MODELING AND CALCULATION OF PERFORMANCE INDICATORS OF COMPUTER INFORMATION SYSTEMS

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Abstract. The efficiency of modern companies depends largely on the efficiency of computer information systems (CIS). The efficiency of the CIS can analyzed by modeling and calculating their performance indicators. For the analysis and modeling of the CIS of the "client-server" class, the most widely used mathematical apparatus of Petri nets and the theory of queuing. Representation of the CIS in the form of a Petri net makes it possible to obtain information about the structure and dynamic behavior of the CIS. The most effective in the case of modeling and analysis of corporate information systems with a service-oriented architecture (SOA) are colored Petri nets (CPN). CPN is a graph-oriented language for designing, describing, modeling, and managing distributed and parallel CIS. Unlike a classic Petri nets, data typing based on the color set concept plays an important role in CPN.

In addition to Petri nets, the theory of Queuing systems (QT) is an effective tool for analyzing CIS. Analysis of QT models in the CIS allows calculating the performance indicators of the CIS in order to determine the optimal mode of their operation.

In addition, the design process CIS models of the individual fragments allows adequately choose the appropriate parameters of equipment and resources of CIS, to forecast the state of the CIS. An attempt on intuitively choose the option of integrating heterogeneous products and parameters of the designed system can lead to a significant loss of productivity at the operational stage and high costs for updating the information system. The use of QT for the analysis and modeling of CIS, in particular with a service-oriented architecture, allows, in addition to the simulation tool, to use the Markov chain apparatus for research.

When modeling and analyzing CIS, it is impossible to limit the creation of a single model, which is due to the complexity of the configuration of interacting components. Hence, accounting and analysis of CIS characteristics within a single model is very complex and often impractical. In this regard, the actual task is to build several complementary models of the CIS operation.

Two models of operation of the main component of the CIS Web server proposed in this paper, which based on the apparatus of Petri nets and the theory of Queuing systems. In General, modeling and analysis of CIS based on CPN is very complex and time-consuming, and therefore specialized software products are used. In particular, the specialized CPN TOOLS package. In contrast to Petri nets, TQS allows, in addition to direct simulation of CIS under certain assumptions about incoming request and service flows, to obtain final formulas for CIS performance indicators in analytical form.

For the simplest flows of receipt and service of requests, the calculation of performance indicators of the CIS can perform on the discrete and continuous Markov chains. The example of calculating the performance indicators of an information system shows that it is possible to regulate certain performance indicators of the CIS within certain limits, mainly due to the number of communication channels and the time for processing documents. At the same time, additional communication channels can be not only physical channels, but also virtual dynamic communication channels.

Thus, the Petri and QT models proposed in this paper for modeling and calculating CIS performance indicators are quite universal in terms of the characteristics of the flows of receipt and service of requests in the CIS.

***Keywords*:** *computer information systems, colored Petri nets, apparatus of Markov chains, queuing theory, state graph, calculation of word load*

Introduction. The efficiency of modern companies depends largely on the efficiency of computer information systems (CIS). The efficiency of the CIS can analyze by modeling and calculating their performance indicators. For the analysis and modeling of the CIS of the "client-server" class, the most widely used mathematical apparatus of Petri nets [1,2] and the theory of queuing [3].

It known [2] that Petri nets are very convenient for modeling systems consisting of many interacting components. From here, Petri nets make it possible to model CIS in the form of a mathematical representation based on kit theory, which is an extension of set theory. Representation of the CIS in the form of a Petri net makes it possible to obtain information about the structure and dynamic behavior of the CIS [2].

It should note that the most effective in the case of modeling and analysis of corporate information systems with a service-oriented architecture (SOA) are colored Petri nets (CPN) [4].

CPN is a graph-oriented language for designing, describing, modeling, and managing distributed and parallel CIS. Unlike a classic Petri nets, data typing based on the color set concept plays an important role in CPN. To describe the dynamic properties of CPN introduces the notion of a network layout with the use of so-called tokens are placed in certain positions. To describe dynamic properties, the CPN introduces the concept of network markup using so-called tokens placed in certain positions. The position has a certain value to be determined from a variety of colors. The color of the position, in turn, determines the type of tokens that are there. CPN is an asynchronous system in which the tokens moved according to the positions of the through transitions. A transition moves a token from an input position to an output position if at least one token is present in all input positions for this transition and a logical condition that restricts the transition (trigger function) is met.

In addition to Petri nets, Queueing theory (QT) is an effective tool for analyzing CIS. Analysis of QT models in the CIS allows calculating the performance indicators of the CIS in order to determine the optimal mode of their operation. In addition, the design process CIS models of the individual fragments allows adequately choose the appropriate parameters of equipment and resources of CIS, to forecast the state of the CIS. This approach is due to the high complexity of modern CIS, it is usually very difficult for the designer to analyze all the performance indicators of the developed CIS at once. An attempt to intuitively choose the option of integrating heterogeneous products and parameters of the designed system can lead to a significant loss of productivity at the operational stage and high costs for updating the information system [3,5].

The use of QT for the analysis and modeling of CIS, in particular with a service-oriented architecture [6], allows, in addition to the simulation tool, to use the Markov chain apparatus for research.

Problem statement. When modeling and analyzing CIS, it is impossible to limit the creation of a single model, which is due to the complexity of the configuration of interacting components [6]. Hence, accounting and analysis of CIS characteristics within a single model is very complex and impractical [7]. In this regard, the actual task is to build several complementary models of the CIS operation.

Two models of operation of the main component of the CIS Web server proposed below, which are based on the apparatus of Petri nets and the theory of Queuing systems.

Modeling and calculation of CIS performance indicators. For heterogeneous applications in the framework of the CPN theory, we consider the following special case of the Web server model.

The model contains three sources of requests from client terminal users, an application server, and a database server. Each source generates the following stream of requests:

– the requests to get static site content (images, static HTML pages, style tables, etc.);

– the requests to get information from the database;

– the requests to save information in the database.

Simulation model CIS in the form of stochastic CPN is shown in fig. 1. To simulate the server processing requests of different types entered into the model coloring i as markers of different shapes <▼ ♦ ■ •>. Markers indicated with a circle, reflect the employment status of a resource of the application server query processing channels to the application server.

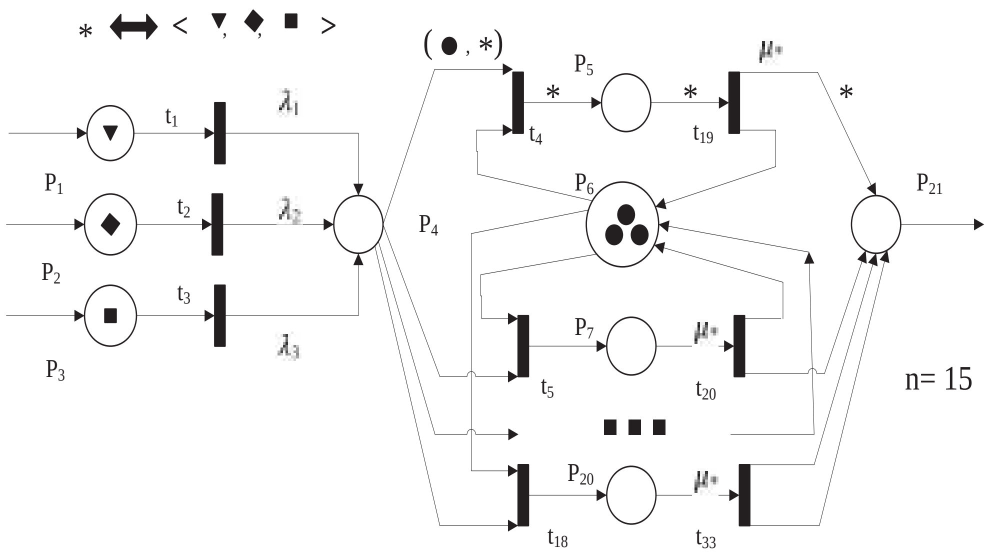

Fig. 1 – Web server model in the form of a colored Petri net

Petri net transitions t_1, t_2, t_3 are associated with request sources, and the intensity of their arrival at the application server inputs is determined by the known values of the intensities λ_1, λ_2, λ_3, respectively. The set of *M* server channels is represented as a subset of loaded M1 channels and a subset of free M_2 channels, provided that $M_1 \cap M_2 = \emptyset$ and $M = (M_1, M_2)$. The moments when the application server starts processing requests are determined by transitions t_4, t_5,..., t_{18}. When the next request received at time t_j, the K_q M_2 service channel with the minimum number starts working. The start time of the K_q channel is determined by the time $\tau_k^q = \tau_j$. The end of request service is determined by transitions t_{19},..., t_{31},t_{33}. The end time of service with the i-th channel coloring K_q is set by the expression (1):

$$t_k^q = \tau_k^q + 1/\mu_i\,; \quad \text{i=1, 2, 3,} \qquad (1)$$

where μ_i is the service intensity of the request with the i-th coloring.

In General, modeling and analysis of CIS based on CPN is very complex and time-consuming, and therefore specialized software products are used. In particular, the specialized CPN TOOLS package [8].

In contrast to Petri nets, QT allows, in addition to direct simulation of CIS under certain assumptions about incoming request and service flows, to obtain final formulas for CIS performance indicators in analytical form. For example, for the simplest flows of receipt and service of requests, the calculation of performance indicators of the CIS can performed on the discrete and continuous Markov chains [9]. In this case, the Web server operation can represented by the following state graph (fig. 2), which corresponds to the uniformity of the request flow and the absence of coloring in the Petri net model shown in fig. 1. Other words, in the model circulates an ordinary request flow with an exponential distribution.

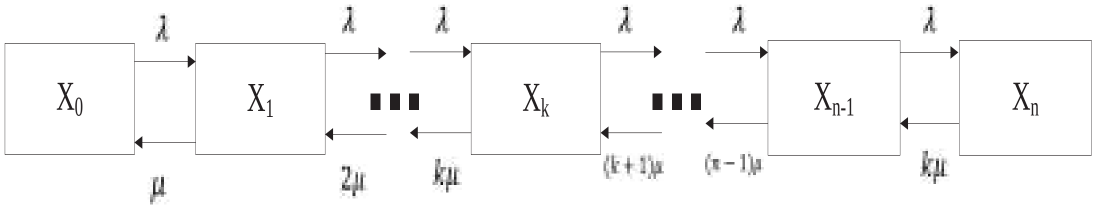

Fig. 2 – Web server state graph

The operation of such a Queuing system model (QMS) from the point of view of QT is as follows.

The operation of such a Queuing system model (QMS) from the point of view of QT is as follows. The simplest stream of requests with a known intensity λ fed to the input of the n-channel CIS. The intensity of the simplest request service flow for each channel determined by the value of μ. According to Fig. 2 in this CIS model, the following set of states is possible:

– X_0 – all channels are free, one request is not served;

– X_1 – exactly one channel is busy (which one is not important), one request is being served;

– X_n – exactly k channels are busy (which ones are not important), k requests are served;

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– X_n – all n channels are busy, n requests served.

If the request finds all n channels busy, the request is rejected (leaves the system unserved).

In the special case considered earlier, we assumed that the number of service channels is $n = 15$, i.e. the Web server is configured to simultaneously work with 15 channels. For the Web server state graph (Fig. 2), in accordance with the mnemonic rule for composing equations [4], the system of differential equations for the probabilities p_i of States X_i defined as:

$$\begin{cases} \dot{p}_0(t) = -\lambda p_0(t) + \mu p_1(t); \\ \dots \\ \dot{p}_k(t) = -[\lambda + \kappa\mu]\, p_k(t) + \lambda p_{k-1}(t) + (k+1)\mu p_{k+1}(t), \\ \dots \\ \dot{p}_n(t) = -n\mu p_n(t) + \lambda pn(t), \end{cases} \qquad (2)$$

where $k = 1, \dots, n$-1.

The system of differential equations (2) integrated under initial conditions:

$$\begin{cases} p_0(0) = 1; \\ p_k(0) = 0;\; p_n(0) = 0 \end{cases} \qquad (3)$$

In this case, the solution of the system of differential equations (2) satisfies the normalization condition:

$$\sum_{k=0}^{n} p_k(t) = 1, \ (t \geq 0). \quad (4)$$

The simplest stream of requests with a known intensity λ fed to the input of the n-channel CIS. The intensity of the elementary service flow for receiving and servicing requests performed over a long-time interval. Mathematically, this mode corresponds to the ergodic mode of operation of the CIS, which corresponds to the following algebraic system of equations:

$$\begin{cases} O = -\lambda p_0 + \mu p_1; \\ \dots \\ O = -[\lambda + k\mu] p_k + \lambda p_{k-1} + (k+1)\mu p_{k+1}; \\ \dots \\ O = -n\mu p_n + \lambda p_{n-1}, \end{cases} \quad (5)$$

Solving the system (5) together with (4), we obtain a formula for the probabilities of the state of the CIS model under consideration:

$$p_k = \frac{\dfrac{\left(\dfrac{\lambda}{\mu}\right)^k}{k!}}{\dfrac{\sum_{k=0}^{n}\left(\dfrac{\lambda}{\mu}\right)^k}{k!}}, \left(k = \overline{0,n}\right). \quad (6)$$

Let's introduce the notation: $\bar{\lambda}$ =λ/μ, where $\bar{\lambda}$ is equal to the average number of requests received by the system during the average service time of one request in one channel. Given the expressions for $\bar{\lambda}$ and multiplying the numerator and denominator (6) by $e^{-\lambda}$, we get:

$$p_k = \frac{\left(\dfrac{\lambda}{\mu}\right)^k e^{-\lambda}}{\sum_{k=0}^{n}\left(\dfrac{\lambda}{\mu}\right)^k e^{-\lambda}} = \frac{p\left(k_1\bar{\lambda}\right)}{R\left(n_1\bar{\lambda}\right)}, \quad (7)$$

where $p\left(k_1\bar{\lambda}\right)$ and $R\left(n_1\bar{\lambda}\right)$ are table functions of the Poisson distribution [4].

Based on the formula (7) , you can get a number of indicators for the operation of a computer information system: the probability of downtime, the probability of failure, the average number of busy channels, average time to fully load the system and so on.

In particular, the following indicators are relevant for the CIS analysis:

1. The probability of servicing the request:

$$P_{обсл.} = \frac{R\left(n-1,\bar{\lambda}\right)}{R\left(n,\bar{\lambda}\right)}. \quad (8)$$

2. Average time to fully load the system:

$$t_{п.з.} = \frac{1}{n\bar{\lambda}}. \quad (9)$$

3. Probability that at least one channel is busy:

$$P_{з.к.} = \frac{P\left(n,\bar{\lambda}\right)}{P\left(n,\bar{\lambda}\right)}. \quad (10)$$

4. Probability of failure:

$$P_{отк.} = 1 - P_{обсл.}. \quad (11)$$

Example of calculating CIS performance indicators

Let the CIS have 15 communication channels (Fig. 1). The flow of applications (documents) is on average λ = 1 1/sec., the average document processing time is $T = 10$ sec. , i.e. μ = 0,1 1/sec. The distribution law is exponential. It is necessary to evaluate the main characteristics of the information system, including the likelihood of immediate processing of the document immediately upon its receipt.

Using the above formulas (6) – (11), we can calculate the following indicators of the CIS:

Probability of failure: $Pf = 0{,}0365$.

Probability of service: $Ps = 1 - 0{,}0365 = 0{,}9635$.

Absolute throughput A, i.e. all documents entering the system are processed almost immediately: $A = 1\text{-}0.9635 \approx 0$

Average number of active communication channels (equal to the average number of requests):

$$n_{av} = \lambda / \mu = 1/0.1 = 10.$$

Usage and downtime rates for communication channels:

$$K_{us} = n_{av} / \text{n} = 0{,}666; k_d = 1\text{-}k_{us} = 0{,}334.$$

If we take the number of communication channels $n = 10$, then the utilization factor becomes close to 1 ($K_{us} = 0.997$). In other words, in the CIS under the above conditions, there is practically no downtime of any service channels.

The example of calculating the performance indicators of an information system shows that it is possible to regulate certain performance indicators of the CIS within certain limits, mainly due to the number of communication channels and the time for processing documents. At the same time, additional communication channels can be not only physical channels, but also virtual dynamic communication channels [11].

Conclusion. The Petri and QT models proposed in this paper for modeling and calculating CIS performance indicators are universal in terms of the characteristics of the flows of receipt and service of requests in the CIS. In addition to simulation modeling, QT allows you to obtain final formulas for CIS performance indicators in analytical form, under certain assumptions about incoming request flows and their service flows. This reflected in the given example of calculating the performance of a computer information system under the formulated conditions of its operation.

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МОДЕЛИРОВАНИЕ И РАСЧЕТ ПОКАЗАТЕЛЕЙ РАБОТЫ КОМПЬЮТЕРНЫХ ИНФОРМАЦИОННЫХ СИСТЕМ

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Аннотация. Эффективность современных компаний во многом зависит от эффективности компьютерных информационных систем (КИС). Эффективность деятельности КИС может быть проанализирована путем моделирования и расчета их показателей эффективности. Для анализа и моделирования КИС класса "клиент-сервер" наиболее широко используется математический аппарат сетей Петри и теория массового обслуживания. Представление КИС в виде сети Петри позволяет получить информацию о структуре и динамическом поведении КИС. Наиболее эффективными в случае моделирования и анализа корпоративных информационных систем с сервис-ориентированной архитектурой (СОА) являются цветные сети Петри (ЦСП). ЦСП – это графо-ориентированный язык для проектирования, описания, моделирования и управления распределенными и параллельными КИС. В отличие от классических сетей Петри, типизация данных на основе концепции набора цветов играет важную роль в ЦСП.

При моделировании и анализе КИС невозможно ограничиться созданием единой модели, что связано со сложностью конфигурации взаимодействующих компонентов. Следовательно, учет и анализ характеристик КИС в рамках одной модели является очень сложным и часто непрактичным. В связи с этим актуальной задачей является построение нескольких взаимодополняющих моделей функционирования КИС.

В данной работе предложены две модели работы веб-сервера как основного компонента КИС, основанные на аппарате сетей Петри и теории систем массового обслуживания. В целом моделирование и анализ КИС на основе ЦСП является очень сложным и трудоемким процессом, в связи с чем используются специализированные программные продукты. В частности, специализированный пакет инструментов ЦСП. В отличие от сетей Петри, ТСМО позволяет, помимо прямого моделирования КИС при определенных допущениях о входящих потоках запросов и услуг, получать окончательные формулы показателей эффективности КИС в аналитической форме.

Ключевые слова**:** компьютерные информационные системы, раскрашенные сети Петри, аппарат цепей Маркова, теория массового обслуживания, граф состояний, расчет количества слов.

МОДЕЛЮВАННЯ І РОЗРАХУНОК ПОКАЗНИКІВ РОБОТИ КОМП'ЮТЕРНИХ ІНФОРМАЦІЙНИХ СИСТЕМ

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Анотація. Ефективність сучасних компаній багато в чому залежить від ефективності комп'ютерних інформаційних систем (КІС). Ефективність діяльності кіс може бути проаналізована шляхом моделювання та розрахунку їх показників ефективності. Для аналізу і моделювання кіс класу "клієнт-сервер" найбільш широко використовується математичний апарат мереж Петрі і теорія масового обслуговування. Подання КІС у вигляді мережі Петрі дозволяє отримати інформацію про структуру і динамічну поведінку КІС. Найбільш ефективними у випадку моделювання та аналізу корпоративних інформаційних систем з Сервіс-орієнтованою архітектурою (СОА) є кольорові мережі Петрі (КМП). КМП-це графо-орієнтована мова для проектування, опису, моделювання та управління розподіленими і паралельними КІС. На відміну від класичних мереж Петрі, типізація даних на основі концепції набору кольорів відіграє важливу роль в КМП.

При моделюванні та аналізі КІС неможливо обмежитися створенням єдиної моделі, що пов'язано зі складністю конфігурації взаємодіючих компонентів. Отже, облік і аналіз характеристик КІС в рамках однієї моделі є дуже складним і часто непрактичним. У зв'язку з цим актуальним завданням є побудова декількох взаємодоповнюючих моделей функціонування КІС.

У даній роботі запропоновані дві моделі роботи веб-сервера як основного компонента КІС, засновані на апараті мереж Петрі і теорії систем масового обслуговування. В цілому моделювання та аналіз КІС на основі КМП є дуже складним і трудомістким процесом, у зв'язку з чим використовуються спеціалізовані програмні продукти. Зокрема, спеціалізований пакет інструментів КМП. На відміну від мереж Петрі, ТСМО дозволяє, крім прямого моделювання кіс при певних допущеннях про вхідні потоки запитів і послуг, отримувати остаточні формули показників ефективності кіс в аналітичній формі.

***Ключові слова*:** комп'ютерні інформаційні системи, кольорові мережі Петрі, апарат ланцюгів Маркова, теорія масового обслуговування, графік стану, розрахунок кількості слів.