delay.size(); // counts the total number of delays in the node

*ro=count/(v*number);* // determines the average node load

This paper considers modern information systems that include transactional systems designed to automate business processes by entering, storing and processing information. They are an important component of infocommunication systems that support workflows [20] and e-commerce applications. Transactional systems play an important role in the operation of such systems by enabling interaction between various components, including web services, servers, local databases and other business transactional participants.

In this paper, the definition of workflows is presented as rule-based software that coordinates and controls the execution of the activities (transactions) that constitute a business process. Workflow can include issues of concepts (Cloud-Fog-Edge), distributed systems, multi-phase maintenance, etc. [21–22].

Simulation models of workflow scenarios

The study of transactional systems using simulation modelling provides accurate estimates of the probabilistic and temporal characteristics in various task processing scenarios in transactional services.

Since transactional services are an implementation of a workflow for servicing a user task, there are an infinite number of implementation options. It can be argued that there is no universal model of workflow definitions. In the following, the developed approaches to the simulation of the main elements of the workflow are presented.

A sequential chain of local transactions is a series of connected mass service systems, where the output from one QS is the input to the other. An example implementation of a workflow simulation model of this type will be shown in Figure 3.

The branching model of system workflow scenarios, allows to consider the processes of a task along the route of local nodes (e.g. Node1 → Node 2, Node 1 → Node 3, Node 1 → Node 4). An example of a service with this approach could be a payment system with different payment methods, the choice of which implements several scenarios. The user information notification system works in the same way with the following scenarios (through SMS, push notifications and mail).

This model includes the ability to choose the path of a request to nodes. The probabilities of user transitions between nodes in the system are given by an indecomposable stochastic matrix $R = \left\| p_{ij} \right\|$, in the case of a system of three nodes:

$$R = \begin{Vmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{Vmatrix}.$$

The route selection blocks "SelectOutputOut" → "Probability", or "Variable" → "Initial value" with reference to the database include the following condition

SELECT *probability of change* **FROM** "DB name"

WHERE *route = "pij"* // select the correct transition, from i to node j

In the scenarios of this model, the intensity of requests to the Semo nodes will be calculated as follows:

$$\lambda_i = \Lambda \times p_{0i} + \sum_{i=1}^{Y} \lambda_j \times p_{ji}. \tag{2}$$

A script for aggregating requests from different sources to merge, process and generate either a merged request by work result or split up and redistribute between the next units in the workflow chain.

When modelling such a structure, it is essential to identify the requests within the workflow, to set the route and conditions for the distribution between nodes in the system.

The result of modelling systems with scenario partitioning and reallocation of requests to nodes in a mass service network is presented in [17].

3) Parallel service (Fork-Join [23]) involves replicating a request to M nodes, with two possible objectives, the first of which involves simulating the process of simultaneously polling two loosely coupled services in order to get a response from all nodes.

The approximate distribution function for the whole network with replication factor equal to m, is calculated by the expression:

$$F_{FJ}(t) \approx 1 - \sum_{i=1}^{M} c_i \left[1 - F_{Si}(t)\right] \prod_{j=1}^{i-1} F_{Si}(t) \approx \sum_{i=1}^{M} (c_i - c_{i+1}) \prod_{j=1}^{i} F_{Si}(t), \tag{3}$$

where c_i – is the replication factor, equal to $c_{M+1} = 0,\ c_1 = 1,\ c_2 = 1 - p_1/4$ and

$$c_i \approx \left(1 - \frac{p_{i-1}}{8}\right)\left(1 - \frac{p_{i-2}}{8}\right),\ \ 3 \le i \le M. \tag{4}$$

The second option involves the need to divide the task into smaller equal parts (data block) and service them simultaneously by parallel nodes [24]. It should be noted that then the maintenance time of the transaction needs to be changed:

$$t^{*}_{\text{serv.}} = \frac{t_{\text{serv.}}}{M}. \tag{5}$$

A simulation model of this type of system has been implemented as follows:

It is worth noting that this simulation model automates the process of changing the number of replicas by introducing the functions described below:

This model has resulted in a software module for characterising parallel transaction processing systems [25].

Modelling results

The result of the simulation of a transaction service as a sequential chain of local transactions branching into parallel service Fork-Join M = 2, is the simulation model shown in Fig. 3.

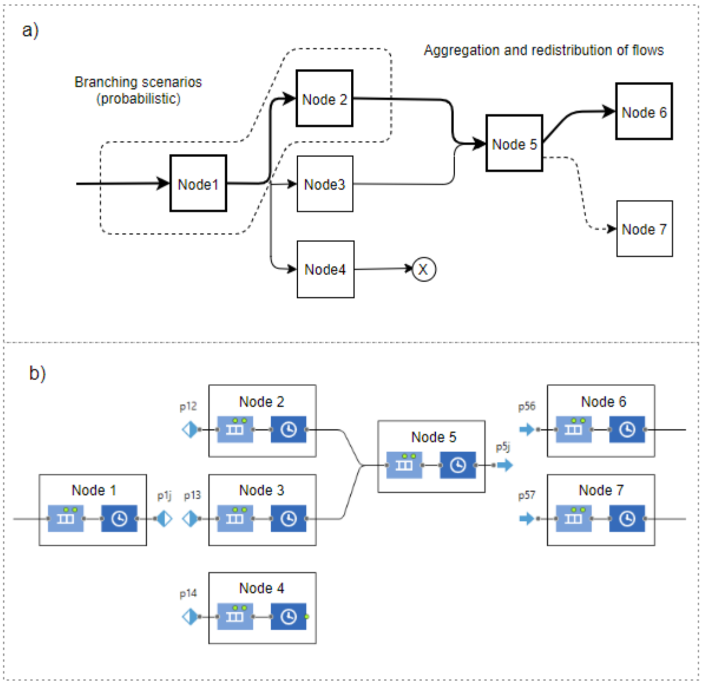

Fig. 1. Branching, aggregation and redistribution of flows a) scheme b) model

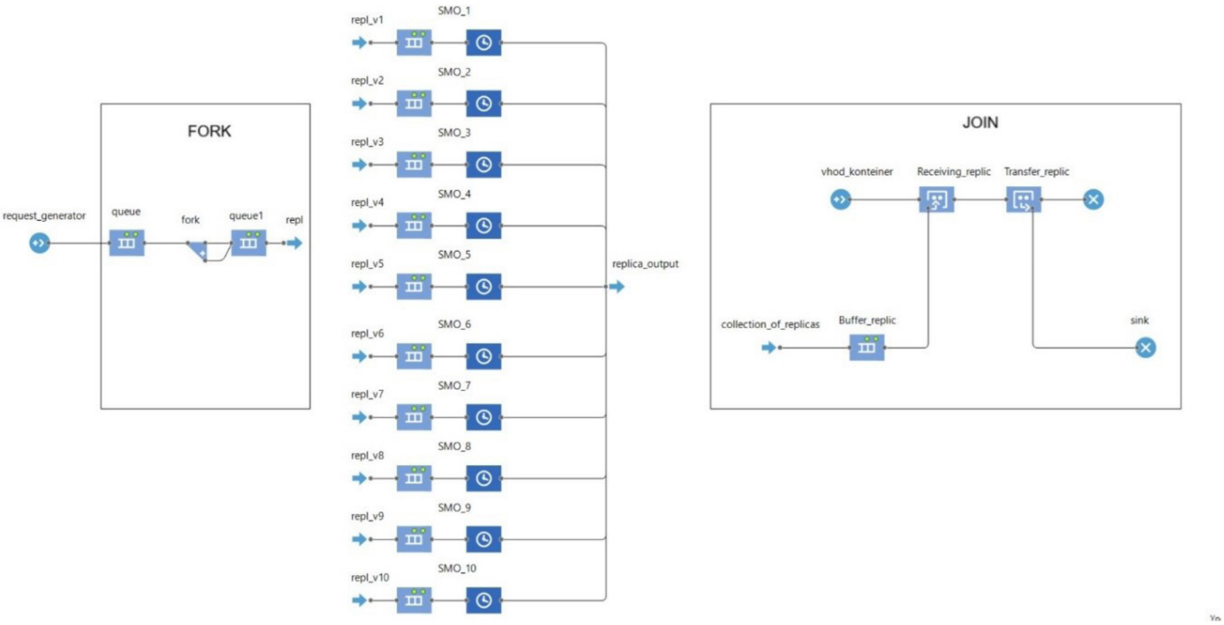

Fig. 2. Fork-Join M node simulation model

As a result of the simulation, the time characteristics were obtained as a function of the input load intensity of the workflow and the performance of its fragments (service intensity μ_i). Also using the convolution equation, the results of analytical modelling were obtained. The M/M/1 systems are independent systems, so the relative error of analytical modelling is insignificant. However, modeling systems with other distribution laws that are not included in the results of Burke's theorem is time consuming and may have a high percentage of inaccuracy. It is for such systems that it is rational to use simulation methods.

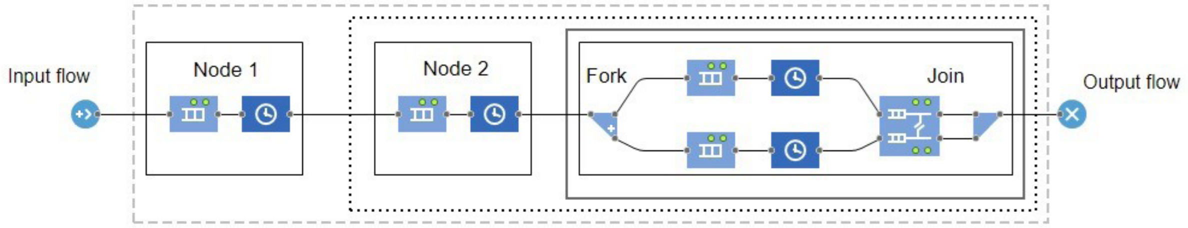

Fig. 3. Transaction chain simulation model with FJ

Table 1

Description of the functional units in the FJ model

Block	Destination	Prerequisite
Function "number_of_nodes"	Changes the number of active nodes by the value defined in the "M_nodes" parameter	**if** (M_nodes == 1) {Nodes_1();} **else if** (M_nodes == 2) {Nodes_2 ();} etc.
Function "Nodes_i" where i=1...M	Determines the probabilities of replica processing by specific nodes	For replica factor M=2 M_1=1/M_nodes; M_2=1/M_nodes; M_3=0; etc.

Queue "Buffer_replic"	Waits for all M replicas to arrive before combining them into an application and ending service	ID=agent.number;
		replica_counter=0;
		for (i=0;i <Buffer_replic. size();i++)
		{
		if ((Buffer_replic.get(i)). number==ID)
		{replica_counter++; }
		if (replica_counter==M_nodes){
		vhod_konteiner.inject();
		i=0;
		break;}}

Pickup "Receiving_replic"	Collects incoming replicas in the "Buffer_replic" block into a single application	Requirement: agent.number==ID;
Dropoff "Transfer_replic"	Transmits application from "Receiving_replic" to system output	Requirement: agent.v_replication==1

$$F_x(t) = F_1(t) * F_2(t) * F_{FJ}(t). \tag{6}$$

As can be seen from Fig. 4, when the input intensity is increased for the whole system, the task service time, or more precisely, the waiting time for service by an application in each element, increases. The increase occurs uniformly until the first node is overloaded at $\Lambda_{crit.} = 1$ request/sec, at this point node 1 is identified as the bottleneck of the system, thereby slowing down the rate of requests to subsequent nodes.

Further modelling suggests that for a given critical input load $\Lambda_{крит.}$, to gradually increase the service intensity at all nodes of the systems, which, as can be seen in Fig. 5, significantly reduces the time to implement the problem.

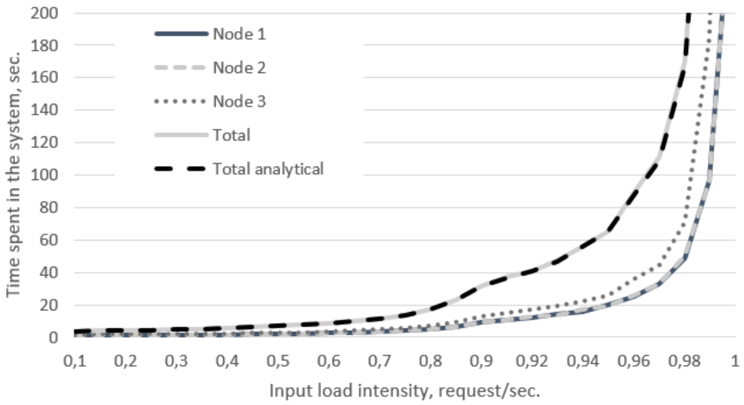

Fig. 4. Dependence of residence time on Λ

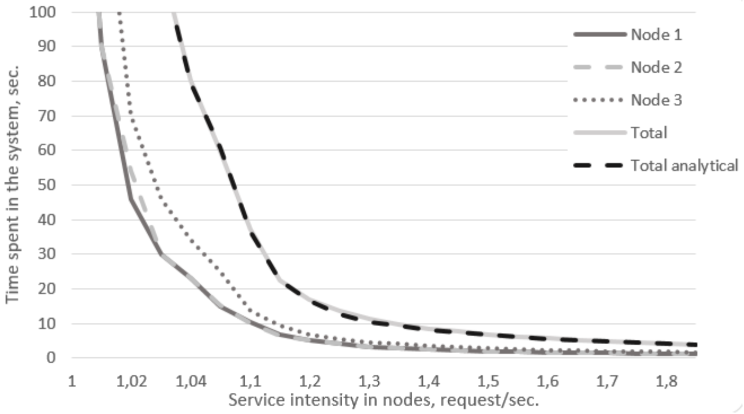

Fig. 5. Dependence of residence time on μ_i

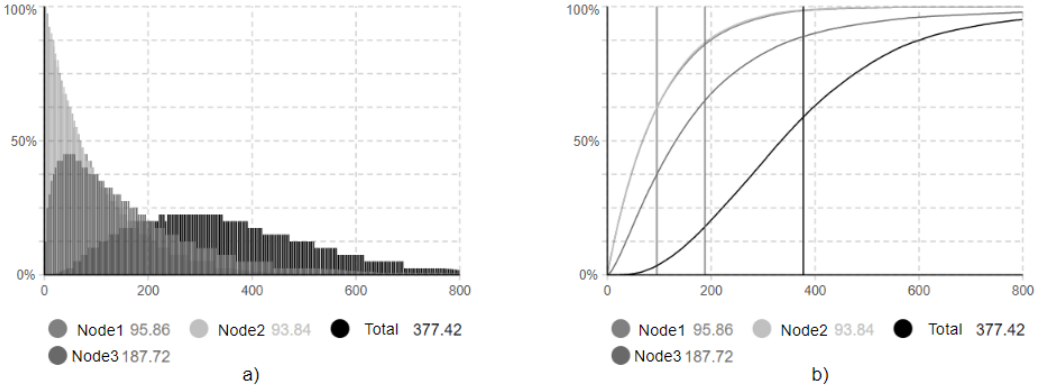

Fig. 6. Density (a) and distribution function (b) of time spent in systems

The moment when the load factor of all nodes $\rho_i \to 1$ at the input intensity $\Lambda = 0.99$ the system tends to overload and has an unacceptable service time. The density and probability of time in the system and in each element are shown in Fig. 6.

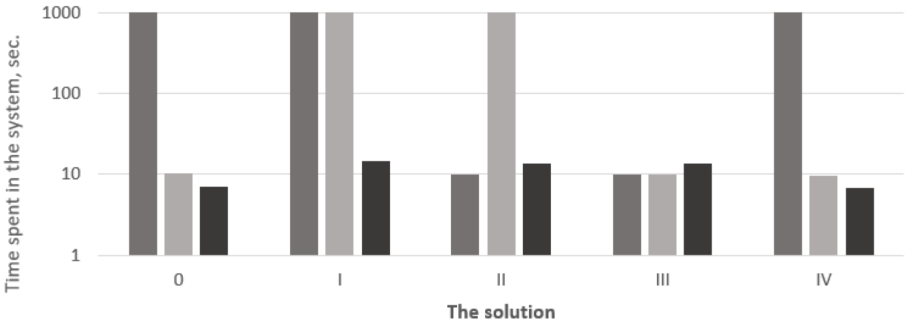

Fig. 7. Dependence of the time in the system on the chosen solution

The question of the rationality of improving the qualitative performance of all elements of the system at the same time has emerged. Simulation modelling allows the time characteristics of the system to be obtained with a minimum of effort by conducting a number of different experiments. This allows you to significantly reduce the cost of resources to provide the required quality of service. For example, Fig. 7 shows the results of a simulation of a transaction chain with the input characteristics given in Table 2.

Table 2

Quantitative characteristics of node performance decisions

	The solution				
	0	**I**	**II**	**III**	**IV**
λ request /sec.	1,2	1,2	1,2	1,2	1,2
μ node 1 request /sec	1,1	1,2	1,3	1,3	1,2
μ node 2 request sec.	1,2	1,2	1,2	1,3	1,3
μ node 3 request /sec	1,3	1,3	1,3	1,3	1,4

The zero solution is the initially set system parameters, and as can be seen from the diagram, with an increase in the performance of a highly loaded node by 1–2 divisions, where division ($\mu = 0.1$), the quality of service of the entire service will not increase, as it will overload the subsequent node. The most rational method in this experiment is to spend the same 3 divisions as in solution IV, but on the first and second node, thereby reducing the load on the nodes and not spending unnecessary resources on the stable node. This approach allows us to calculate the characteristics of the system when implementing an algorithm based on the equivalent microservices workflow focused on the quality-of-service delivery [26].

Conclusion

As part of this work, simulation models of the functional blocks required to create holistic infocommunication services were developed by assembling them into the request service workflow scenarios presented in the following elements:

1) a sequential chain of local transactions;
2) branching workflow scenarios;
3) scenarios for merging. splitting and redistributing query flows;
4) Fork-Join parallel service.

The model blocks presented are suitable for the layout of different variants of complex services. The use of simulation modelling was found to provide accurate estimates of the probabilistic and temporal characteristics of task servicing in transactional service scenarios. More complex task processing scenarios can be considered in further studies, such as:

1) multiphase mass service networks;
2) distributed systems in workflow scenarios (Edge-Cloud computing concept);
3) systems for priority processing of requests;
4) transactional systems for handling requests initiated by session services.

This will extend the scope of simulation modelling and provide more accurate results for more complex task processing systems in transactional services.

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