Model of the Application Processing Process in Reconfigurable Automated Monitoring Systems

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Abstract

The paper proposes an approach to modeling query processing processes in reconfigurable automated monitoring systems based on the use of a model of a controlled reconfigurable system and queuing models. The problem of modeling is determined to be associated with an additional factor, reducing the time spent in the queue, taking into account changes in performance as a result of dynamic adaptive adjustment of the monitoring system to the operating conditions. A composite flow model describing the change in the nature of the tasks performed in the monitoring system is defined, approaches to constructing optimal reconfiguration control based on minimizing the functional of losses over a finite time interval are proposed. The joint representation of the processes in automated monitoring systems as the service of applications in a managed queuing system is substantiated. The constructed model of the functioning process and the analytical dependencies obtained for it make it possible to analyze the processing requests in automated monitoring systems for further optimization. Based on the obtained ratios, an experimental model study was carried out.

Keywords: Automatic control system, reconfiguration, monitoring, queuing system, Markov chain

Introduction

To analyze the likely-time characteristics of reconfigurable multifunctional automated monitoring systems (MF AS), the most effective is the use of queuing models. They are characterized by an active change in the order of request processing, which necessitates the application of the theory of managed queuing systems (QMS) [1, 2]. In [3, 4], an overview of the classes of QMS is given and five types of management are considered: input flow management, service mechanism, system structure, service discipline and integrated management. Approaches to the construction of loss functionals are considered, including average waiting times, random loss function, average costs of using a maintenance device and switching between modes of operation. When analyzing MF AS, two approaches can be applied to solving optimal control problems: Howard and linear programming. In [1], general approaches to the modeling of MF AS by controlled queing systems based on Markov and semi-Markov processes and circuits are considered. Approaches to the synthesis of controlled

QMS have been developed, in particular with dynamic requirements, variable sets of parameters of service devices and variable service intensity [2,5].

With the help of queuing models, the problems of structural synthesis of suitable controlled QMS and strategies for optimal management of MF AS can be solved. For example, in [6] the possibility of finding the number of service channels and their performance for a closed multichannel queing system according to the requirements for its characteristics is considered – nomograms for solving synthesis problems are obtained. Thus, in [7], the issues of modeling multichannel QMS when managing the queue discipline and service discipline by the administrator, as well as the distribution of resources between processing channels, are considered. A special case of QMS is the failure of servicing devices: management of a two-server computing system with failures [8]; two strategies for managing the maintenance of applications in a single-channel QMS G/M/1 with a random discipline of server removal [9]. A more general task involves connecting backup service devices. Thus, in [10], the application of the dynamic programming method for controlling multilinear QMS with a set of plug-in backup service devices is considered. Another special case is the use of heterogeneous devices and devices with variable performance. In [11], controlled QMS with heterogeneous devices with two optimization criteria are considered: NJM (mean number of jobs minimization) and PCM (processing cost minimization). In [12], a single-line queuing system with variable service intensity characteristic of computing and communication systems is considered. To increase the automation effect, several controllability factors are used simultaneously. Thus, in [13], the issues of managing heterogeneous heterogeneous servers with failures and continuous recovery using managed QMS are considered. In [14], the issues of using semi-Markov QMS with a group input flow for the analysis of systems in the presence of rest devices, single or double Markov flow of breakdowns, multiphase QMS with a monotonous control strategy are considered.

The analysis of known approaches and modeling methods carried out above in order to manage the service of applications during the functional development of MF AS showed the need to adapt known approaches and use reconfigurable systems [15-19]. Since the problem of modeling the MF AS is associated with an additional factor, in relation to the factor of reducing the time spent in the queue, taking into account changes in performance as a result of dynamic adaptive adjustment of the monitoring system to the conditions of its implementation.

Application service model in the MF AS based on BMAP/G/N/1

The solution to this task is a joint representation of the processes of functioning and functional development of the MF AS a service of applications based on a managed batch Markovian arrival process (BMAP). The general ideas of modeling the process of functional development are determined by the following initial provisions:

– functional channels serve applications for monitoring of natural-technical systems;

– changes in requirements are modeled by changes in the flow of applications;

– the process of functional development is modeled by changing the performance of channels and creating new functional channels.

The processing of tasks in the MF AS can be presented in the form of a QMS with an expectation (Figure 1). Without losing the generality of the approach to modeling, we will present the MF AS in the form of a single-channel QMS with expectation. The input stream of applications is the sum of single streams of the same type of applications: $\Lambda = \sum_{j=0}^{J} \lambda_j$.

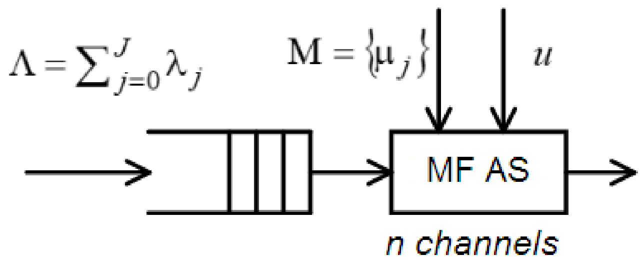


Figure 1 – A model of the application processing in the MF AS

A feature of the MF AS highlighted in the work is the different intensity of service for different classes of applications: $M = \{\mu_j\}$. The adaptation allows to increase the productivity of servicing applications. The probabilistic nature of the receipt and processing of applications for reconfiguration of the monitoring system itself allows us to present this process in the form of a QMS (Figure 2).

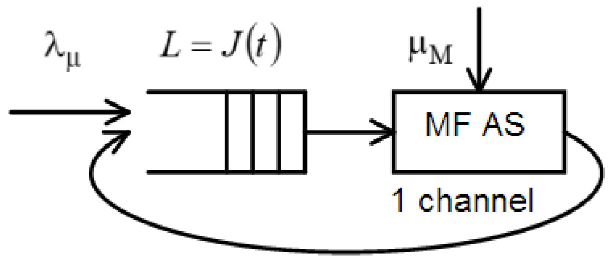


Figure 2 – Model of the MF AS reconfiguration process

Without losing generality, we can consider that the dedicated server unit of the MF AS has one channel and at the same time the performance of only one channel can increase. In general, the performance gain of the server block μ_M decreases when the reconfiguration stage increases. The input stream of modernization requests λ_μ is formed when new types of processing tasks appear and has the intensity: $\lambda_\mu << \Lambda$. Processed applications are returned to the system. There are applications in the service queue by the number of task types: $L = J(t)$.

Combining the two presented models allows us to consider MF AS a controlled QMS with expectation. In accordance with this, the queing model can be represented as a controlled random process $\xi(t)$with control $u(t)$. The quality of control U for a certain period of time $[s, t)$ is characterized by the functional

$$L_{[s,t)} = L_{[s,t)}[x,u] = L[x(\tau), u(\tau); s \leq \tau < t] \quad (1)$$

depending on the trajectories of the MF AS $x_{[s,t)}$ and the controls used in this section $u_{[s,t)} = u[\tau, x_\tau]$. As a functional, the loss function is considered, showing the effects of processing applications for the provision of monitoring services.

The purpose of control is to minimize the target functional:

$$R_{[s,t)}(\delta) = R_{[s,t)}(x_s, u_s; \delta) \Rightarrow min \quad (2)$$

which is provided by the construction of such a control strategy δ^* for which

$$R_{[s,t)}(\delta^*) = inf\ R_{[s,t)}(\delta), \ (0 \leq s < t < \infty). \quad (3)$$

Since the management of the MF AS is implemented at a finite time interval, the risk functional has the following form:

$$R_t^T[x, u; \delta] = M^\delta\{L_{[s,t)}/x_t, u_t\}. \quad (4)$$

The presented version of the controlled QMS can be given in the form of *BMAP/G/N/1* or in the special case of *BMAP/SM/N/1*. In accordance with [14, 20], such CFR can be described using multidimensional Markov chains. Then, for N=1 (the number of serving servers), the process of servicing applications for automation in the MF AU is represented as a three-dimensional process:

$$\xi_n = \{i_{t_n}, v_{t_n}, m_{t_n}\}, n \geq 1 \tag{5}$$

where$i_{t_n}$is the number of applications in the MF AS at time $t_n + 0$; v_{t_n} is the BMAP state of the control process (input stream of applications) v_t at time t_n; $m_{t_n}$is the state of the semi-Markov control service process m_t at time $t_n + 0$.

Such a process is described by a multidimensional quasi-split Markov chain with a state space:

$$\{(0,1,\dots) \times (0,1,\dots,W) \times (0,1,\dots,M)\}, \tag{5}$$

and transient one-step probabilities of chain transitions ξ_n:

$$P(i,v,m,j,v',m') = \\ = P\{i_{n+1} = j, v_{n+1} = v', m_{n+1} = m'\}, v, v' \in \overline{0,W}, m, m' \in \overline{1,M}, \tag{6}$$

represented in the form of square matrices P_{ij} of size $(W+1)M$.

Nonzero matrices $P_{ij}$of one-step probabilities of chain transitions ξ_n describing the functioning of the MF AS have the form:

$$P_{0j} = V_j, j \geq 0; P_{ij} = Y_{j-1+1}, j \geq i-1, i > 0, \tag{7}$$

where the matrices $V_s, Y_s, s \geq 0$are defined using generating functions

$$V(z) = \sum_{s=0}^{\infty} V_s \cdot z^s = \frac{1}{z}(-D_0 \otimes I_M)^{-1}(D(z) \otimes I_M - D_0 \otimes I_M) \cdot \beta\big(-D(z)\big), \quad (4.28)$$

$$Y(z) = \sum_{s=0}^{\infty} Y_s \cdot z^s = \beta\big(-D(z)\big), \tag{8}$$

where$\beta\big(-D(z)\big)$ is the matrix generating function of the number of applications received by the MF AS during service requests for monitoring:

$$\beta\big(-D(z)\big) = \int_0^{\infty} e^{D(z)t} \otimes dB(t). \tag{9}$$

Stationary probability distribution $\pi(i,v,m)$ of the MF functioning as ξ_n can be represented in vector form:

$$\vec{\Pi}(z) = \sum_{i=0}^{\infty} \vec{\pi}_i \cdot z^i, \tag{10}$$

where$\vec{\pi}_i$is a vector sorted in lexigraphical the order of the arguments (v,m) of stationary probabilities $\pi(i,v,m)$. Finding the stationary probability distribution in vector form is possible from the equation:

$$\vec{\Pi}(z)\left(zI - \beta\big(-D(z)\big)\right) = \vec{\Pi}(0) \cdot (-D_0 \otimes I_m)^{-1} \cdot (D(z) \otimes I_m) \cdot \beta\big(-D(z)\big),$$

by finding the vector $\vec{\Pi}(0) = \vec{\pi}_0$ and then by recurrent formulas finding any given $\vec{\pi}_s$:

for$s = \overline{0, N-1}$:

$$\vec{\pi}_{s+i} = \left[\vec{\pi}_s - \sum_{i=0}^{s} \vec{\pi}_i V_s^i\right] \cdot \left(V_s^{i+1}\right)^{-1}; \tag{11}$$

for$s = \overline{N, MW-1}$:

$$\vec{\pi}_{s+i} = \left[\vec{\pi}_s - \sum_{i=0}^{N} \vec{\pi}_i V_s^i - \sum_{i=N+1}^{s} \vec{\pi}_i Y_{s-i+1}\right] \cdot (Y_0)^{-1}. \tag{12}$$

Algorithm for optimal performance management of MF AS

Within the framework of this work, when conducting modeling, we considered the following performance management strategies::

– implementing the choice to service an application from the next queue in one way or another, for example, first-come-first-served (FCFS), first-come-last-served (FCLS) and service-in-random-order (SIRO);

– implementing the ordering of applications according to their certain particular characteristics, for example, by the number of applications of the appropriate type that came to the MF AS during the last reconfiguration cycle;

– implementing the solution of optimization problems for controlled Markov chains using dynamic programming based on complex risk functions. These strategies allow us to find optimal solutions for the case of the observed application processing process in the MF AS. Finding strategies when describing QMS as a controlled Markov chain (with discrete observation at random times – the model is described by a semi-Markov chain) allows us to determine the quality of control through a loss functional of the form:

$$L_{[s,t)}[x,u] = \sum_{t=s}^{t} l_{x(t)x(t+1)} u(t), \quad (13)$$

where $l_{x(t)x(t+1)}$ is the loss of effect during the transition from state $x(t)$ into $x(t+1)$ taking into account the control $u(t)$. The expression for MF AS takes the form:

$$R_t^T[x,u;\delta] = M^{\delta}\left\{\sum_{t=s}^{T} l_{x(t)x(t+1)} u(t) / x_t, u_t\right\}, \quad (14)$$

with the strategy price $\Phi_t^T[x,u] = \inf_{\delta} R_t^T[x,u;\delta]$ with an additive loss functional has the form:

$$\Phi_t(x) = \min_{u \in U_x}\left[l_x(u) + \sum_{y \in X} p_{xy}(u) \Phi_{t-1}(y)\right]. \quad (15)$$

With the continuous nature of observations, the solution of the problem requires the compilation and solution of optimization equations based on differential equations linking the price of state change with optimal strategies:

$$-\frac{d\Phi_t(x)}{dt} = \min_{u \in U_x}\left[l_x(u) + \sum_{y \in X} a_{xy}(u) \Phi_t(y)\right], \quad (16)$$

where $\Phi_t(x)$ and $\Phi_t(y)$ are rates strategy at time x and y.

The algorithm for choosing the optimal management strategy is implemented in a finite period of time by increasing the throughput of processing applications through one functional channel according to expressions (13-16).

Simulation results and conclusions

The following performance management and reconfiguration strategies have been modeled and investigated:

– SIRO (in random order);

– according to the maximum of accepted tasks during the planning period:

$$\delta = \max_{n \in N} n, \quad (17)$$

where n is the number of applications received at the input of the MF AS during time T.

The reconfiguration time is generally distributed according to some law F_{μ} with intensity (performance) μ_M which is usually exponential. The reconfiguration performance of the service device μ_M decreases depending on the stage of reconfiguration. A power function can be considered as a function of decreasing reconfiguration performance:

$$\frac{1}{\mu_{j,k}} = \frac{\kappa_j}{\mu_{j,k-1}} = \frac{\kappa_j^k}{\mu_{j,0}}, \quad (17)$$

where $\mu_{j,k}$ is the service performance of the j-th tasks stream after the k-th reconfiguration stage; κ_j is the performance reduction coefficient; $\mu_{j,0}$ is the service performance of the stream at the initial time.

Figure 3 shows graphs of changes in the average service time for two types of requests for controlled (a) and random (b) selection of the flow type for performance changes.

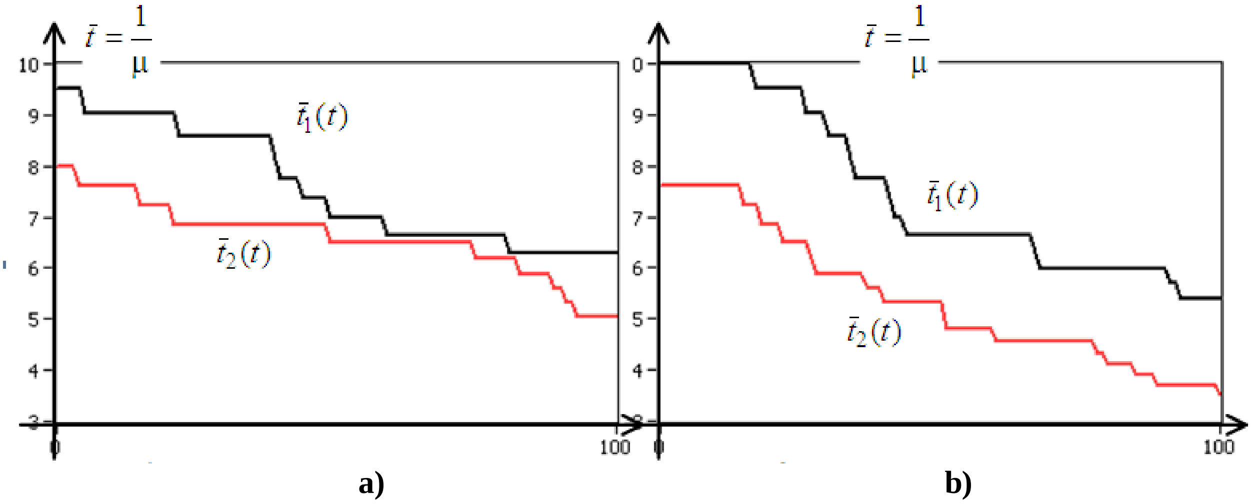


Figure 3 – Graphs of the dependence of performance changes by query types: a) controlled performance changes, and b) random performance changes

To conduct experiments, a simulation model has been developed "A simulation model of a performance-controlled QMS: Manage_SMO.vi" (Figure 4). The simulation model is based on the LabVIEW environment and allows us to manage the flow of applications, the initial performance of the service device by type of applications and choose the discipline of performance management.

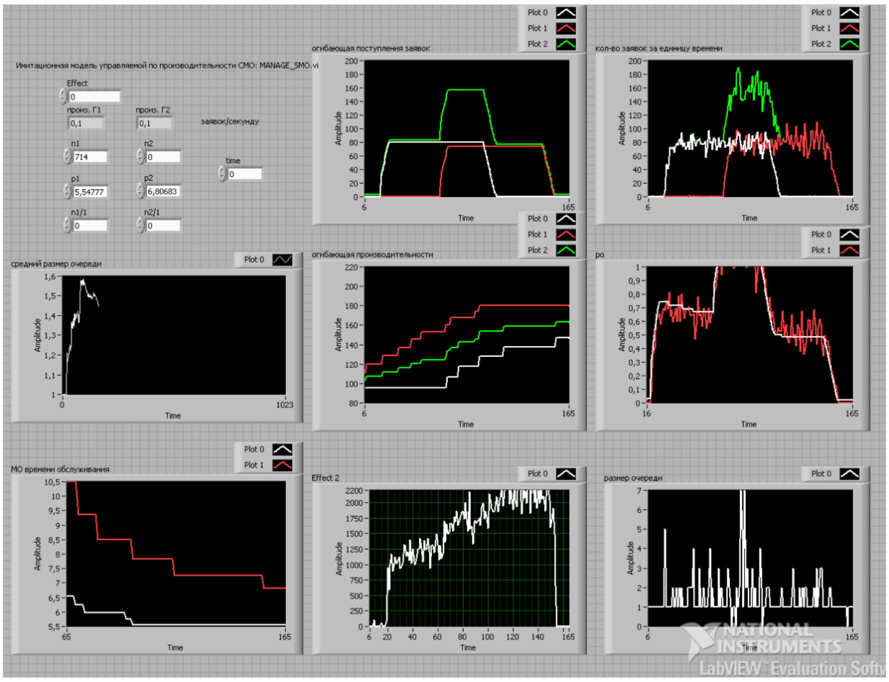


Figure 4 – Simulation model of a performance-controlled QMS (main interface)

The paper examines two disciplines of task maintenance:

– FIFO (first come – first served);

– FCLS (first come – last served).

The results were compared by the magnitude of the effect:

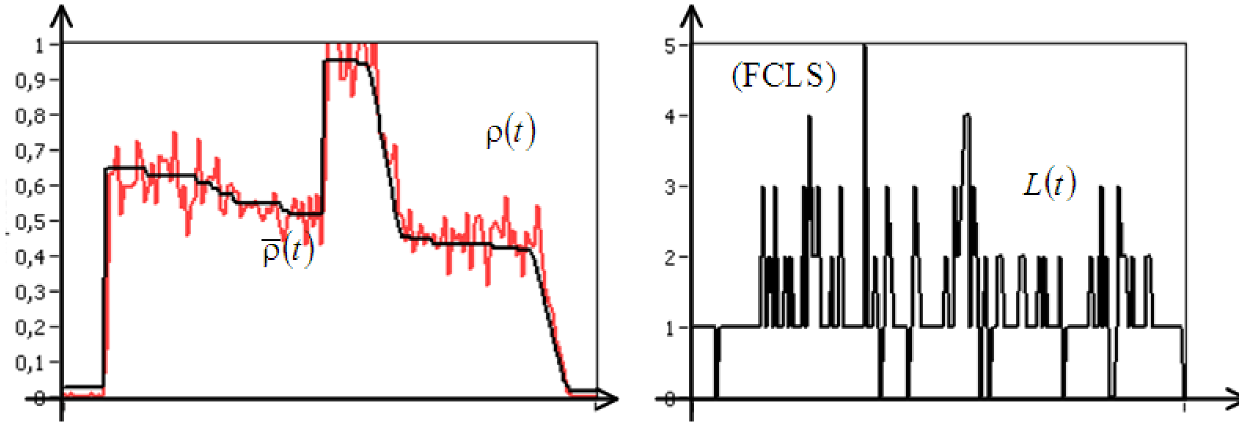
$$E = \sum_{i=0}^{N} \xi_i(t_i), \tag{18}$$

where $\xi_i(t_i)$ is the magnitude of the effect of processing the *i*-th request, *N* is the number of processed requests during the planning period.

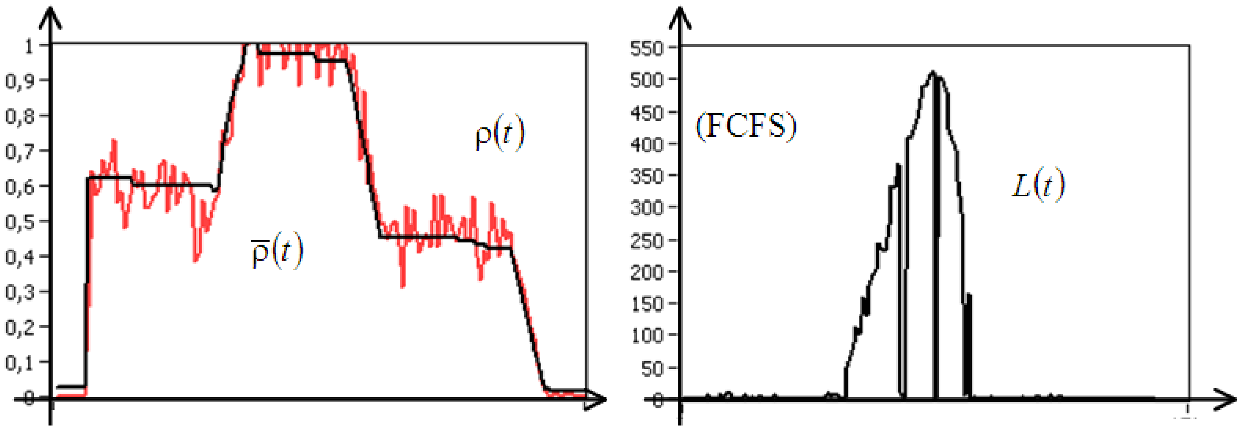
Figure 5 shows graphs of changes in the relative throughput $\rho(t)$ and $\bar{\rho}(t)$, as well as the queue size $L(t)$ for the simulated state:

$$\rho(t) = \frac{\Lambda(t)}{\bar{\mu}(t)}, \bar{\rho}(t) = \frac{\bar{\Lambda}(t)}{\bar{\mu}(t)}. \qquad (19)$$

Figure 6 shows graphs of changes in the effect of processing tasks in the QMS from time to time.

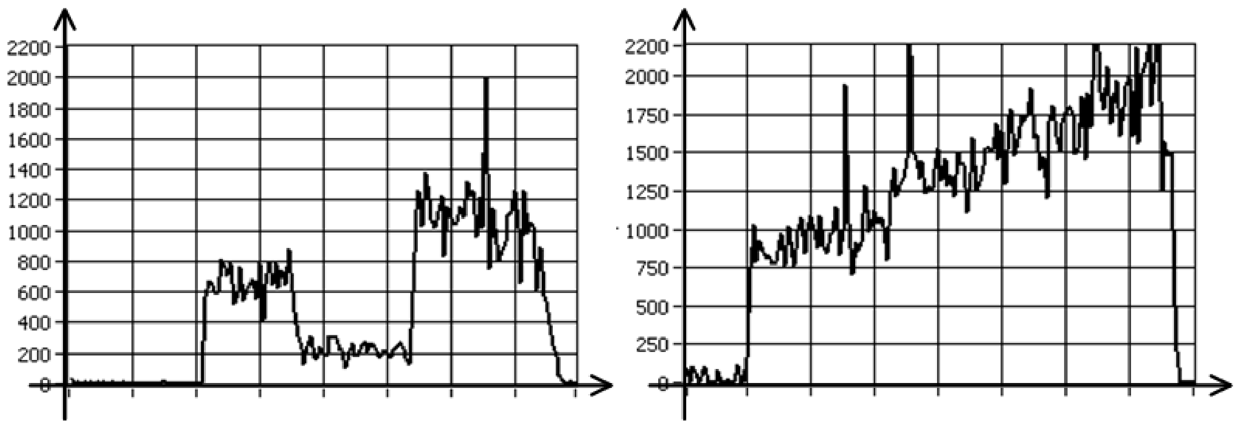


a) FCLS relative throughput
b) FCLS queue size



c) FCFS relative throughput
d) FCFS queue size

Figure 5 – Graphs of changes in relative throughput and queue size from time to time for FCLS and FCFS



a) FCFS
b) FCLS

Figure 6 – Graphs of changes in the effect of processing tasks in the QMS from time to time

The results show that changing the discipline of task maintenance significantly changes the effect of task maintenance in the CFR. Changing the performance management strategy also makes it possible to achieve a significant reduction in the risk functionality. The direction of further research is the study of the discipline of service based on the solution of optimization problems, the construction of optimal performance management schemes, modeling of multi-channel QMS.

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