Simulation application for evaluating of efficiency of mining systems automatization

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Abstract: The fact that application of simulation is expedient for concrete proposal selection is shown in the article after analysis of existing proposals of mine works automation. To solve this task, models of mine technical systems were developed on queuing theory base with software implementation on a specialized simulation language GPSS World. Methods of mine technical systems automatization efficiency estimation, which is based on the minimum labor input criterion of cycle in entered mine-geological conditions is proposed. As example task solution of selection of efficient automatization mine technical system variant with use the proposed method. In the article conclusion we showed prospects of further work which is reduced to creation of specialized software product for engineer.

Key-Words: - Automatization, mining systems, simulation, queuing system

1 Introduction

An analysis of achievements of the leading companies in the field of automatization of underground mining works: Atlas Copco, GIA Industry, Sandvik (Sweden), Caterpillar (USA), Dyno Nobel (Norway), Normet (Finland), PAUS (Germany), Siamtek (Canada) [1,2] showed that all proposals has only one decision. It is enter of automated equipment as: drilling rigs, loading machines, anchor drilling rigs, chargers. It is human-adapted technologies. However, many operations cannot be performed automatically such as bafring-down, communications build-up, connection of detonators, etc. As a result, the effect of automatization can be lost. We face with a task of evaluating of input of automated processes proposals in mining systems.

Task is complicated by arrangement decisions multivariance, diversity of automatization processes proposals and random kind of technological operations because of external environment influence, equipment failures, etc. Math modeling is used to solve such tasks. Often we have to take a serious simplification and assumptions to show the dynamics of the modeled system because analytical and numerical methods do not allow us to describe some parts of mining system and interaction between them. Frequently it lead to huge differences between simulating results and real system behavior. Simulating with showing of mining technological system dynamics displayed on computer in some algorithm, which simulates action is the most effective 3-7.

Simulation is advisable for mining technical systems computer researches and automatization effectivities evaluation [8-12].

2 Engineering of mining technical systems conceptual model

Majority of operations in mining are discrete with a finite number of variables. These operations include beginning and end of drilling, loading and unloading of coal, the beginning and end of the combine, and others.

Conceptual model which showing the mining systems was developed. This model is presented in the form of a "black box" with managed and unmanaged inputs (Fig. 1).

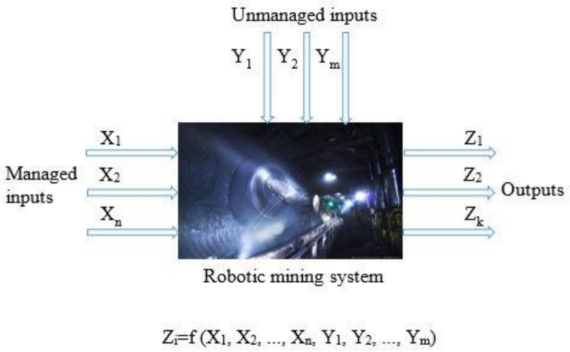

Fig. 1 conceptual model of mine technical system

Constructive and technological parameters are attributed to managed inputs (X_1, X_2, …, X_N): the number of tunneling machines, blast holes quantity and depth, duration of technological operations, equipment type and characteristics, etc. Unmanaged inputs (Y_1, Y_2, …, Y_M) are attributed to physical-mechanical properties of adjacent strata, technical parameters of excavation. Output of the model (Z_1, Z_2, …, Z_K) is laboriousness and tunneling cycle average duration.

The tunnel equipment set is represented as a system **T**, which moves in massif between **A** and **B** points (Fig. 2).

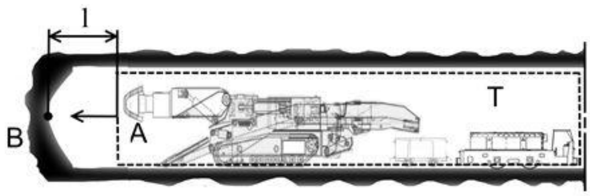

Fig. 2 excavation scheme

At the end of the excavation works system moves at some step 1 to the last point B. Step, that system has to move before next cycle will start, is a request on moving of excavation machines to the last point. Quantity of requests decreases with moving of tunneling equipment.

For service of request a set of equipment must execute sequence of operations: rock excavation, rock lading and roof supporting.

Time of each operation depends from many determinate and random factors. Determinate factors are a mine working cross-section and length, blast-hole depth and number, excavation machines number. Random factors are process operation duration, solid physical and mechanical properties, etc. However, generally operation duration is determined by random probability distribution function of service duration by equipment unit.

3 Formalization of conceptual model

For formalization of conceptual model used a queuing theory [13-16], and requests consistently pass through the facilities: for example, drilling rig, loader and anchor drilling rig. Service time is random.

Mining system models were developed as closed multi-channel and multi-phase queueing networks, where equipment next cycle readiness moments is a request. Requests service is a delay on excavation processes cycle time in facilities simulating appropriate equipment. Technological process duration shown by entering of random delay in facilities. The number of requests incoming on system input sets the excavation length.

$$m = \frac{L}{l_c} \quad (1)$$

where L – excavation length, l_c – scraper working progression for a cycle.

In real conditions equipment can starts the next cycle after the end of previous, moreover time interval between cycle start and end depends on random factors. This peculiarity is displayed in model by feedback enter, whereby next request enter on queuing network's input after previous request appearance on network's output. In this way, feedback forms input request stream. Request appearance rate is equal to request service rate, therefore input queue do not forms. Research task reduces to total time of request service and degree evaluation of equipment use.

Average excavation cycle duration calculated in model as sum of random amounts:

$$t_ц = (\sum_{i=1}^{m} t_{\mathrm{p}i} + \sum_{i=1}^{m} t_{ni} + \sum_{i=1}^{m} t_{ki}) / m \quad (2)$$

where t_{pi}, t_{ni}, t_{ki} – random request service time value by facilities simulating equipment for rock destruction, rock loading and roof supporting at the i-cycle.

Average laboriousness of excavation cycle calculated as:

$$T_ц = \frac{\sum t_{pi} n_{pi} + \sum t_{ni} n_{ni} + \sum t_{ki} n_{ki} + \sum (t_{pi} t_{ni} t_{ki}) n_{bi}}{m} \quad (3)$$

where $t_{pi}\,n_{pi}$, $t_{ni}\,n_{ni}$, $t_{ki}\,n_{ki}$, $t_{вi}\,n_{вi}$ – laboriousness of rock destruction, rock loading, roof supporting and ancillary works at the *i*-cycle, n_{pi}, n_{ni}, n_{ki}, $n_{вi}$ – number of people, engaged in appropriate processes.

Depending of the excavation conduct mining system described by double-channel multi-phased closed queueing network (rock blasting method) or dual-circuit closed double-channel multi-phased queueing network (mechanical method). Request in models is an equipment readiness moment to the next excavation cycle, facilities in model is an excavation machines serving requests in random time. Requests entrance rate determined by its servicing speed (Fig 3, 4).

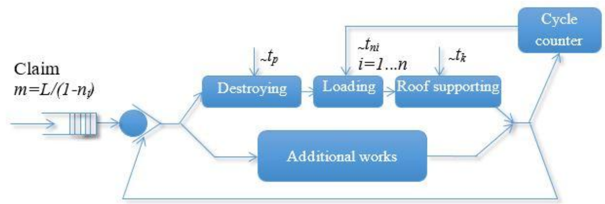

Fig. 3 mining system model (rock blasting method) as queueing network

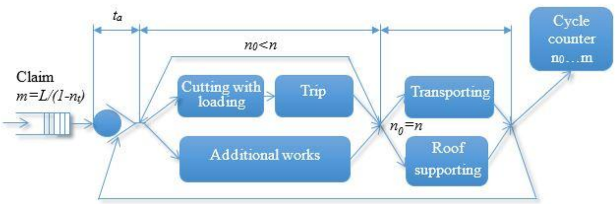

Fig. 4 mining system model (mechanical method) as queueing network

With using a rock blasting method on the one channel request extends through drilling rigs, loaders and anchor drilling rig (Fig. 3). Additional works displayed on the other channel. In the end of excavation cycle served request is fixed by cycle counter and allow an entrance to system input for unserved request. Request service time represented as a function:

$$t_p = f(n_{bh}, l_{bh}, P^d, f_h, S, n^d);$$
$$t_n = f(S, f_h, l_{bh}, \eta, P^l, n^l, k_l V_{hv}); \quad (4)$$
$$t_k = f(S, l_e, n_r)$$

where t_p, t_n, $t_к$ – random rock destruction, rock loading, roof supporting time values; S – tunnel profile; f_h – rock hardness coefficient, n_{bh} – the number of blast-holes for a cycle; l_{bh} – blast-hole length; η – blast-hole use coefficient; k_l – rock loosening coefficient; P^d, P^l – drilling and loading machines efficiency; n^d, n^l – the number of drilling and loading machines; $V_{h.v.}$ – haulage vehicle volume; l_e – excavation length of roof support in one cycle; n_r –number of laborers involved in roof supporting.

For accounting of time changing in loader trip with scraper working progression, system supported by the cycle counter which increase transporting time depending on excavation cycle number:

$$t_{ni} = f(l_t), i = (l, m) \quad (5)$$

where l_t – rock transporting trip length; m –the number of required for excavation.

Requests consequentially pass through two interconnected queueing networks in model of mining system which shows process of excavation (Fig. 4). The first queueing network contains facilities, simulating excavation combine, rollback machine and equipment for communications increasing, the second one – facilities, simulating roof supporting mechanism and equipment for materials transporting. In first network request service lasts in random interval

$$b = f(n_s, R, f_h, V_{hy}) \quad (6)$$

where n_s – the number of sinkers; R – combine efficiency.

Request leaves the system after inequality adequacy: $n_0<n$, where n_0 – rollback machine completed transporting rounds count; $n=V/Q$ – rounds count, required for complete rock transporting (V – destructed rock value, Q – rollback machine value). If $n=n_0$, then request enter to the second queueing network. After the time $c=f(S, f_h)$, request becomes executed. Cycle counter fixes next cycle, then next request enter becomes available. Requests incoming interval a is equal to the time of request servicing by both queueing networks $a=(b+c)$.

4 Software implementation models

As mining technologies models program realization instrument the most suitable solution is GPSS World language [17-22], since nowadays it is most effective and widespread software for complicated discrete systems PC-simulating, and successfully used for mining queueing network simulating [23].

Using GPSS World had been developed typical program organization unit (POU) for mining models constructing: "cutting with lading", "drilling", "charging", "lading", "roof supporting". POU "cutting with loading" represented on Fig. 5.

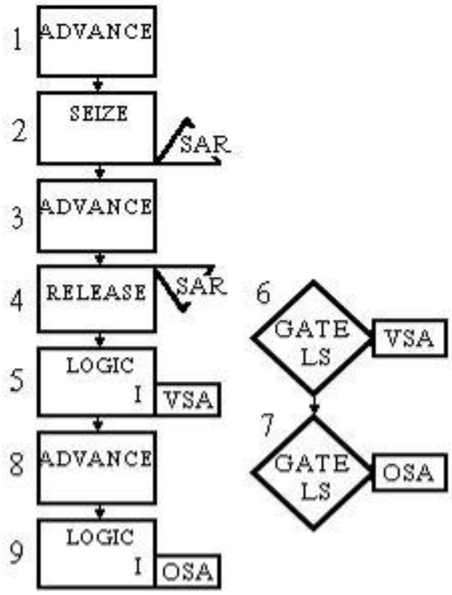

Fig. 5 block diagram of POU "Cutting and loading"

In block 1 (ASSIGN), necessary to set the rollback machine required rounds to destroyed rock transporting:

$$n = \frac{Q}{V_{h.y.}} \quad (7)$$

Delay in block 2 (ADVANCE) simulates rollback machine coming to a combine for loading in time:

$$t_{a.c.} = \frac{L}{v_{r.m.}} \quad (8)$$

where $v_{r.m.}$ – rollback machine speed.

A combine functioning for a time simulated by three blocks: SEIZE – combine is not available, ADVANCE – combine cutting part processing scraper working on the specified program, RELEASE – combine is available. Combine processing time is:

$$t_c = \frac{T_d l_c S}{n_w} \quad (9)$$

where T_e – excavation laboriousness, L_c – forwarding of scraper working for a cycle, n_w – the number of mineworkers.

After rollback machine loading it drives off from combine to unloading place, this operation reflecting in block 6 (ADVANCE) with time:

$$t_{d.c.} = \frac{L}{v_{r.m.}} \quad (10)$$

In block 7 (LOOP) going value n_0 decreasing on 1 and equality n_0=0 check. If condition not satisfied, then transact transfers to block 2 simulating empty rollback machine coming to combine for lading.

Developed POU allow creating of mining systems models, which may be used for researches of automatization efficiency evaluating; selection of rollback machine bucket optimal volume; maximum length of rock mass transporting way with excavation cycle efficiency limitation; selection of rollback machine volume, etc.

With use of computer engineering in GPSS World syntax had been developed simulation models of mining systems. Queueing networks characteristics define by the model structure:

1) Multi-channel: $N_k = N_s$, where N_k – queueing network channel count, N_s – segment count in model flowchart.

2) Multi-phase: $N_f = N_n$, where N_f – queueing network phases count, N_n – facilities reflecting blocks count in model flowchart.

3) Insularity: after passing all operation simulating blocks request return to block, reflecting excavation cycle start.

5 Assessment methodology and example of using

Method of mining systems automatization efficiency evaluation on developed simulation models with certain mining and geological conditions on cycle laboriousness minimum criteria is offered.

In existing mining system model a blocks subset $a \in B$ displaying technological operations executing are allocated, and technological operations time is changed due to offering of automatization option. For example, in block, which simulates combine cutting part control, time reduced on 20-30% due to automatic scraper working processing and cross-section bust exclusion.

For every variant with cycle time limit keeps a condition

$$\sum_{i=1}^{m} t_i < t_{ave} \qquad (11)$$

where t_i – time of i-operation; t_c – cycle time, m – excavation cycle operation count, t_{ave} – general average cycle duration of mining system automated variants.

In model a blocks subset $b \in B$ with operations required human involvement are allocated. Humans count (n_i) and processing time (t_i) for *i*-operation are introduced. In model laboriousness of *i*-operation is a multiplication $n_i t_i$.

For every variant excavation cycle laboriousness value estimated by equation

$$T_i = \sum_{i=1}^{m} n_i t_i \qquad (12)$$

Then choose a variant with $T_i = min$ and check a condition (1).

As an example we give solution of task which is to choose effective variant of mining system automatization with proposed method use.

Research object is a mining systems simulation models with set of different equipment, which produced in Russia: drilling rigs “1 SBU-2K” and “YBSH-532”; blasting excavation complex “Sibiri-2TM”; combine “KP-25”; rollback machines “MPKT”; lading machine “PNB-3D2”; electric locomotive “AM-8D”, wagon “VPK-10”; trolley “VG-3,3”; tubbing placer “TY-3r”. Seven alternative mining systems variants with different sets of equipment were considered for same mining and geological conditions.

Simulate modelling has been done for excavation with length 600 m, overall rock section 29.05 m^2, roof supporting with metallic frame lining “SVP-33” on rock with rock-hardness ratio 6 by professor M. M. Protodyakonov scale.

In the mining system automatization efficiency evaluation on simulation models suitable solutions of technological operations automatization has been chosen and results of simulating experiments robotic and existed technologies has been compared. As a result has been received series of recommendations and statements.

In mining systems has been suggested to mount on drilling rigs the drilling bar positional steering and rotation-supply speed automated control system. The system supports steering of drilling bar on variable blast-hole scheme, scraper working drilling with manipulators based on reprogrammable blast-hole position scheme with bar space-control and supply bar control. Automated guidance with drilling bar program eliminates blast-holes marking operation and reduces bar transposition time from blast-hole to blast-hole. An opportunity of several robots service by one operator allows reduce the number of people, employed in drilling bar control.

For explosive blast-hole charging has been suggested to apply a self-propelled (hinged) charge machines with remote control which extra stocked by charging hosepipe emitter and charging process control panel. It allows reduce blast-hole charge time and workers count.

For lading automatization has been suggested to set up a distance or automatic load control system on loaders. It allows carriage rock lading by loader in ventilation time of scraper working. Lading time reducing on 10-15% is possible due to stabilization of load cycles and operator’s personal errors exclusion.

Metallic frame roof supporting has been suggested to substitute on anchor bracing with automated self-propelled (hinged) anchor drilling rigs use. It allows reducing roof supporting process time and exclusion anchor elements set up operation.

With combine use in mining system has been suggested automatic control of it’s operating part. Owing to automatic scraper working processing by harvester shaft, cross-section bust is excluded, as a result scraper working destroying time can be reduced on 20-30%.

Using developed POU existing and with suggested solutions mining systems models has been created.

Due to simulation excavation cycle duration and laboriousness has been defined for every variant. Data is displayed in diagram on Fig. 6.

Mining excavation technologies simulating by dint of suggested method allows making a preliminary evaluation of several technological variants and choose more effective.

By the cycle duration and laboriousness minimum criteria according to shown method preferable mining system automatization variant have a following equipment set: YBSH - 532; PNB-3D2; AM-8D; VG-3,3; SVP-33 (variant 6). Operation automatization in this system allows reduce working cycle time on 27-47%, laboriousness on 65-84%.

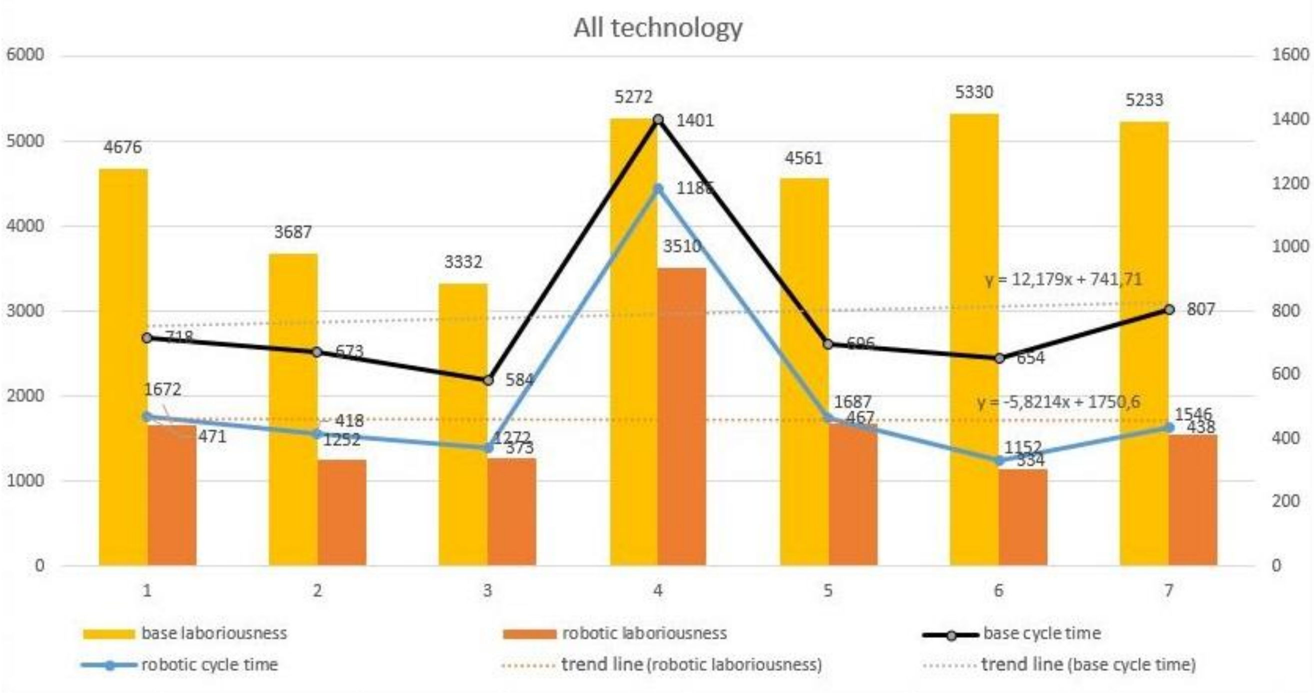

Fig. 6 excavation cycle duration and laboriousness diagram

6 Conclusion

Simulating with showing of mining systems via queuing theory, followed by software implementation on a specialized simulation language GPSS World allows through experiments to evaluate the effectiveness of the proposed method of proposals for automation of operations.

Developed simulation models will take part in base of software product of computer mine technical systems simulation. The product will compete with systems like Datamine, Micromine, Mineframe, Surpac, Vulcan owing to:

- registration of mining works dynamics
- possibility of random period of technological operations execution accounting and equipment interaction in scraper works space
- formalized comparison and selection of optimal technical and organizational options for mining
- evaluation of technologies automatization efficiency

Implementation of the software will enable engineers with little experience in modeling, investigation and optimization of mining systems to solve complex engineering problems to assess the effectiveness of automation and technology choice of the optimal variant, which eventually will reduce the costly risks during the design phase of the mine.

References:

[1] V. Konyukh, Simulation of mining in the future, *Proceedings of the IASTED International Conference on Automation, Control, and Information Technology - Control, Diagnostics, and Automation, ACIT-CDA*,Novosibirsk, Russian Federation, 2010, pp. 1-6, Code 89101.

[2] V.N. Oparin, World experience in automation of mining operations at the mines. *Publishing house Siberian Branch of the Russian Academy of Sciences*, Novosibirsk, Russian Federation, 2007 (in Russian).

[3] A.G. Bagdasaryan "System Theoretic Viewpoint on Modeling of Complex Systems: Design, Synthesis, Simulation, and Control" RECENT ADVANCES in COMPUTATIONAL INTELLIGENCE, MAN-MACHINE SYSTEMS and CYBERNETICS, WSEAS Press, Cairo, Egypt, December 29-31, 2008, pp. 248-253.

[4] S.M. Radu, G. Dolea, R. Cretan "Modeling and Simulation of coal winning process on the mechanized face", RECENT ADVANCES in CIVIL and MINING ENGINEERING, WSEAS Press, Antalya, Turkey October 8-10, 2013, pp. 30-35.

[5] F. Adriana, B, Sorin "Software engineering used in simulation of Flexible Manufacturing Systems", ADVANCES in COMPUTER

SCIENCE, WSEAS Press, Prague, Czech Republic, September 24-26, 2012, pp. 304-309.

[6] M. Gallo, M. Di Naro, L.C. Santilo "A simulation based approach to support risk assessment", RECENT ADVANCES in AUTOMATIC CONTROL, MODELLING and SIMULATION, WSEAS Press, Morioka City, Iwate, Japan, April 23-25, 2013, pp. 86-92

[7] R. Wei, S. Zhang, W. Karunasena, N. Sivakugan, H. Zhang "Blast Simulation in Underground Mines Using the Combined Finite-Discrete Element Method", Proceedings of the 7th WSEAS International Conference on Simulation, Modelling and Optimization, WSEAS Press, Beijing, China, September 15-17, 2007, pp. 256-261.

[8] A. Andrei and S. Dinescu, Modeling And Simulation of The Complex Mining Production Systems For Coal Extraction, *Recent Advances in Civil and Mining Engineering, WSEAS Press*, Antalya, Turkey, 2013. pp. 248-255.

[9] S. Hubalovsky, Modeling and Computer Simulation of Static, Dynamic and Feedback Systems as Tool of Development of Logical Thinking, *International Journal of Mathematics and Computers in Simulation. North Atlantic University Union NAUN*, Vol.8, 2010, pp. 276-285.

[10] J.D. Rairan, Robot Path Optimization Based on a Reference Model and Sigmoid Functions. *Int J Adv Robot Syst*, 2015, 12:19. doi: 10.5772/60063.

[11] C. Rossi, L. Aldama and A. Barrientos. Simultaneous Task Subdivision and Allocation using Negotiations in Multi-Robot Systems, *Int J Adv Robot Syst*, 2015, 12:16. doi: 10.5772/59880.

[12] G. Guizzi, T. Murino and E. Romano. A Discrete Event Simulation to model Passenger Flow in the Airport Terminal. *Mathematical methods and applied computing, vol. 1, WSEAS Press*, Athens, Greece, 2009, pp. 427-434.

[13] L. Kleinrock, *Queueing theory*, Moscow, Russian Federation, 1979.

[14] A.N. Starodubov, The generalized structure of model of a power technological complex in the form of systems of mass service. *Separate release of the Mining Informational and Analytical Bulletin (Scientific and Technical Journal)*. Moscow, Russian Federation, 2013, Vol.OB6, pp. 145-151 (in Russian).

[15] V.V. Sinoviev, Modeling multi face gallery tunneling using a simulation approach, *Mining Informational and Analytical Bulletin (Scientific and Technical Journal)*, Moscow, Russian Federation, Vol.SV6, pp. 138-144 (in Russian).

[16] A.M. Lou and A.D. *Kelton Simulation modeling and analysis*, Sankt-Petersburg, Russian Federation, 2004 (in Russian).

[17] V.V. Devytkov, *The methodology and technology of simulation studies of complex systems: current status and prospects of development*. Moscow, Russian Federation, 2013 (in Russian).

[18] V. Okolnishnikov, S. Rudometov, and S. Zhuravlev, Simulation environment for industrial and transportation systems, *Proceedings of the International Conference on Modelling and Simulation*, Prague, Czech Republic, 2010, pp. 161-165.

[19] A.N. Starodubov, V.V. Sinoviev and M.U. Dorofeev, Simulation of the technological complex for deep coal processing. *Coal*, Moscow, Russian Federation, Vol.2, 2010, pp. 8-12 (in Russian).

[20] V.A. Poletayev, V.V. Sinoviev, A.N. Starodubov and I.V. Chicherin, *Design of the computer integrated production systems*, Kemerovo, Russian Federation, 2011 (in Russian).

[21] V.V. Sinoviev, A.N. Starodubov, A.E. Majorov, and V.N. Kochetkov, Simulation approach in modeling complex in Energy coal processing. *Monthly production and mass magazine Energetik*, Moscow, Russian Federation, Vol.1, 2013, pp. 26-29 (in Russian).

[22] Chromy, M. Kavacky, J. Diezka and M. Voznak, Markov Model M/M/m/∞ in Contact Center Environment, *Recent Researches in Communications and IT, WSEAS Press*, Corfu Island, Greece, 2011, pp. 180-185.

[23] V.V. Sinoviev, V.V. Okolnishnikov, A.N. Starodubov and M.U. Dorofeev, The Experience of Discrete Event Simulation Robotic Technology of Mining. *Proceedings of the 19th International Conference on Systems (part of CSCC '15) Recent advances in systems*, Zakynthos Island, Greece, 2015, pp. 499-502.