Actors Interactions Research in Cloud Computing Environments Using System Dynamics Methodology

Aleksandr Skatkov, Elena Mashchenko, Victoria Shevchenko, Dmitry Voronin
Sevastopol State University,
Sevastopol, Russian Federation
{AVSkatkov, maschenko, VIShevchenko, voronin}@sevsu.ru

Abstract—**The process of cloud actors interactions has been described. This problem was considered in order to identify the key factors that affect the level of quality of services in the cloud computing environment. A model of the cloud actors interactions has been proposed using the system dynamics methodology. The model allows to identify and to research the cause-and-effect relationship between the actors interactions outlines and other cloud elements in terms of cloud services quality management.**

I. Introduction

Nowadays the usage of cloud technologies for the distributed heterogeneous computer system implementation is rather common. Such systems are widely used to support resource intensive research of applied and fundamental large-scale problems.

Many companies, research organizations and universities use cloud computing environments to accommodate their scientific and business applications. This gives companies an opportunity to reduce their costs caused by the processes of IT infrastructure creation and support. Thus, owners of cloud computing systems can significantly reduce the total cost of IT infrastructure ownership by using modern IT technologies [1]. Nowadays the model of scientific cooperation and labor division gets active dissemination [2]. This model is based on the collaboration of geographically distributed international researchers teams under the concept of Service-Oriented Science [3]. This concept allows you to organize distributed access to diverse scientific resources. It helps to automate the process of scientific research and to improve the calculating performance. An increasing number of scientific communications and resource intensive calculations are carried out thanks to information technologies that are available as cloud services.

The tendency of cloud services development indicates that different models of the provided services form new kinds of services that can be combined in a generalized EaaS (Everything as a Service) model [4]. Consequently, the current cloud architecture standards and description models of actors interactions in cloud computing environments need to be expanded taking into account the specificity of knowledge-intensive tasks.

Due to increasing complexity of the provided cloud services, the issues of quality management in computing environments acquire paramount importance. In [5] some descriptions and definitions of cloud services quality metrics are provided. In [6] the necessity of quality-level agreements for actors interaction is substantiated. It describes some audit process properties but does not provide a formal description of this process.

The work [7] considers the following: an analytical overview of IT audit methods, cloud audit features and a comparative analysis between cloud and traditional IT audit methods. Publications [8] – [13] are devoted to three main problems: shared data integrity esurience, cloud security and data storage audit.

In [14] the authors proposed an extended reference model of cloud computing environment that was adapted for large-scale scientific computing. In the constructing process the authors of the model have used the following best practices: reference NIST architecture [15-17], Open Cloud Computing Interface [18] and IT Service Management (ITSM) methodology, which is described in IT Infrastructure Library (ITIL) [19-21]. It should be mentioned that Open Cloud Computing Interface was developed by the working group Open Cloud Computing Initiative of international Open Grid Forum organization.

For further development of the model [14], the authors propose to describe cloud actors interactions in terms of system dynamics [22]. The usage of system dynamics paradigm has the following advantages [23]:

- the opportunity to use complex performance criteria;
- the ability to research using even incomplete information;
- the possibility to study dynamic situations in which some cloud parameters may vary in time;
- the ability to study system behavior by identifying the cause-effect relationships and feedback loops interactions;
- good interpretability of systematic flow diagrams, which allows to carry out joint expert actions needed for problems discussion, models formation and development of agreed decisions.

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II. Problem Statement

In this study the authors propose the development of an extended reference cloud computing model [14], which is adapted for large-scale scientific computing. The description of interactions between the actors is made in terms of system dynamics.

The object of the study is a high performance cloud computing environment. The subject of the study is the interaction between actors in cloud computing environment. Actors' properties and the main interaction scenarios are described in the extended reference model [14].

The aim of the study is to improve efficiency of cloud computing environments functioning and to ensure guaranteed level of cloud services quality. To achieve the goal of the research it is necessary to solve the following problems:

1) construction of a model of the interaction between actors in the cloud computing environment using system dynamics methodology;

2) detection and research of cause-effect relationships and outlines of interactions between actors and other elements in terms of cloud services quality management;

3) identification of the key factors that influence the level of the cloud services quality.

The research was made using the following methods: system analysis, system dynamics [22],]23], ITSM-ITIL management methodologies of information systems quality [19-21], decision-making theory.

III. Model of Actors Interactions in Cloud Environments

A. Modeling stages

The simulation process has the following steps:

1) Cause-effect diagram creation. This diagram offers to detect key factors, to determine basic model variables and to identify the polarity of the connections. Conceptual model of cloud actors interactions can be built on the basis of a cause-effect diagram.

2) Flow diagram development. It should be considered which variables are to be submitted to "stock", which – to "rate", and which – to "dynamic variables". The key system parameters that describe the state of constantly changing of resources should be presented as the stock-variables. «Rates» are active system components, they change the «stock» values. In its turn, the «stock» determine the «rate» values. Dynamic variables help to transform parameters values of the simulated system.

3) Creation of computer model in the simulation environment AnyLogic. It takes into account the laws of relationships between variables based on the flow diagram.

4) Checking the adequacy of the model can be based on the data of the consumers log files, monitoring services of Providers and Auditors.

5) To carry out a series of computer experiments with the model taking into account the dynamic priority of actors purposes.

In this article the authors consider the first three stages of research based on the example of one management loop.

B. Cause-effect diagram outlines

Cause-effect diagram is presented on the Fig. 1. On the diagram the main seven balancing loops are considered. They reflect the interactions between the following cloud actors [5,14]: Consumer, Provider, Auditor, Broker, Crisis manager and Composite architect. The notifications of the main balancing loops are the following:

1) Control loop of the provided level of IT service quality for the Consumer – L1.

2) Level of IT services quality monitoring made by the external Auditor– L2.

3) Control loop of the Broker's finance used in cooperation with the Consumer and Provider – L3.

4) Level of the Provider's resource management – L4.

5) Control loop of the actors' triad («Consumer - Broker-Provider») interaction – L5.

6) The level of services development. It is intended for the development of new types of services based on composite applications. Management is carried out by the Composite architect – L6.

7) Outline of crisis situations resistance in terms of scientific research data processing in the cloud – L7.

The developed conceptual model imply that different types of cloud actors are represented as various sub-systems. The territorial and functional distribution of the serviced objects is taken into account within the parameters of different types of delays that are connected, for example, with Consumer's requests or Provider's resources distribution. The numbering of equations was supplemented with notifications of their types. They determine the order of solutions [22]: the levels equations (U), the rate equations (T), the auxiliary equations (V). In the subsystems description the model from [24, 25] was used as a basic conceptual model.

C. Subsystem of IT services level of quality management on the Consumer's side

In order to simplify the model a number of Consumers' unprocessed requests is used as a parameter, that reflects the decrease of IT services quality level.

The equation (1) describes the dynamics of change in the amount of Consumers' unprocessed requests at time t.

$$U: \quad \lambda_Z(t-\Delta t,t) > \mu_Z(t-\Delta t,t) = \\ = \begin{cases} 1, & Z(t) = Z(t-\Delta t) + \Delta t(\lambda_Z(t-\Delta t,t) - \mu_Z(t-\Delta t,t)) \\ 0, & Z(t) = Z(t-\Delta t) \end{cases} \quad (1)$$

where Δt – the step of model time sampling; Z – the number of unprocessed Consumer's requests; λ_Z – the rate of the input flow of requests from the Consumer to the Provider; μ_Z – the rate of processing of Consumer's requests using Provider's services.

EaaS model is considered as an expansion of IaaS [4,5]. It describes the process of heterogeneous computing resources provision used to execute applications on cloud infrastructure. In conformity with to the services level agreement the Provider is to guarantee that the Consumer will get certain amount of services according to the selected tariff plan. The load of the services solving the Consumer's tasks changes with time. The dynamics of unused Consumer's services amount can be described by the equation (2).

$$U: \quad \lambda_s(t-\Delta t,t) < \mu_S(t-\Delta t,t) = \\ = \begin{cases} 1, & S(t) = S(t-\Delta t) + (\mu_S(t-\Delta t,t) - \lambda_S(t-\Delta t,t)) \\ 0, & S(t) = S(t-\Delta t) \end{cases} \quad (2)$$

where S – the amount of unused Consumer's resources; λ_S – the flow rate of Consumer's services seizing; μ_S – the release flow rate of Consumer's services releasing.

As it is shown by the equation (3), the seizing speed depends on the number of unperformed Consumers' requests and on the current demand in services.

$$V: \quad P(t) = \frac{Z(t-\Delta t,t)}{\tau_z(t)}, \quad (3)$$

where P – the actual seizing speed of services; τ_Z – the nominal average time needed for the processing of Consumers' requests made by the Provider's services.

Actual release speed of the services can be described by the equation (4). To maintain a positive balance of services the auxiliary limitation (5) is used. The equation (6) describes the service time τ_Z.

$$V: \quad A(t) = \frac{S(t-\Delta t,t)}{\Delta t}, \quad (4)$$

$$T: \quad \mu_S = \min(P(t), A(t)), \quad (5)$$

$$V: \quad \tau_Z(t) = \tau_{\min} + \frac{\tau_c \cdot N_z(t)}{S(t)}, \quad (6)$$

where $\tau_{\min}$ – the minimum time needed for request service; τ_c – the nominal average Consumer's requests processing time (it takes into account the chosen tariff plan and it can be defined as a table function); N_z – the indicator of the number of concurrent processed Consumer's requests.

$$V: \quad N_Z(t) = \lambda_z(t-\Delta t,t) \cdot (\tau_{\min} + \tau_c) \quad (7)$$

$$V: \quad (N_Z(t) < N_{SLA}) and (\tau_Z(t) < \tau_{SLA}) \\ I_Z(t) = \begin{cases} 1, & I_Z(t-\Delta t) \\ 0, & I_Z(t-\Delta t)+1 \end{cases} \quad (8)$$

As is shown by the equation (7), the indicator N_z is determined based on the average level of processing activity and the amount of permissible delay for the processing requests.

In the case when the processing time and the number of unprocessed requests exceeds a predetermined limit it is considered that SLA violation occur. In this case the corresponding incident is fixed in Consumer's subsystem (see equation (8)).

The Consumer's budget $B(t)$ depends on several parameters: the number of processed requests, the cost of the Provider's tariff plan and the penalties for processing time exceeding. The dynamics of Consumer's budget can be described by the equation (9).

$$U: \quad B(t) = B(t-\Delta t) + (\lambda_B(t-\Delta t,t) - \mu_B(t-\Delta t,t)), \quad (9)$$

where λ_B – the rate of the Consumer's budget growth; μ_S – the rate of budget expenditures.

Thus, on Consumer's side there are three control loops in the proposed cloud management model. The first one controls the Consumers' requests processing, the second – releases resources of cloud infrastructure, the third – controls the Consumer's budget. Requests and budget management is related to internal business processes of the Consumer. Resource management is a cross-cutting business process that links Consumer's and Provider's subsystems.

Next, the model, implemented in the simulation environment AnyLogic 7.3, is discussed.

D. Simulation model of IT services level of quality management on the Consumer's side

Fig. 2 shows a flow diagram of IT services quality level management for the actor Consumer.

Consumer's processing request control loop is represented by the three stock units: *RequestInSysten*, *UnprocessedRzeequest* and *ProcessedRequest.* It corresponds to the equation (1). Rates *Receipt* and *Processing* redistribute Consumers' requests in accordance with the equations (6) − (8). The control loop that releases cloud infrastructure resources is represented by the three stocks: *TariffPlan*, *Service* and *Free.* It corresponds to equation (2). According to equations (3) − (5), the processes of cloud infrastructure resources seizing and releasing are modeled by the rates *Seize* and *Release*. According to equation (9) the budget control loop is represented by stocks *Expenses* and *Profit.* Communication

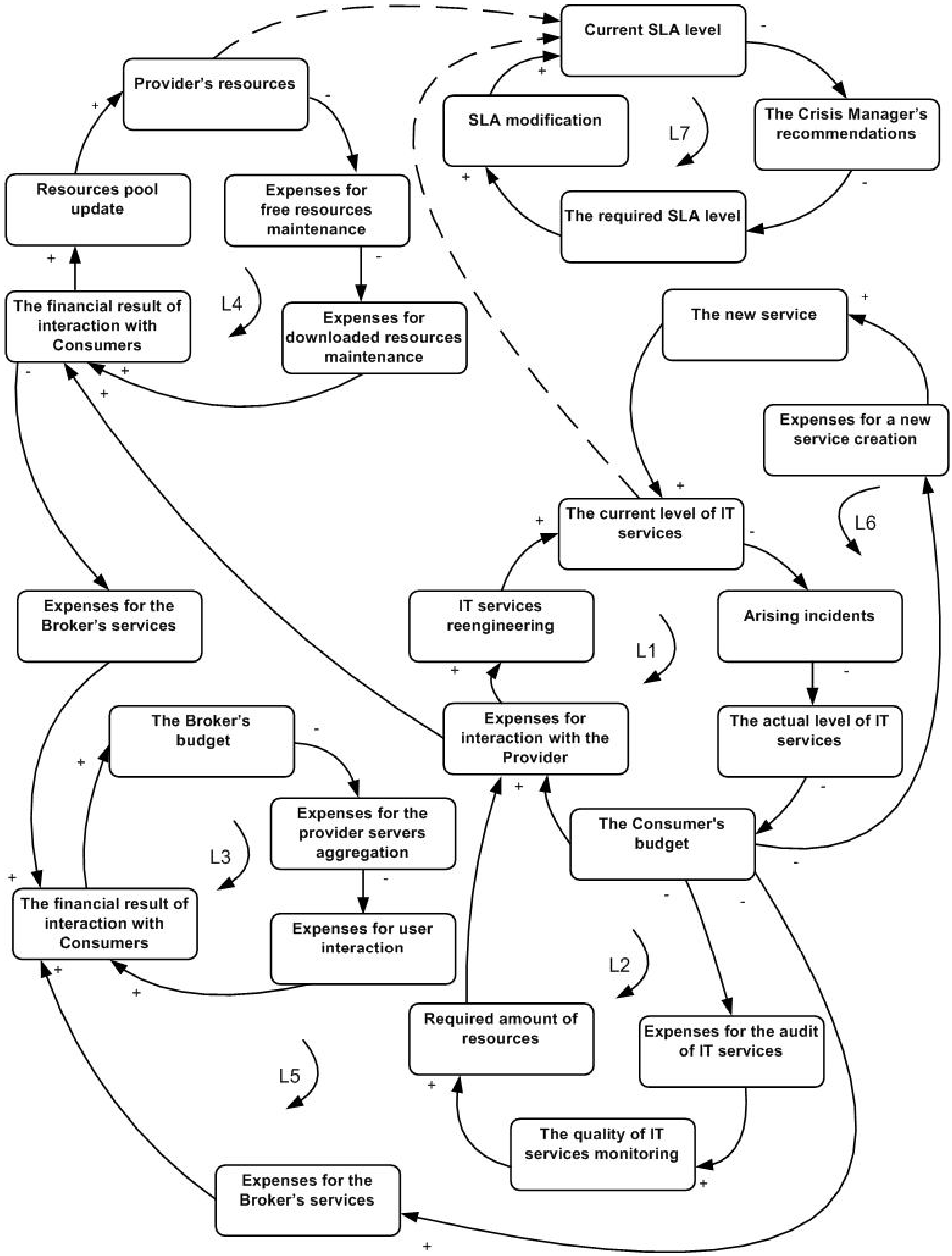

Fig. 1. Cause-effect diagram

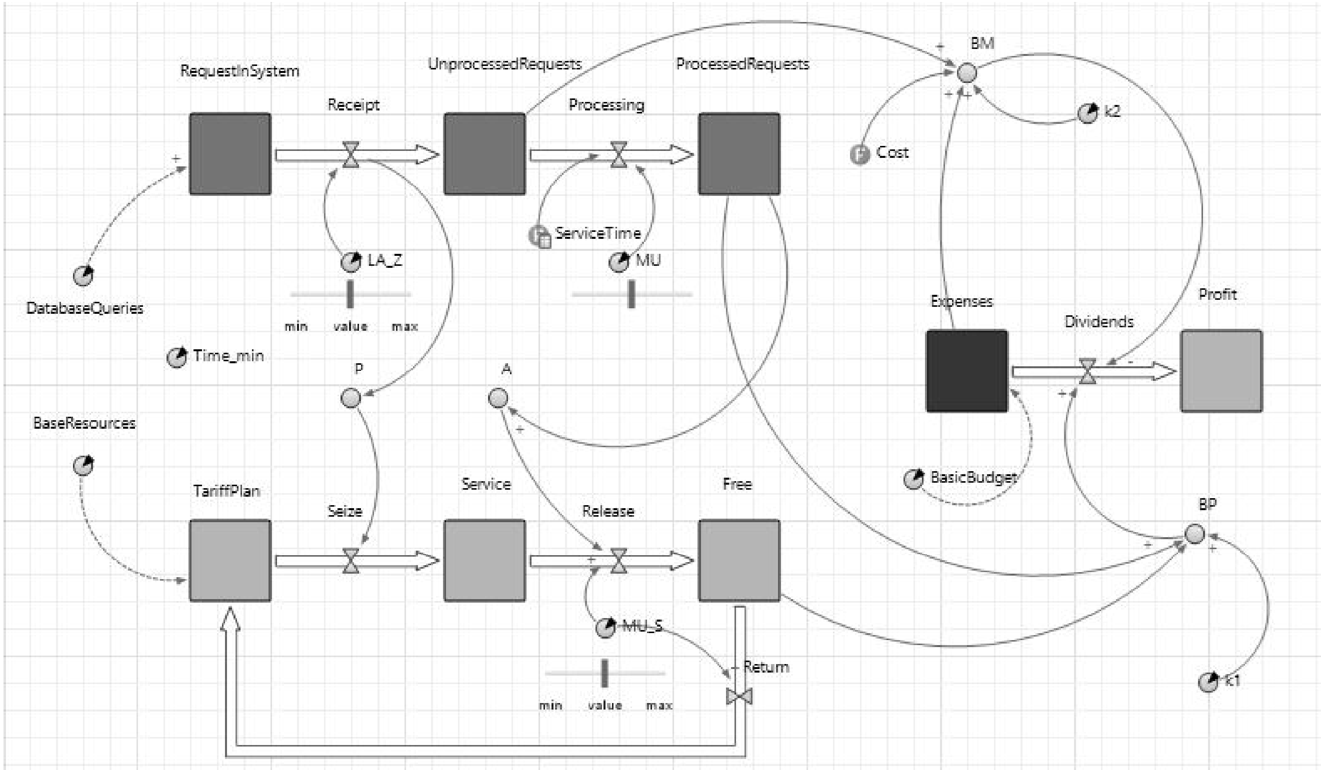

Fig. 2. A flow diagram that manage the level of IT services quality for the actor Consumer

between them is carried out by means of rate *Divedends,* reflecting the dynamic balance between the expenditure part of the budget (variable *BM)* and its revenues (variable *BP).* The research of the model was made taking into account the daily change of the input requests rate from Consumer to Provider. The period of simulation is one month. We assume that processing of consuming scientific problems in the cloud computing environment includes four stages:

1) *Reading and transmission of the data related to multidimensional objects monitoring systems (type 1):* with rate λ_Z^1, which ranges $[1000,50000]$ requests per hour. Nominal average requests service time $\tau_c^1 = 0.0005$ hour.

2) *Primary data processing (filtering, classification and clustering processes) (type 2):* with rate λ_Z^2, which ranges $[1,10]$ requests per hour. Nominal average requests service time $\tau_c^2 = 0.25$ hour.

3) *Entering the user data for the research process (type 3):* with rate λ_Z^3, which ranges $[1,100]$ requests per hour. Nominal average requests service time $\tau_c^3 = 0.02$ hour.

4) *Archiving of information received per day (mun 4):* with rate λ_Z^4, which ranges $[1,50]$ requests per hour. Nominal average requests service time $\tau_c^2 = 0.05$ hour.

Schedule oscillation intensities ranges of daily Consumer's requests are shown on the Fig. 3.

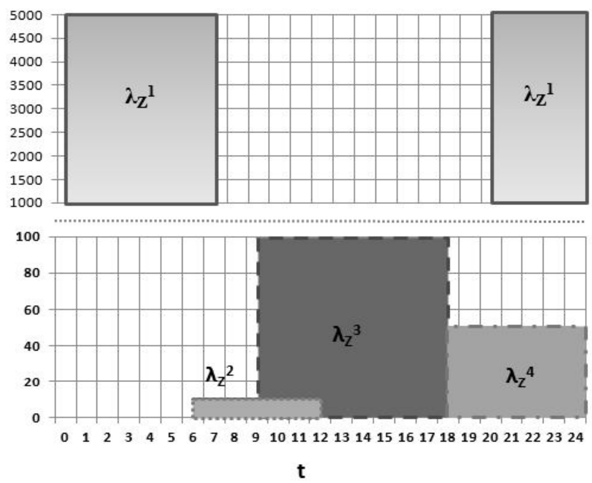

Fig. 3. Schedule of intensities range fluctuation of the Consumer's requests during the day

Consumer's budget growth rate is calculated by the equation (10). It is relevant to economic indicator TR (total revenue).

$$V: \quad \lambda_B(t) = \sum_{w=1}^{W} N_Z(t) \cdot k_1 - c_1, \tag{10}$$

where k_1 – conditional profitability ratio from processing a single request; w – number of the processed requests.

The rate of Consumer's budget expenses is calculated by the equation (11), which corresponds to the economic indicator OPEX (Operational Expenditures).

$$V: \quad \mu_B(t) = \sum_{v=1}^{V} I_Z(t) \cdot k_2 + c_1 + c_2 \tag{11}$$

where k_2 – conditional ratio of losses occurred due to SLA violations during the request processing; v – the serial number of the request, which processing resulted in an incident; c_1 – conditional factor, corresponding average monthly amount of two economic indicators: TFC (total fixed costs) and TVC (total variable costs); c_2 – conditional factor, corresponding average daily cost assignment for the current Provider's tariff plan.

Using this interpretation of the dynamic variables λ_B, μ_B, substituting equations (10) and (11) to equation (9) the value of the rate variable $B(t)$ is relevant to economic indicator EBITDA (Earnings before interest, taxes, depreciation and amortization).

The performed parametric experiment allows us to construct a decision-making matrix for the case of large-scale research tasks processing in the cloud computing environment. The matrix can be useful to determine the efficient work-stages allocation. Fragments of the experimental results are shown in Tables 1 – 3 and in Fig. 4 – 6.

TABLE I. THE FIRST SERIE OF EXPERIMENTS (WITH LOW REQUEST INTRODUCTION RATES)

t	Initial values	1	2	3	4	5	6
λ1		1000	1000	1000	1000	1000	1001
N1		505	1032	1532	2027	2251	2640
I1		51	96	143	191	237	286
B1	Results	-1,255	7,603	10,438	17,628	22,768	24,582
t	Initial values	7	8	9	10	11	12
λ1		1001	1	2	2	2	1
N1		3050	3352	3973	4902	5382	5974
I1		355	296	244	192	144	95
B1	Results	29,581	32,035	133,265	246,157	361,106	490,88
t	Initial values	13	14	15	16	17	18
λ1		1	1	1	1	1	1
N1		6287	6791	7560	7972	8389	9108
I1		44	0	0	0	0	0
B1	Results	650,086	824,378	1009,431	1223,119	1460,552	1723,13
t	Initial values	19	20	21	22	23	24
λ1		1001	1001	1001	1001	1001	1001
N1		9414	10034	10630	11100	11556	11860
I1		0	0	0	0	45	99
B1	Results	2010,741	2206,377	2455,035	2713,193	3001,403	3311,837

With the help of simulation, according to the given input parameters, the best (see Table III) and the worst (see Table II) decisions were obtained. The main selection criteria were the following: quality of services and the level of budget profitability.

The strategies that were considered in the example can be expanded and adapted to the specific conditions of the cloud environment when solving the consuming scientific problems.

TABLE II. THE SECOND SERIE OF EXPERIMENTS (WITH MEDIUM REQUEST INTRODUCTION RATES)

t	Initial values	1	2	3	4	5	6
λ2		2500	2500	2500	2500	2500	2501
N2		509	1016	1544	2051	2557	3075
I2		150	300	449	593	738	879
B2	Results	-105,156	-220,242	-344,941	-479,066	-628,806	-789,118
t	Initial values	7	8	9	10	11	12
λ2		2501	1	2	2	2	1
N2		3579	3986	4587	5101	5577	6077
I2		1038	988	938	887	839	789
B2	Results	-986,483	-983,462	-981,581	-976,729	-979,399	-977,641
t	Initial values	13	14	15	16	17	18
λ2		1	1	1	1	1	1
N2		6574	7068	7572	8051	8596	9085
I2		740	690	640	592	541	489
B2	Results	-976,173	-974,892	-971,413	-972,963	-966,482	-959,751
t	Initial values	19	20	21	22	23	24
λ1		2501	2501	2501	2501	2501	2501
N2		9589	10119	10630	11132	11621	12143
I2		439	593	736	894	1039	1186
B2	Results	-954,701	-1160,83	-1379,72	-1638,72	-1911,8	-2212,06

TABLE III. THE THIRD SERIE OF EXPERIMENTS (WITH LOWER BOUNDARY OF INTENSIVE INTRODUCTION REQUEST TYPE 1 AND AN UPPER LIMIT RATE OF REQUESTS TYPE 2,3,4)

t	Initial values	1	2	3	4	5	6
λ3		1000	1000	1000	1000	1000	1001
N3		505	1032	1532	2257	2559	3271
I3		51	96	143	191	253	308
B3	Results	-1,255	7,603	10,438	8,635	3,839	-0,152
t	Initial values	7	8	9	10	11	12
λ3		1001	1	2	2	2	1
N3		3766	4483	4992	5491	5985	6585
I3		269	238	207	178	138	98
B3	Results	93,146	190,578	296,544	410,715	547,559	699,965
t	Initial values	13	14	15	16	17	18
λ3		1	1	1	1	1	1
N3		6994	7500	7973	8475	8969	9422
I3		58	17	0	0	0	0
B3	Results	870,104	1057,324	1257,403	1484,68	1739,389	1927,066
t	Initial values	19	20	21	22	23	24
λ3		1001	1001	1001	1001	1001	1001
N3		9950	10387	10903	11417	12232	12450
I3		2	60	121	184	238	298
B3	Results	2126,874	2345,509	2582,367	2841,845	3137,16	3459,052

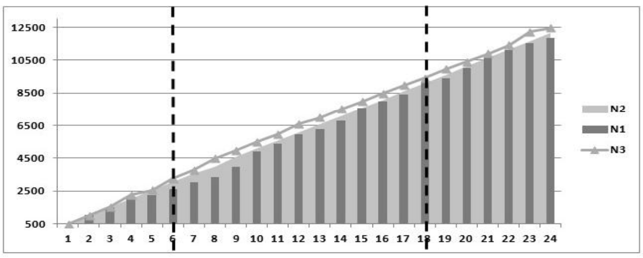

Fig. 4. Accumulation schedule of requests rates which were processed during the day

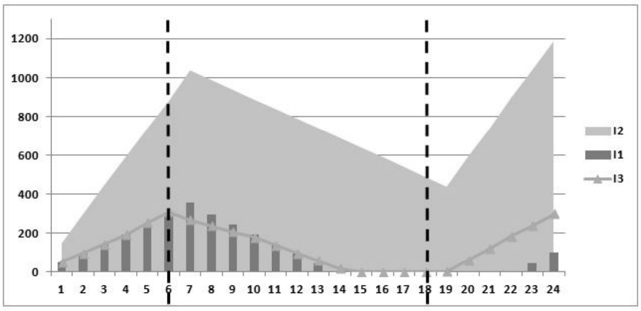

Fig. 5. Accumulation schedule of requests rates, whose processing time exceeded SLA

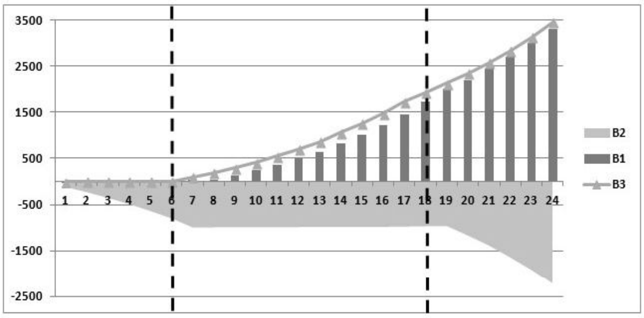

Fig. 6. Schedule of the Consumer's budget dynamics during the day

IV. CONCLUSION

Within the framework of the research, two problems have been considered. The first applies to the cloud computing efficiency increasing, the second – to the guaranteed level of cloud services quality providing. The considered approach was proposed to solve these problems in the cloud computing environment. It includes the construction of complex of models used for quality of service management.

The obtained results are the following:

1) a model of actors interactions in the cloud computing environment has been constructed using the system dynamics methodology;

2) cause-effect relations and outlines of actors interactions were identified and partially researched in terms of quality management of cloud services;

3) the model of IT services level management on the Consumer's side has been constructed. It is described by the expressions (1) – (9);

4) the simulation model of the IT services quality level management on the Consumer's side has been realized;

5) complex criteria of services quality management effectiveness have been defined in expressions (10) and (11). Unlike known they have been reduced to following economic indicators: TR (total revenue), OPEX (Operational Expenditures), EBITDA (Earnings before interest, taxes, depreciation and amortization);

6) a series of experiments was carried out. It allows you to build a decision-making matrix to determine the effective distribution of work stages for the processing of consuming research tasks in the cloud computing environment.

Prospects for further research. Based on the received characteristics several activities can be done. The first activity is connected with expert assessment and lies in the experimental data processing that can be got from the monitoring cloud computing systems. The second – deals with the research of complex criteria used for the effectiveness of services quality management (10), (11). The third is to make recommendations to the decision-making systems. In addition, it is expected to expand a complex of models of services quality management for other cause-effect diagram outlines. Also the development of different actors interactions scenarios in cloud infrastructure and quality management strategies for cloud computing environments looks rather prospect.

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