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**Arutiunian V.**

# ANALYSIS OF THE RELIABILITY OF THE INFORMATION SYSTEM OF MASS NOTIFICATION WITH «CLIENT-SERVER» ARCHITECTURE AND USING GOOGLE MAPS SERVICE

*Об'єктом дослідження даної роботи є відновлювана після відмов інформаційна система, що складається з кінцевого числа n апаратно-програмних клієнтських систем, підключених за допомогою відповідного інтерфейсу до сервера S. Дана система являє собою клієнт-серверну модель для сучасної системи масового оповіщення населення при надзвичайних ситуаціях. Система передбачає використання сервісів інтерактивних карт місцевості для обробки або доповнення даних, переданих з мобільних девайсів потерпілих, які вже були отримані сервером і опрацьовані через запрограмовані в ньому алгоритми. В ході дослідження були побудовані і використані математичні моделі інформаційної системи, що розглядалася. Апроксимована відновлювана після відмови інформаційна система «клієнт-сервер» з кінцевим числом станів. Отримано граф станів, який описує її поведінку, а також складена система диференціальних рівнянь Колмогорова. Використано пряме перетворення Лапласа від системи диференціальних рівнянь. В роботі побудована математична модель для опису поведінки системи з урахуванням кінцевої надійності системи сервісу Google Maps. Також для визначення надійності моделі був розрахований окремий випадок роботи системи без урахування виходу з ладу клієнта. Це пов'язано з тим, що клієнтська частина у кожного потенційного потерпілого має індивідуальні особливості і залежить від типу використовуваного пристрою. Проаналізовано поведінку інформаційної системи при наявності відмов, яка описується системою диференціальних рівнянь зі змінними коефіцієнтами. Даний аналіз показує, що інформаційна система має досить високу надійність за основними характеристиками. Завдяки використанню запропонованої математичної моделі забезпечується можливість отримання різних характеристик надійності інформаційних систем типу «клієнт-сервер». Рішення отриманих диференціальних рівнянь дозволяє проводити дослідження цих характеристик в широкому діапазоні зміни інтенсивностей відмов і відновлення компонентів системи.*

**Ключові слова:** *інформаційна система масового оповіщення, надійність інформаційних систем, архітектура «клієнт-сервер», сервіси інтерактивних карт.*

## 1. Introduction

Currently, due to the intensive development of distributed information systems, the «client-server» architecture of computer networks has become widespread. In this case, the term «client-server» is used to designate such architecture of an information system in which its functional components interact according to the «request-response» scheme [1, 2]. The information system considered in this paper is used for mass notification of the population in emergency situations, so it should have a sufficiently high reliability, like any other warning system. Development of models for determining various characteristics of the reliability of information systems is an important task, in particular, to determine the reliability of information systems with «client-server» architecture. The relevance of developing similar models and a mathematical apparatus for studying the reliability of the distributed information systems under consideration in stationary conditions and under the influence of external factors leading to an increase in the failure rate of the system components is confirmed by the work of many scientists [3–5]. Taking into account the capabilities of modern mobile devices and the analysis of existing mass warning systems for the population operating in the United States, Japan, Poland, the author of this work has developed a «client-server» model for a modern mass warning system in emergency situations. This information system provides for the use of services of interactive terrain maps for processing or supplementing data transmitted from mobile devices of victims, which have already been received by the server of the system and worked through programmed algorithms [6].

Continuing this line of research, the author chose a recoverable information system consisting of a finite number $n$ of hardware and software client systems connected via an appropriate interface to the server $S$ as *the object of research.*

*The aim of research* at this stage is development and testing the model to study the reliability of the information system of mass notification with the «client-server» architecture and the use of the Google Maps service.

## 2. Methods of research

Taking into account the probabilistic nature of the functioning of the considered information system in the stationary mode and under the conditions of external destabilizing influences, when developing a mathematical model, we approximate the behavior of the system by a Markov process with a finite number of states. Let's suppose that the failure of any component of the information system is determined immediately after its occurrence and the restoration of the failed component immediately begins. In the information system, simultaneous failures are possible in several client systems with a healthy server. In this situation, failed client systems are restored, and efficient ones continue to operate in the «client-server» mode. In the case of a server failure, as in the case of a failure of the Google Maps service, the work of the information system of mass notification is interrupted until the restoration of the operational state of both components of the system. Also let's suppose that the information system under consideration has only three possible states. In the first state, one or more client systems and a server simultaneously fail. In the second state, one or more client systems and the Google Maps service simultaneously fail. And, finally, one or several client systems, the server and the Google Maps service simultaneously fail in the third state of the system. In this case, the information system stops functioning until the end of the recovery process of the server, the failed client systems and when one or more client systems, the server and the Google Maps service simultaneously fail. At the same time, the overall recovery rate of the failed components of the system is redistributed between the server, the Google Maps service and the failed client systems, which leads to a decrease in the recovery rate of all system components. After their recovery, the information system of mass notification continues to operate in a stationary mode. The failure rate of Google Maps is not a discrete value.

To build mathematical models of the considered information system, let's introduce the following notation:

$E_0$ – the state of the information system in the absence of failures in client systems and in the server;

$E_i$ $(i=1, 2, ..., n)$ – the state of the information system in the presence of failures in $i$ client systems;

$E_0^*$ – the state of the information system in the event of server failure and no failures in client systems;

$E_i^*$ $(i=1, 2, ..., n)$ – the state of the information system with simultaneous server failure and failures in $i$-th client systems;

$E_{ii}$ $(i=1, 2, ..., n)$ – the state of the information system, during which $i$-th failed client systems are restored and Google Maps service fails;

$E_{ij}$ $(i=1, 2, ..., n;\ j=1, 2, ..., n)$ – the state of the information system in which the failed server is restored and the Google Maps service fails;

$\lambda_s$ – server failure rate;

$\lambda_{ki}$ $(i=1, 2, ..., n)$ – the failure rate of the $i$-th client system;

$\lambda_{mi}$ $(i=1, 2, ..., n)$ – the failure rate of the Google Maps service;

$\mu_{si}$ $(i=1, 2, ..., n)$ – the intensity of the recovery of the server when there are simultaneous failures in $i$-th client systems;

$\mu_{ki}$ $(i=1, 2, ..., n)$ – the intensity of the recovery from the failure of the $i$-th client system;

$\mu_{mi}$ $(i=1, 2, ..., n)$ – the intensity of recovery from the failure of the Google Maps service.

By approximating an informational «client-server» system that is restored after a failure with a finite number of states, it is possible to make up a graph of states that describes its behavior (Fig. 1).

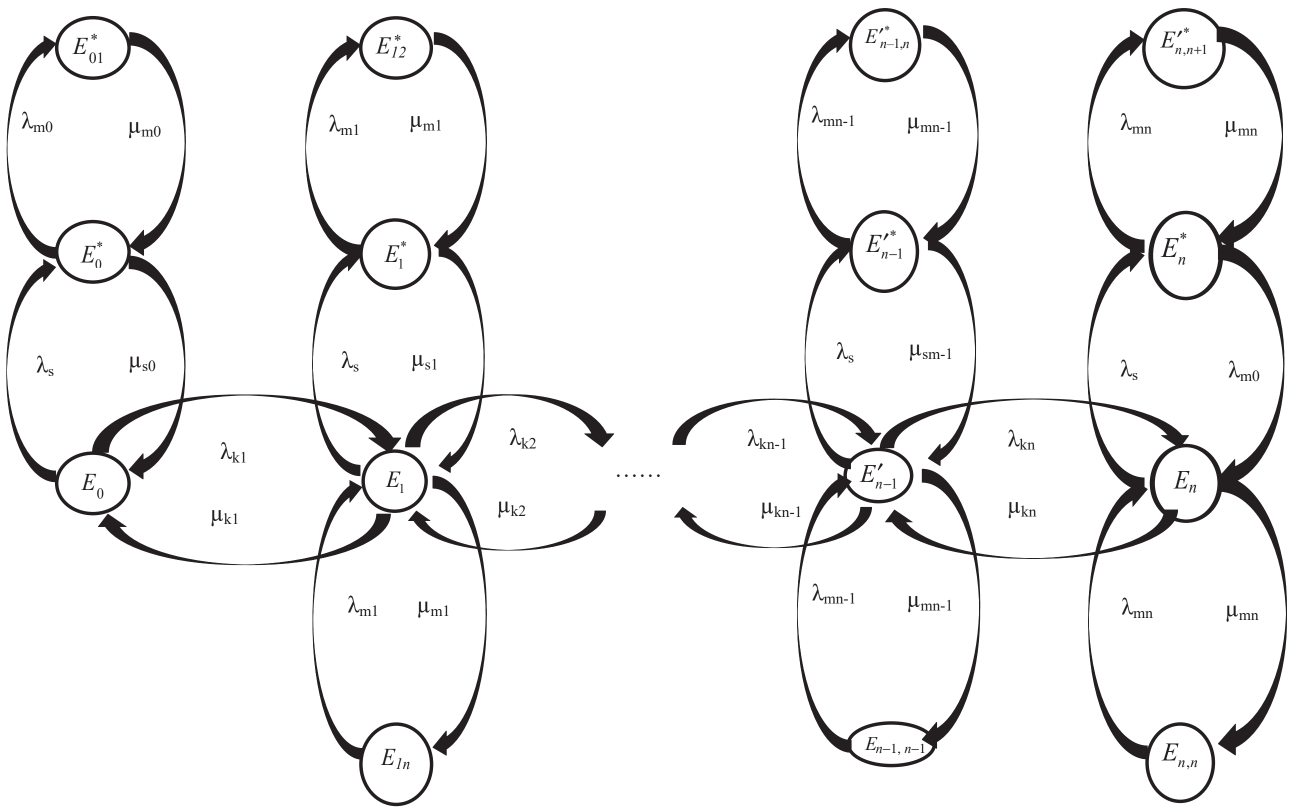


**Fig. 1.** Graph-states of the «client-server» system with failures and recovery of system components

Let's denote:

$p_i(t)$ $(i=1, 2, ..., n)$ – the probability that the system is in the $E_0$, $E_1$, ..., $E_n$ state;

$p_i^*(t)$ $(i=0, 1, 2, ..., n)$ – the probability that the system is in the $E_0^*$, $E_1^*$, ..., $E_n^*$ state;

$p_{ii}(t)$ $(i=1, 2, ..., n)$ – the probability that the system is in the $E_{1,1}$, $E_{2,2}$, ..., $E_{n,n}$ state;

$p_{ij}^*(t)$ $(i=1, 2, ..., n;\ j=1, 2, ..., n+1)$ – the probability that the system is in the $E_{0,1}$, $E_{1,2}$, ..., $E_{n,n+1}$ state.

Let's make system of the Kolmogorov differential equations [9]:

$$\begin{aligned}
&p_0'(t)=\mu_{s_0}\cdot p_0^*(t)+\mu_{k_1}\cdot p_1(t)-(\lambda_s+\lambda_{k_1})\cdot p_0(t);\\
&p_i'(t)=\mu_{s_i}\cdot p_i^*(t)+\mu_{k_{i+1}}\cdot p_{i+1}(t)+\lambda_{k_i}\cdot p_{i-1}(t)+\mu_{m_i}\cdot p_{i,i}(t)-\\
&-(\lambda_s+\lambda_{k_1}+\mu_{k_i})\cdot p_i(t)-\lambda_{m_i}\cdot p_{i,i}(t),\ (i=1,2,\ldots,n-1);\\
&p_n'^*(t)=\mu_{s_n}\cdot p_n^*(t)+\lambda_{k_n}\cdot p_{n-1}(t)+\mu_{s_n}\cdot p_{n,n}(t)-\\
&-(\lambda_s+\mu_{k_n})\cdot p_n(t)-\lambda_{m_n}\cdot p_{n,n}(t);\\
&p_i'^*(t)=\lambda_s\cdot p_i(t)-\mu_{s_i}\cdot p_i^*(t),\ i=0,1,2,\ldots,n;\\
&p_{i,i}'^*(t)=\lambda_{m_i}\cdot p_i(t)-\mu_{m_i}\cdot p_{i,i}(t),\ (i=1,2,\ldots,n);\\
&p_{i,j}'^*(t)=\lambda_{m_i}\cdot p_i^*(t)-\mu_{m_i}\cdot p_{i,j}^*(t),\\
&(i=0,1,2,\ldots,n;\ j=1,2,\ldots,n+1),
\end{aligned}\tag{1}$$

with initial conditions:

$$\begin{aligned}
&p_0(0)=1;\ p_i(0)=0,\ (0\le i\le n);\\
&p_i^*(0)=0,\ (0\le i\le n);\\
&p_{i,i}(0)=0,\ (1\le i\le n);\\
&p_{i,j}^*(0)=0,\ (1\le j\le n+1).
\end{aligned}\tag{2}$$

The direct Laplace transform of the system of differential equations (1):

$$\begin{aligned}
&sp_0'(s)-1=\mu_{s_0}\cdot p_0^*(s)+\mu_{k_1}\cdot p_1(s)-(\lambda_s+\lambda_{k_1})\cdot p_0(s);\\
&sp_i'(s)=\mu_{s_i}\cdot p_i^*(s)+\mu_{k_{i+1}}\cdot p_{i+1}(s)+\lambda_{k_i}\cdot p_{i-1}(s)+\mu_{m_i}\cdot p_{i,i}(s)-\\
&-(\lambda_s+\lambda_{k_1}+\mu_{k_i})\cdot p_i(s)-\lambda_{m_i}\cdot p_{i,i}(s),\ (i=1,2,\ldots,n-1);\\
&sp_n'^*(s)=\mu_{s_n}\cdot p_n^*(s)+\lambda_{k_n}\cdot p_{n-1}(s)+\mu_{s_n}\cdot p_{n,n}(s)-\\
&-(\lambda_s+\mu_{k_n})\cdot p_n(s)-\lambda_{m_n}\cdot p_{n,n}(s);\\
&sp_i'^*(s)=\lambda_s\cdot p_i(s)-\mu_{s_i}\cdot p_i^*(s),\ i=0,1,2,\ldots,n;\\
&sp_{i,i}'^*(s)=\lambda_{m_i}\cdot p_i(s)-\mu_{m_i}\cdot p_{i,i}(s),\ (i=1,2,\ldots,n);\\
&sp_{i,j}^*(s)=\lambda_{m_i}\cdot p_i^*(s)-\mu_{m_i}\cdot p_{i,j}^*(s),\\
&(i=0,1,2,\ldots,n;\ j=1,2,\ldots,n+1).
\end{aligned}\tag{3}$$

Solving the system of differential equations (1) by numerical methods for known values of constants and time-dependent variables, the coefficients $\lambda_s$, $\lambda_{ki}$, $\lambda_{mi}$, $\mu_{si}$, $\mu_{ki}$, $\mu_{mi}$, it is possible to obtain a solution. This solution will be presented in the form of probabilities of finding the considered information system with the «client-server» architecture in any of its states $E_0$, $E_i$, $E_0^*$, $E_i^*$, $E_{ii}$, $E_{ij}$. And also get almost any characteristics of the reliability of the information system of mass notification.

## 3. Research results and discussion

Based on the work of scientists who worked on this problem [7–10], a system of differential equations is compiled for solving a common problem:

$$\begin{aligned}
&p_0'(t)=\mu_{s_0}\cdot p_0^*(t)+\mu_{k_1}\cdot p_1(t)-(\lambda_s+\lambda_{k_1})\cdot p_0(t);\\
&p_i'(t)=\mu_{s_i}\cdot p_i^*(t)+\mu_{k_{i+1}}\cdot p_{i+1}(t)+\lambda_{k_i}\cdot p_{i-1}(t)+\mu_{m_i}\cdot p_{i,i}(t)-\\
&-(\lambda_s+\lambda_{k_1}+\mu_{k_i})\cdot p_i(t)-\lambda_{m_i}\cdot p_{i,i}(t),\ (i=1,2,\ldots,n-1);\\
&p_n'^*(t)=\mu_{s_n}\cdot p_n^*(t)+\lambda_{k_n}\cdot p_{n-1}(t)+\mu_{s_n}\cdot p_{n,n}(t)-\\
&-(\lambda_s+\mu_{k_n})\cdot p_n(t)-\lambda_{m_n}\cdot p_{n,n}(t);\\
&p_i'^*(t)=\lambda_s\cdot p_i(t)-\mu_{s_i}\cdot p_i^*(t),\ i=0,1,2,\ldots,n;\\
&p_{i,i}'^*(t)=\lambda_{m_i}\cdot p_i(t)-\mu_{m_i}\cdot p_{i,i}(t),\ (i=1,2,\ldots,n);\\
&p_{i,j}'^*(t)=\lambda_{m_i}\cdot p_i^*(t)-\mu_{m_i}\cdot p_{i,j}^*(t),\\
&(i=0,1,2,\ldots,n;\ j=1,2,\ldots,n+1),
\end{aligned}\tag{4}$$

with initial conditions:

$$\begin{aligned}
&p_0(0)=1;\ p_i(0)=0,\ (0\le i\le n);\\
&p_i^*(0)=0,\ (0\le i\le n);\\
&p_{i,i}(0)=0,\ (1\le i\le n);\\
&p_{i,j}^*(0)=0,\ (1\le j\le n+1).
\end{aligned}\tag{5}$$

To determine the reliability of the model, let's calculate the special case of the system without taking into account the failure of the client [7].

The state probabilities for the system (Fig. 2) are determined by the formulas:

$$\begin{aligned}
&P_{E0}=\frac{\mu_s\cdot\mu_m}{\lambda_s\cdot\lambda_m+\lambda_s\cdot\mu_m+\mu_s\cdot\mu_m};\\
&P_{E0}=\frac{\lambda_s\cdot\mu_m}{\lambda_s\cdot\lambda_m+\lambda_s\cdot\mu_m+\mu_s\cdot\mu_m};\\
&P_{E0}=\frac{\lambda_s\cdot\lambda_m}{\lambda_s\cdot\lambda_m+\lambda_s\cdot\mu_m+\mu_s\cdot\mu_m}.
\end{aligned}\tag{6}$$

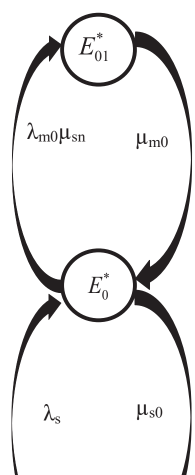


**Fig. 2.** Graph-states of the «client-server» system with failures and recovery of system components without a client's failure

Having solved this system of equations (6), it is possible to calculate the probabilities of the system states for a particular case without client failure.

## 4. Conclusions

The model used to study the reliability of the information system of mass notification with the «client-server» architecture and the use of the Google Maps service makes it possible to obtain solutions in the form of probabilities of finding the system in any of its states. It is also possible to obtain various characteristics of the reliability of an information system.

### References


1. A Game Theory Approach in Information Security Risk Study / Shing M.-L., Shing C.-C., Chen K. L. et. al. // 2010 International Conference on E-business, Management and Economics IPEDR. 2011. Vol. 3. P. 201–203.
2. Tyurin S. F., Grekov A. V. Functionally Complete Tolerant Elements // International Journal of Applied Engineering Research. 2015. Vol. 10, Issue 14. P. 34433–34442.
3. Ar'kov P. A. Kompleks modeley dlya poiska optimal'nogo proekta sistemy zashhity informatsii // Izvestiya Yuzhnogo federal'nogo universiteta. Tekhnicheskie nauki. 2008. Vol. 85, Issue 8. P. 30–36.
4. Antonov A. V., Plyaskin A. V., Tataev H. N. On the issue of reliability calculation for redundant structures in view of ageing elements // Dependability. 2013. Issue 1. P. 55–67.
5. Schäbe H., Shubinsky I. B. Limit reliability of structural redundancy // Dependability. 2016. Issue 16 (1). P. 3–13.
6. Arutiunian V. E. Suchasna kliient-serverna model prohramnoho kompleksu masovoho opovishchennia u nadzvychainykh sytuatsiiakh: processing // Kompiuterni ta informatsiini systemy ta tekhnolohii. Kharkiv: KhNURE, 2018. P. 69–71.
7. Potapov V. I. Modeli i algoritm chislennogo resheniya zadachi protivoborstva izbytochnykh, vosstanavlivaemykh posle otkazov tekhnicheskikh sistem // Problemy upravleniya i informatiki. 2015. Issue 4. P. 70–78.
8. Viktorova V. S., Stepanyants A. S. Modeli i metody rascheta nadezhnosti tekhnicheskikh sistem. Moscow, 2013. 219 p.
9. Potapov V. I. Zadachi i chislennye algoritmy optimizatsii nadezhnosti apparatno-izbytochnoy tekhnicheskoy sistemy v konfliktnoy situatsii pri razlichnykh strategiyakh zashhity ot atak protivnika // Mekhanika, avtomatizatsiya, upravlenie. 2015. Vol. 16, Issue 9. P. 617–624.
10. Potapov V. I. Development of models for research of reliability of information system restored after refusals with architecture «client-server» // Omsk Scientific Bulletin. 2018. Vol. 5, Issue 161. P. 143–146. doi: http://doi.org/10.25206/1813-8225-2018-161-143-146
11. Kozlov B. A., Ushakov I. A. Spravochnik po raschetu nadezhnosti apparatury radioelektroniki i avtomatiki. Moscow: Sovetskoe radio, 1975. 472 p.


***Arutiunian Volodymyr,*** *Postgraduate Student, Department of Information Technology, Zaporizhzhya Institute of Economics and Information Technologies, Ukraine, e-mail: vova.ara@gmail.com, ORCID: http://orcid.org/0000-0002-3573-8393*