Development of simulation model for the site of mining and transportation of ore of the mining and processing plant

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Abstract. This paper presents the results of simulation modeling of the mining and transportation of ore at a mining and processing plant. A hybrid multi-agent-simulation approach is used to analyze the bottlenecks of the simulated process.

1. Introduction
The work of Alenichev V.M. and Sukhanov V.I. [1-2] and also [3-4] is devoted to the development of problem-oriented decision support system (DSS) and the use of geographic information systems in the design and planning of mining at open pits. The experience of using GPSS discrete-event simulation modeling to mining and processing production is presented in [5], modeling of the organization of ore flow and cost management of a mining enterprise is presented in [6]. The use of the AnyLogic simulation system for the task of analyzing mining in an underground potash mine is presented in [7]. The multi-agent approach was used in the problem of optimizing solutions in a multi-agent system for improving the quality of iron ore sinter [8] and in designing and pre-project analysis of mine robot-technical systems [9].

For the task of modeling the site of mining and transportation of ore of the mining and processing plant (GOK), data of Lebedinsky GOK is taken, which is in open sources. The task deals with the extraction and transportation of minerals to the processing plant.

At present, many hybrid models of multi-agent dynamic processes have been developed, such models include the network of needs and capabilities Skobelev P.O. and Wittih V.A. [10], hybrid approach implemented in the AnyLogic system [11]. In this work, we use the model of the multi-agent resource conversion process (MPPR) and its software implementation in the form of a dynamic situation simulation system Bpsim.MAS [12] and the method for analyzing bottlenecks [13] for modeling mining and processing production. The work [5 -6] is devoted to the development of problem-oriented decision support systems in the design and planning of mining at quarries.

2. Objects of research and experiment technique
For the calculation of queuing networks (SMO), the theory of probabilistic networks is used, which is based on Markov and semi-Markov processes. Finding bottlenecks in the network is an important aspect of analyzing its work. The network node creates a bottleneck which load factor $U_k$ approaches unity. From the point of view of the application of operational analysis of probability networks to the model of MPPR in the analysis and elimination of bottlenecks, it is necessary to analyze the following parameters: 1) the utilization rate of the node (the operations and agents correspond to nodes, it is also necessary to analyze the utilization rate of the means); 2) the average duration of the application in the...
queue to the operation, the agent (the size of the queue of applications to the operation, the average queue of applications to the agent rule); 3) the attendance rate of the node and the average duration of processing requirements in the node. Similarly, the queue evaluates the average state of resources (both input and output in relation to a particular operation or agent rule).

Consider the process of mining and transporting ore. Transportation is carried out: from the bottom to the transshipment sites - by road, from the transshipment sites to the processing plants - by rail. The transportation distance from the quarry to the processing plant is 14 km, for trains. Railway transport - 25 trains consisting of: 25 electric locomotives, 50 motor-cars, 225 dump cars. Road transport: BelAZ - 50 pcs. The length of transportation by road is 1.2 km. Agents in the model are used to redistribute applications, collect and analyze statistics on bottlenecks. The number of excavators for mining and reloading - 27 pcs.

3. Experiments
The number of trains and vehicles is the key parameters in our task, through their variation and diagnosis of bottlenecks - queues for loading and transportation. General data for experiments: eight working hours shift is simulated. The main results of the experiments are summarized in a table.

| Compositions (Comp.) | Belaz Minqueue ofBelaz $U_k$ Belaz The average of Belaz $U_k$ train comp. The average of train comp. Labor for loading for railway trains, t Final production, t |
|----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| 25                   | 50 10                  | 69% 14,56 0           | 86% 2,8               | 34263                  | 26190                  |
| 25                   | 40 1                   | 86% 4,99 0            | 86% 2,8               | 34263                  | 26190                  |
| 32                   | 38 1                   | 87% 4,13 1            | 76% 6,03              | 29462                  | 30555                  |
| 29                   | 37 0                   | 88% 3,76 0            | 83% 3,89              | 29462                  | 29682                  |

4. Conclusion
A multi-agent simulation model was developed for the extraction and transportation of Lebedinsky GOK to diagnose bottlenecks. Because of the conducted simulation experiments, the bottlenecks of the processes were diagnosed and recommendations for their elimination were made. As part of the logistics process model, recommendations were made on the distribution of railroad trains (29 trains) and vehicles (37 BelAZ).

5. Acknowledgment
The work is supported by 211 acts of the Government of the Russian Federation, agreement No. 02.A03.21.0006.

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