Digital Field concept toward enhanced efficiency of coal mines

EA Khoyutanov1*, NA Nemova2**, EA Abeuov3 and LM Abdieva3
1Chersky Institute of Mining of the North, Siberian Branch, Russian Academy of Sciences, Yakutsk, Republic of Sakha (Yakutia), Russia
2Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
3Karaganda State Technical University, Karaganda, Kazakhstan

E-mail: *khoiutanov@igds.ysn.ru; **nemova-nataly@mail.ru

Abstract. Increasingly high uncertainty, complexity and variability of the mineral mining sector performance necessitates integration of digital technologies to improve business. Coal mines use DT much more less than the oil and gas industry. It seems a promising way to make use of the experience gained in the oil and gas industry to advance the Digital Field concept and Industry 4.0 as a basis for the sustainable tactical and strategic operation of business in coal mining. Digitalization of mineral resources and mineral reserves, geotechnologies and control provides a real-time picture of production and marketing. Furthermore, efficiency of coal exploration, mining, dressing and consumption is increased. It is expedient to use 3D modeling in evaluation of coal reserves, qualities and occurrence conditions to adapt mines to better and rival scenarios of development of structurally complex coal fields.

1. Introduction
The objective reality for the global and Russian mining sector is functioning in the conditions of increasing uncertainty, variability, complexity and ambiguity [1, 2]. An efficient way of enhancing competitive ability of business and product is integrated digitalization, starting from strategy and finishing with current activities. Digitalization is yet often understood as old-fashioned and ill-implemented automation of process flows or office activities using new hardware/software. In the meanwhile, the review of the projects connected with Information Technologies (IT) and Digital Technologies (DT) shows that many large- and moderate-size companies, including mining companies, in the world elaborate and implement concepts oriented at maximization of utilization of capabilities offered by the advanced computer engineering and data processing.

The efficiency of IT and DT in the mining sector can be proved by the following information on the oil and gas industry which commonly and dynamically switches to integrated digitalization. As early as the 1990s, 3D computer-aided seismic modeling allowed reduction in the cost of new deposit exploration by 40% on average, with increase in volume of proved reserves by 2.5 times. The oil recovery factor at ‘smart’ reservoirs is 2–10% higher than in traditional fields as per Cambridge Energy Research Associates (CERA), and the operating and capital expenditures of mining are cut down by 10 and 50%, respectively. According to BP (Technology Outlook, 2018), thanks to the technological development, the cost of mining will drop by 30% by 2050, including 30% of this reduction owing to digitalization [3].

In solid mineral mining, with less economic significance and lower capabilities, effect of automation, informatization and robotics is weaker but yet has weight at a scale of a specific mine.
Digital transformation of open pit mining, dynamically expanded since the early 2000s, has gradually improved the process efficiency. For instance, the system designed by VIST Group for loading and fueling control of dump trucks with capacity of 55 t and higher enabled an increase in haulage capacity at some open pits by 6–8%. The monitoring and control system made it possible to enhance mining machine capacity by 5–20%, to raise their availability by 7–10%, to reduce operation expenditures by 7–10% and to decrease no-purpose use of fuel by 15–100%. The high-precision navigation system improved efficiency of drilling rigs by 11–25%, enabled optimization of drilling and blasting performance and assisted in control and stabilization of mineral quality and cargo traffic optimization with stimulated efficiency of the latter by 5–10% [4].

More than 90% of Russian mining companies engaged in digital transformation are faced with the common obstacles which though look newly in the new reality, namely, lack of required assets and finance (50% of respondents), lack of required knowledge and skills of personnel (29%), immature digital culture (27%) [5]. DT-based optimization of process flows usually enhances production efficiency and financial performance in the mining industry. As a consequence, assets are found easily given adequate objective setting and feasibility studies. The other two obstacles require special care and concern as they are connected with shallow understanding of the problem by management and owners of a company, high labor content of personnel training and formation of special-purpose and innovation-oriented qualified teams.

The recent big-league Industry 4.0 and the fourth industrial revolution integrate equipment, technology, management, IT and DT within the united information space, which allows them to communicate with other and with the external environment in real time and at minimized participation of decision-makers.

Implementation of Industry 4.0 in the coal industry assumes some promising trends and technologies [6]. In exploration and planning, these are: virtualization of search and exploration, remote earth sensing, improvement of geoinformation systems based on 3D geological modeling, modeling and reality association, internet integration of data on space and time, digital design and adaptable layout and planning concepts. In preparation and extraction of coal reserves, these include: effective physicochemical geotechnologies, unmanned robotic mining, digital geomechanics modeling, geodynamics and air monitoring, integrated IT, analytics, automated control, borehole mining, technological innovations in rock fracture and disintegration, Smart Mine. It is intended to integrated these and other potential blocks into control systems to improve precision of prediction and planning of basic performance indicators in mineral mining.

Digital modeling, mine planning and design as well as management take a ranking place in the specified set of problems. The main subjects of comprehensive analysis toward resource-saving, environmentally sound and economically reasonable mining should be mineral deposits subject to their increasing complexity, spatial variability and ambiguity. The backbone for the decision-making on technology and management should become the most reliable 3D and 4D modeling with regard to natural, limit, achievable and investment potentials of mineral deposits [7].

2. Digital Field as the basic asset of a coal mine

Development of a coal mine with regard to integrated digitalization using IT and DT is connected, first, with a coal field as an object of development and, second, with a manmade neighborhood of this object. The manmade neighborhood of a mine should ensure implementation of all objectives governed by all production chains between coal producers and consumers, and shaping the final cost of a marketable product. The concepts of Smart Mine and information–communication technologies are in detail; discussed in [4, 6, 8] and are addressed in this paper only in the context of interaction with Digital Field.

The analyses implemented for many years shows that coal fields are studied incompletely and insufficiently accurately despite the increasing complexity of their structure, properties and quality of coal in the present reality. Traditionally simplified understanding of a coal deposit nature ends with various and often adverse consequences during mining, which dictates continuous updating of the
project and operation paper to adapt the engineering solutions to the adjusted geological and economic conditions [7, 9–11].

For this reason, we now focus on the experience of the oil and gas industry which actually operates in a difficult and indefinite geological environment of deep-level hydrocarbon reservoirs. Since the early 200s, top oil and gas companies and the related research agencies readily engaged in development of various methods of information control. Although there is no a uniform approach in the world, the Digital Field technologies are widely introduced and applied at the stage of mine planning and design [3, 12, 13]. The scope of DD technologies embraces all processes from exploration and extraction decision-making to production optimization and management, and occupational safety and health.

The new-generation technologies of process-flow control include Smart Field (Shell), I-Field (Chevron), Field of the Future (BP), Smart Wells (Schlumberger), Digital Reservoir (Gazpromneft), Intelligent Reservoir (Lukoil) etc. These are the assets equipped with systems of monitoring, remote control and business software [12]. We think a sufficient and accurate definition is “A Digital Field is the evolutionary integration of drilling, exploration and digital control technologies with the advanced communication technologies” [14] in combination with geological, geophysical, geotechnical, statistic, economic and other data to be processed, interpreted, analyzed, stored and easily accessed. Given various explanations and approaches, there exists another and interesting definition [15]: “A Digital Field in an intelligent approach to management when all infrastructure and process flows are planned, organized and controlled at clearly set objectives, and the control function serves self-coordination of the components (units, machines, people), which favors achievement of the set objectives within the whole life of engineering solutions at the sustainability and self-sufficiency of the system”.

The theory and application of the Digital Field technologies in coal mining allow structuring and optimizing exploration and production owing to: maximum reliable geological, geomechanical and geotechnical modeling of coal fields and seams, including various information envelopes (patterns of dirt and coal inside host rock masses; contour lines of tectonic faulting, zones of weathering and oxidation; outlines of different stress–strain behavior and stability of rock mass; 3D jointing networks, etc.); combination and integration of different process flows (drilling and blasting, excavation and haulage, quality and loss control); management over different mining scenarios at all stages of mine project life toward enhanced efficiency of the technology and business.

Management in the framework of the Digital Field enables production of minerals in the preset quantity, at the market-governed quality, and at the minimized and tolerable expenses. The mining plan is flexible and can be varied in accordance with the current business climate and market environment.

The geoinformation analysis of structure of a coal field assumes wide application of mining and geological information systems. The review of the main foreign and Russian software products shows their similarity in terms of architecture and function. The choice of a specific product is often subjective. One or another product can be effective at a specific locality, which is not a reason for extending its usability to another deposit without any regard to specificity of the latter.

The present authors use Mineframe and Micromine systems which enable detailed engineering and 3D modeling of mineral deposits, multi-variant appraisal, as well as mine planning and optimization. Collected and comprehensively examined information on coal fields in Siberia and Russian Far east, and the associated processing–consumption chains, and digitalization promoted setting and solution of the problems connected with adjustment of coal production process flows, including coal having naturally nonuniform process and application properties, extracted from structurally complex seams, control and management of coal reserves and quality, as well as elaboration of operational and economic discipline.

Digital modeling and analysis provided a better insight into the natural potential of coal seams. On this basis, improvability of production–marketing chain from a mine to a consumer was revised. The approaches applied, results obtained and solutions proposed [10, 16, 17] are well embedded in the Digital Field concept and enhance efficiency of production and sales of coal additionally differentiated
by the consumer properties. These are achieved by means of selective mining of coal in longwalls and extraction from coal pillars, separate dressing of coal with refined grade composition, reduction of coal loss in production and supply chains, as well as sound managerial and economic efforts aimed at cost saving.

The Digital Field concept ensures transparent and understandable management at all levels. Each object of subsoil use has boundary (mining lease), which defines the range of the mineral body possibilities and their convertibility into reality. The boundary has limit which is a characteristic of a time-varying ultimate mineral resource potential. An accurate evaluation and real-time re-evaluation of the mineral resource potential depends on the level of IT and DT application at a mine. After a mineral deposit is put into operation, the limit potential is taken as a base for the evaluation of an achievable potential of a coal field, dependent on mining and processing technologies in use, marketing of products and the mine management model. The achievable potential can grow or diminish when new knowledge on a deposit is got, and/or more effective technological innovations appear and go well within the Digital Coal Field concept.

3. Conclusions
Increasing higher uncertainty, complexity, ambiguity and changeability of internal and external environment of functioning coal mines necessitate integrated application of highly capable information and digital technologies for the improvement of business processes. It is wise to use the experience gained by the advanced oil and gas industry in application of the Digital Reservoir concept in exploration, mining, processing and consumption of coal.

Mineral deposits in mining these days have more complex structure and occur in difficult ground conditions and in extreme climatic conditions. The conventional and more simplified understanding of the nature of coal as compared with the oil/gas reservoirs and ore bodies leads to unfavorable consequences during mining. That is, inefficient use of the mineral resource potential, high total loss of coal produced and sold, and, which is critical, worse efficiency of coal production and supply chains.

Continuous variation in climatic, geological, geotechnical and economic conditions in operation of mines and preps requires prompt response to any possible scenarios of the development of events toward effective and competitive managerial decision-making. More careful and rapid adaptability of coal mines ensues from maximally wide and correct application of the discussed provision of Digital Field.

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