Adaptive optimization as a design and management methodology for coal-mining enterprise in uncertain and volatile market environment - the conceptual framework

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Abstract. The work is devoted to the problem of cost-effective adaptation of coal mines to the volatile and uncertain market conditions. Conceptually it can be achieved through alignment of the dynamic characteristics of the coal mining system and power spectrum of market demand for coal product. In practical terms, this ensures the viability and competitiveness of coal mines. Transformation of dynamic characteristics is to be done by changing the structure of production system as well as corporate, logistics and management processes. The proposed methods and algorithms of control are aimed at the development of the theoretical foundations of adaptive optimization as basic methodology for coal mine enterprise management in conditions of high variability and uncertainty of economic and natural environment. Implementation of the proposed methodology requires a revision of the basic principles of open coal mining enterprises design.

1. Introduction
Market economy conditions have significantly changed the characteristics of the business environment, criteria and strategy for ensuring viability of coal-mining enterprises of Russia. The ability of coal mine producers to meet demand for coal products and to provide high economic efficiency of invested capital are of fundamental importance in the market conditions.

For a majority of contemporary Russian coal mining enterprises the main barrier to achieve these objectives is a high degree of variability of business environment conditions. The variability of the business environment is evident in the seasonal and random changes in the demand and prices for coal product. Variability also affects the price and availability of material and human resources. Also, macroeconomic parameters changes add significantly to the variability of the market environment. As a consequence, uncertainty of future values of the parameters of the business environment is a fundamental and inevitable factor of market environment.

The second significant factor preventing the achievement of these objectives is a complete mismatch between majority of mines design parameters and their market environment. In a centralized planned economy, the positive effect of economies of scale was considered as a major source of economic efficiency. As a result a dominant strategy in coal mining production was a creation of big mining companies to exploit this effect to the full extent. Unfortunately, the bigger a scale of production system is, the higher inertia of that system is in a sense of time it takes to react to
changing market conditions. Following this approach in the volatile market environment leads to significant economic losses. Historically creation of the finished coal products stock was considered as a basic mechanism for coal mining industry to protect it against market demand variations. This mechanism used to be well established and efficient in the planned economy environment. In the volatile market conditions it leads to excessive growth of working capital, economic risks increase, lower investment attractiveness and competitiveness of coal mines.

In recent years, the issue of coal-mining enterprises efficiency in the volatile market environment has been actively investigated by Russian scientists [1-5]. The aim is to achieve market competitiveness of coal mining companies and bring them to the level of efficiency corresponding to the global energy market. However, the issue is still under consideration and approach to develop coal mining system robust and adaptable toward market variation needs further research. The problem under consideration is of systemic nature. To resolve it – it is necessary to revise the principles and methods of production systems design, as well as organizational and managerial processes. All above mentioned proves a relevance importance of the research approach presented in this article.

The object of the study. The production system of the open pit coal mining, operating in a volatile and uncertain environment in the market economy.

The subject of research. Conceptual framework and design principles for coal mining enterprise operating in volatile market environment, including models and algorithms of adaptive control at the strategic and operational level of management in the short-term and long-term (investment) time frame.

Research methods: theory of adaptive systems and mathematical theory of optimization.

2. Results
The general concept of the necessary transformations of coal mines can be defined as the alignment of the dynamic properties of coal mining system with dynamic properties of the market environment. The implementation of this concept involves a change of the design principles of production systems, as well as changes in the organizational, economical and management systems of coal mining.

In the time frame of business planning cycle in order to decrease level of economic risk and to increase net cash flow at optimum stock level the production planning principles need to be changed. The leading principle in this respect should be the synchronization of the coal production rate with a variation of market demand. A necessary condition for transition to the synchronized mode of operation is the achievement of a low enough level of coal mine production cycle time. That means that production cycle time has to be less than time horizon for reliable demand prediction, and less than the time constant corresponding to maximum frequency in the power spectrum of market demand for coal product in the chosen market segment. These premises were defined in [7] as a condition of predictability and controllability for adaptive mode of production system operation.

In the frame of long-term corporate investment cycle the most important decisions are associated with target markets, placement, production capacity and dynamic parameters of newly build and modified mines. As a result, the whole corporate system of production and logistics units have to be optimized in order to increase the market share and profitability of the coal mining corporation, and reduce investment risks. Marketing and investment policies should guide development of production capacity and dynamic parameters of new mining enterprises according to the dynamic structure of demand at the target market.

The “lower frequency” part of market demand in power spectrum has to be served by mines with a high production capacity and lower dynamic properties – relatively long production cycle. As demand variability at this part of the demand power spectrum is relatively low, so, adaptation of this part of corporate production facilities should use coal stocks buffering mechanisms. Thus, corporate exploits the opportunity of economy of scale effect.

The “higher frequency” part of market demand in power spectrum has to be served by mines with a lower production capacity and high dynamic properties – short production cycles. Since this component of demand in power spectrum displays a high volatile behavior, excess production capacity...
is considered as the most relevant mechanism for market environment uncertainty adaptation. The economic rationale for reserve production capacity should be based on the comparison of the volume and cost of capital invested in the creation of a reserve power with the amount and cost of capital tied up in stocks of finished coal products and work-in-process.

To reduce the production rate and the level of investment risk within the life cycle of the enterprise, and increase responsiveness of the open pit mining production system to variations of the market demand, it is necessary to change its fundamental design principles. Systems of coal mining should be formed on the basis of adaptive phased design patterns, providing the ability to change production capacity and volume of economic resources used at any stage of the life cycle in accordance with changes in the market environment and, at the same time, reducing technology driven capital tied up in mining works for time periods far beyond the horizon of market size long term prediction.

3. Discussion
As it is known, the viability of the biological, social or economic systems is determined by their ability to adapt to changing environmental conditions. The adaptive system is a system able to modify its behavior algorithms, functional and material structure with the aim of maintaining or achieving optimal state when changes in the external environment occur [6].

Thus, the ability of mining companies to change their parameters or structure in accordance with the changes of the market environment at different stages of the life cycle, determines their viability, and in an economic sense, their efficiency and competitiveness.

Adaptation should be considered as a step-by-step process aimed at maximum possible increase of economic efficiency at each step based on achievement of cost leadership and the level of dynamism adequate to the variability characteristics of the mining and geological conditions and market environment. As it was shown in [7], a necessary condition for such type of adaptation process is the formation of capacity of the control object to modify its parameters or structure during a time period that do not exceed the time frame of significant changes in the natural and business environment within control cycle at all levels of organization system.

The lack of adaptation capabilities for majority of coal mining corporate systems in Russia manifests itself in the conflict between the indicators of economic efficiency and ability to sustain uncertainty and variability of external environment. This conflict is predetermined and embedded in the production system long before its manifestation – at the stage design of its life cycle due to major criteria used in its design. Until this time the prime concerns of designers at this stage are issues of final surface location of mining works, production capacity, parameters of the working area. As a consequence, the dynamic parameters of the production system are not considered and not taken into account when major decisions regarding choice of mining system and technological processes are taken.

Generally speaking, the entire conceptual mining framework developed in the conditions of centralized planning economy including design criteria, design methodology, social legislation limitation and policies define capabilities and economical and technical limitations of existing enterprises. In the radically different environment of market economy the design, technical, technological and management decisions taken within this obsolete framework produce evident and significant negative effects, create economical conflicts. These solutions have become a basic causal factor limiting the adaptability of coal mines to the characteristics of volatile and undefined external environment. One may consider these negatives effects as a clear and lucid signals – the prevailing system of design production and management in the mining industry has to be changed.

The fundamental premise laying at the foundation of traditional mining conceptual framework is a supposition of environment stability and predictability. As a result, a designer supposes that it is possible to rely upon the data regarding economic and natural environment parameters available at the moment of decision taking to make “optimal” decisions. These optimal decisions are considered to be valid at a current time, as well as over the period of the life cycle, the duration of which usually exceeds 50 years or more. Obviously, in a market economy for a specific period of time it is
impossible to provide a reliable forecast of the economic environment parameters, including average market demand. Limited predictability and uncertainty parameters of the economic environment in the long term is the root cause of significant economic risks that affect the investment attractiveness of coal mines and determining the amount of deviation of the parameters from the optimum.

To reduce the economic risks, ensure the sustainable operation of enterprises throughout the life cycle it is necessary to overcome the current conceptual mining industry framework. That means that decision making processes at all stages of life cycle should meet the terms of adaptability. To this end while making design decisions one should consider external environment parameters as time dependent and known with acceptable accuracy only within a certain time horizon. These parameters should not be used for making decision beyond the horizon of their reliable prediction. Consequently, the system of coal mining should be designed so that it could change its parameters or structure in accordance with changes in the external environment. To ensure these conditions, the trajectory of development of the enterprise within the framework of the whole life cycle should be considered as a sequence of investment cycles. The duration of each investment cycle should be chosen in such a way that condition of predictability and controllability condition mentioned above to be fulfilled.

Obviously, traditional methods of making design decisions in mining industry do not meet these conditions. The source of the problem is a supposition of rigid spatial structural relationship of the open pit working space. This supposition is useful in a sense that it helps designer to define a fairly narrow limits for the trajectory of working space development during life cycle of open pit mine and set such parameters as a final depth of the pit to achieve maximum NPV – discounted net income over the entire life cycle of coal-mining enterprises. In turn, the decision made regarding the final borders location of a pit that will be reached over 50 years or more, determines and limits such crucial structural, technical and economic relationship for a distance of rock mass transportation, the dependence of the current stripping ratio, variable costs of the current and maximum depth of the pit.

It is worth mentioning that rigid spatial structure supposition which fixes location for the final borders, leads to a such trajectory of working space that maximizes operating costs and investment at the initial and middle stages of the life period. That means that return on these cost will be shifted into distant and uncertain future. This kind of spatial trajectory of working space predefines essential technology driven capital investment tied up during the major part of the whole span of mine life cycle in the hope to achieve economy at very distant time, for many decades of years to come. This approach to optimization could be justified in some degree in the stable and predictable economic environment of centralized planned economy and state ownership of the means of production. In the conditions of market economy, the values of many parameters of the economic environment, which are to be used to calculate the optimum value of the final depth of mining (volume of demand, inflation, interest rates, cost of capital, prices for the main types of resources and so on) for remote periods of time, are characterized by a high degree of uncertainty. As a result, there is a high degree of uncertainty with regard to the final depth of the pit and all the technical characteristics which are deducted from it, as well as structural proportions and economic parameters of the company.

Failure to comply with the terms of adaptability at the design stage determines the instability of the design decisions and the need for periodic essential design parameters correction during the reconstruction. However, the reconstruction implements and fine-tunes the parameters, but does not change the spatial structural relationships and enterprise development trajectory of the.

To assess the dynamic features of coal mining system in the timeframe of the whole life cycle it was proposed [7] to use the “index of adaptability”. One may calculate that index as a ration of the time frame of changes in economic parameters of the external environment that significantly affect the nature of the design solutions to the time it takes to change some critical characteristics of the production system, such as production capacity, type of technology and its main parameters.

As analysis has shown [7], there are just a few environment parameters with essential influence on the character of the design decisions. They are: the level of market prices; volume of demand in the chosen market segment; the width of power spectrum of the market demand; the cost structure of the major resources used by the coal mining enterprise.
In a stable market environment the period of significant changes to these parameters may arise in a
time span of 7-10 years; for volatile environment this period of relative stability may shrank to 2-3
years and even less than that.
Technology, for which the value of adaptability is more than one, should be classified as flexible,
i.e. capable of adaptive behavior. Indeed, the technology for which the specified index is less than one,
should be characterized as rigid, with a low level of adaptability.

Taking into account current and projected fundamental shifts in the patterns of global energy
consumption there is no wonder that the horizon for reliable forecast of technical and economic
parameters that determines the choice of optimal trajectory for enterprise development shrinks all the
time. As a result, a rigid nature of most open pit mine enterprises, which use deepen-longitudinal
development systems, became apparent [Figure 1a, b].

Figure 1. Systems coal fields development: a, b – deepen-longitudinal (“rigid”); c, d – deepen-solid
cross (“adaptive”).
As the coal-mining enterprises cannot change the dynamic characteristics and long term trends at the energy markets and reduce the uncertainties in the external business environment, then the only effective way to satisfy conditions for adaptability is the development and implementation of design solutions that break the chain of cause-and-effect relationships, which form the “rigid” coal mining conceptual framework.

A radical solution of this problem is a transition to phased, flexible technologies of mining operations [Figure 1c, d]. These technologies may be considered as ones which to a great extent fulfill and idea of adaptive behavior and the mentioned above criteria of predictability and controllability. The basic idea behind these technological solutions is to increase the number of degrees of freedom in the choice of possible directions of development of the working space of the open pit mine, and reduce the transport distances of the rock mass. For many coal mining companies an adequate choice might be, for example, mining technological system, referred to as “group deepen-solid cross”, for which the spatial-temporal characteristics of each stage can vary in accordance with changes in the characteristics of the business environment [8, 9].

The determination of the direction and parameters of mining operations in this case is carried out at each successive stage of enterprise development. Duration of stages, during which the parameters of the mining system remain unchanged, are determined not by the inertia of the enterprise but by the level of instability and uncertainty of the natural and market environment over time. As a consequence, the enterprise avoids technologically defined capital tie-up in the mining works, and investment into questionable economical benefits to be gain in the future periods beyond the horizons of reliable prediction.

An ability to change the parameters of the production system in accordance with the significant changes in the business environment delivers evident economic and competitive benefits: characteristics of the enterprise on each segment of trajectory is sufficiently close to the optimum so that the maximum value of cash flow at the current settings of economic and natural environment is achieved.

Essential advantage of the “group deepen-solid cross” technology is an essential reduction for distance of rock mass transportation. This results in a significant improvement of the dynamic characteristics of the production system, as well as radical reduction of the cost of production during most of the trajectory segments. The duration of the production cycle in the same geotechnical conditions, when using this and similar technological systems, can be reduced by several times in comparison with the currently widely used deepen-longitudinal development system.

Such dynamic capabilities gives a possibility to radically change the mode of coal mining enterprise operation and switch to so-called “synchronized” or “just in time” mode. This mode of operation means that stock buffers all along production-logistic chain of mining industry are reduced to minimum with a corresponding reduction of capital tied up in a finished products and work in a process. Analysis of demand in Kuzbass regional energy market has shown that the synchronized mode of operation might be used to satisfy more than 95% of potential demand.

Studies have shown that the proposed use of “flexible” technologies also allows the rate of resources consumption by the producers to be reduced significantly (2-3 times), which would increase the production efficiency of open-pit coal mining and, as a result, would enhance its resource potential.

4. Conclusions
Thus, the transition to adaptive optimization as a basic methodology to design and manage open pit mine enterprises gives them a possibility to survive and prosper in volatile and uncertain economic environment of postindustrial era. Flexible models for open pit mines working space development allows mining companies to achieve a significantly higher productivity and production efficiency and, consequently, get competitive edge in the fierce competition at the world energy market.

It should be noted that to great degree all the benefits of transition toward new design and control methodology are still in the area of opportunities, of possible but not real future. To make these
benefits real, significantly higher level of dependability for all processes in production, logistic has to be achieved. New, more sophisticated and robust methods for coordination of production and supporting units and processes at all organizational levels and control cycles need to be developed and applied. Higher labor competence and discipline, employee involvement and cooperation are required. Therefore, a transition to a new and higher level of management should be accomplished.

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