Identifying factors which induce transitive processes in blasthole drilling in structurally complex rock masses

AS Regotunov*, RI Sukhov and DA Grashchenko
Institute of Mining, Ural Branch, Russian Academy of Sciences, Yekaterinburg, Russia
E-mail: *pochta8400@inbox.ru

Abstract. A new methodological approach is proposed to identify the effect of changing conditions on the performance of drilling operations in open pit mining. Drilling is presented as a subsystem of the more general system called a “mine”, the stability of which is affected by multiple factors. This paper describes the first stage of implementing the proposed methodological approach to identify the blasthole drilling factors that govern the transitive processes as necessary reactions of the “drilling operations” subsystem when adapting to the changing operating conditions. The revealed main factors which affect the “drilling operations” subsystem stability at the level of blasthole drilling at the pilot site of a mine are presented.

1. Introduction
A mine as a system evolves in the continuously changing conditions of the external and internal environments. These changes always influence all critical subsystems possessing a certain structure, including the subsystem “drilling operations”. The elements of the subsystems are personnel, rock mass, blasting technology drilling machines and drilling tools. Development of the subsystem is accompanied with internal discrepancies which are overcome via transitive processes as the necessary actions within implementation of innovative solutions on adaptation of the “drilling operations” subsystem to the changing conditions of a mine [1]. The main transitive processes are: modification of drill bit design, drilling method and mode to fit specific rocks; improvement of drill design and drilling process control; adjustment of rock properties; perfection of maintain and repair. The instability can be caused in the development of the “drilling operations” subsystem by [2]: introduction of technological innovations; enhancement of technological performance in the conditions of gain in productivity; modernization of actually used technologies to prevent undesirable external impacts (nature, economy, society, etc.); changes because of production cutback due to stagnation or product ramp-down.

2. Drilling process analysis
The largest mining and processing plant are already faced with some problems connected with unstable development of the “drilling operations” subsystems mainly due to the undesirable external and internal impacts. As the depth of the open pit mines is increasing, the sizes of the working zones and sites on benches reduce while the total length of the mining front grows. This results in the decreased number of blastholes per blocks, increased number of blocks subjected to simultaneous drilling operations and in the frequent distance replacement of drilling machines. Drilling machines in operation in open pit mines insufficiently fit with strength characteristics of rock mass and ore bodies,
and with the required production outputs; regarding physical and mechanical properties of structurally complex rock mass, drilling modes fail to promote maximum capacity of drills and highest endurance of roller bits. As a consequence, the cost of drilling tools can reach 70% of total drilling cost, especially in strong and extremely strong rocks [3]. Moreover, the lack of the reliable predictive information on the behavior of rock mass in drilling planning often leads to the wrong choice of roller bits and to the higher wear of drilling machines and tools. The unbalance in the functioning of the “drilling operations” subsystems in mines in the present economic reality contributes to the common employment of obsolete and worn drilling machines [4]. Under the circumstances, the safe, efficient and stable development and performance of the “drilling operations” subsystem in a mine requires implementation of the comprehensive analysis of the production activities to reveal efficient transitive processes and regimes. The complexity of selecting transitive processes suitable to the changing environment consists in the deficiency of the objective information on the integrated effect of many various factors (see the Table 1) on the critical indicators of the “drilling operations” subsystem performance, namely, drilling rate, capacity, energy content and cost.

**Table 1. Governing factors of transitive processes in “drilling operations” subsystem**

| Factors               | Description                                                                 |
|-----------------------|-----------------------------------------------------------------------------|
| External factors      | Independent of production activity of a mine                                |
| Socio-economic        | Inflation, social instability, tax reform, changes to legislation, crisis phenomena, market factors |
| Geotechnical          | Overburden pressure, high mining rate, open pit mine design                 |
| Geological            | Physical and mechanical properties, structure (jointing, rock mass quality, strength) and texture of rock mass, hydrology, useful component content |
| Safety requirements   | Hygienic and sanitary conditions, legal requirements, safety standards in industry |
| Internal factors      | Dependent of production activity of a mine                                 |
| Management            | Lack of knowledge on market situation, managerial inefficiency, condition of means of production (drilling machines) |
| Technology            | Blasting pattern design (length and diameter of holes, minimum burden, distance between holes in row, spacing between rows), operating conditions of drilling machines, capacity of drilling machines, designs of drilling machines and tools, conditions of working sites |
| Service               | Extent of exploration, appropriate preparation of drilling sites, duly maintenance and repair, scope of auxiliary operations (hole cleaning, redundancy of holes, moving), compliance of service regulations |

The ample theoretical and experimental studies in the field of roller bit drilling disclose physics and multifactorial nature of rock fracture, and reveal some correlations between individual factors. However, it is yet impossible to correlate all effective factors as their mechanisms are extremely complex. For this reason, the drilling process is often represented in a simplified form, which neglects uncertainties governed by the spatial and time variability of the medium integrating the rock mass properties and many other factors.

Thus, the ration transitive processes in the “drilling operations” subsystem as the necessary reactions to the changing factors predetermined by the variability of the operating environment should be revealed based on the real-time measurement and analysis of a set of natural, technological, technical and economic factors of drilling performance.
The Institute of Mining, UB RAS is developing a procedure to reveal the set of factors governed by the changing conditions of blasthole drilling, including the review of source data and standards of drilling, measurement of drilling parameters using special instruments, statistical analysis of actual drilling performance, determination of potential rational transitive processes as per the revealed factors which have the highest effect on drilling performance, as well as joint evaluation of safety and economic efficiency of the selected transitive processes.

The first implementation stage of the procedure included a prototype instrumentation engineering to control blasthole drilling parameters. The instrumentation ensures measurement and recording of data on operation of drill drives and roller bits, and synchronizes these data with the measurement of the current blasthole depth. The information received from the drill is then used to adjust strength characteristics of rocks, as well as drilling mode and energy content. The input data are subjected to the statistical analysis (determination of the first and third quintiles, median, average values, maximums and minimums, etc.).

An extraction block at an Uralbest’s open pit was chosen for the test drilling in structurally complex rock mass to reveal basic factors to affect stability of the “drilling operations” subsystem using the designed instrumentation. The progress indicator of the “drilling operations” subsystem at this stage was selected to be the drilling penetration rate. Figures 1 and 2 show the change in some factors measured during the test drilling. The same measurements were taken in further drilling in the test extraction block.

**Figure 1.** Time history of drilling penetration rate.

**Figure 2.** Time history of factors which have influence on drilling penetration rate.
The test data analysis has revealed that the moments of instability in the “drilling operations” subsystem during blasthole drilling are mainly caused by the natural factors of the structural complex rock mass: sharp and short-term \( 1 \) and comparatively smooth and long-term \( 2 \) and \( 3 \) changes in the rock strength properties expressed in terms of Rzhevsky’s drilling work index. Under such conditions of drilling, roller bit bearings experience high loading, which can drastically worsen the drilling tool reliability and lead to its early failure. In this case, the transitive process to bring the subsystem back to stability is recommended to be the shock absorption by a special damper set above the bit to reduce the undesirable impact on the roller bit bearings.

The longer period testing, for a week, a month, or a year, can provide fuller information on the changes in the operating conditions of the “drilling operations” subsystem. This can help finding optional transitive processes (engineering solutions) aimed to reduce the unwanted impacts of the operating medium variability on the subsystem stability.

3. Conclusions
The authors have proposed a procedure to revealing a set of factors which govern the necessity of the transitive processes in the “drilling operations” subsystem. The procedure includes the analysis of inputs and standards of drilling, measurement of drilling parameters using special instrumentation, statistical analysis of actual indices of drilling performance, determination of a list of rational transitive processes, as well as the joint evaluation of safety and economic efficiency of the selected transitive processes.

As the first stage of the proposed procedure implementation, the instrumentation for the drilling performance measurement has been designed and engineered and tested in the structurally complex rock mass. The tests are going to be continued to reveal more factors which have influence on the operating conditions of the “drilling operations” subsystem during longer periods of its functioning.

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