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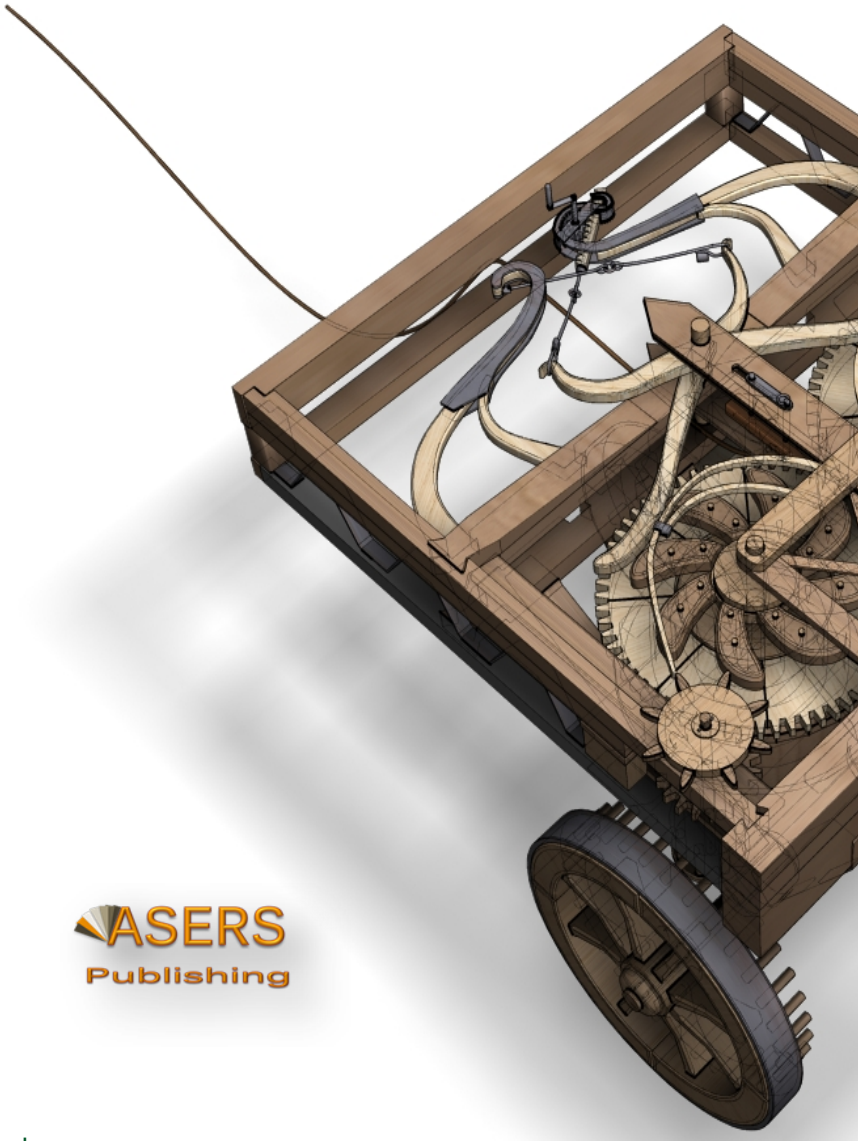

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Technological and Economic Substantiation for Efficiency of Involvement in the Processing of Complex Reserves of Coal Deposits

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Abstract:

The technique of grounding the involvement in mining of coal reserves with complex conditions of occurrence taking into account the reduction of specific capital investments for construction of new horizons of existing and new mines. The algorithm of estimation of influence of factors that complicate the testing of stocks and affect their production. The method of evaluation of the carrying value of opening and preparing the mine workings. The proposed approach allows the subsoil user to choose the most effective design solution, taking into account the degree of involvement in processing of complex inventory, but the investor – is to assess the feasibility of participation in specific investment project.

Keywords: modernization of mining assets; involvement in testing; capital investments; technological solutions; design solutions; methods of property valuation.

JEL Classification: L11; L23.

Introduction

The main factor that forms investment activity in relation to any field is its resource return. It is determined by the ability of modern technical and technological solutions to maximize the extraction of minerals. This characteristic for the field for a subsoil user is largely determined by the geological conditions of occurrence and the state of the infrastructure that will have a great impact on the efficiency of investments. Thus, the two actively interacting parties – the subsoil user and the investor – are interested in an objective assessment of the appropriateness of involving in the development of stocks. In addition, there is also a third party: the state, as a defender of the interests of society in terms of rational use of mineral resources and obtaining benefits in the form of tax revenues (Shaklein 2005, Bondaletova 2012, Hower *et al.* 2017).

According to the distribution of coal reserves in the fields of operating mines according to the conditions of their occurrence, the specific weight of production using high-performance foreign equipment will be limited in the range of 25-30% due to a significant differentiation of the conditions of occurrence of reserves even within a single mine. As a result, the problem of developing a mechanism for justifying the field of application of high-performance technology is very relevant.

The urgency of the problem lies in the fact that in conditions of the exhaustion of natural energy resources and the increasing complexity of their extraction, it is necessary to develop such a mechanism to comprehensively

substantiate their maximum extraction, which will allow the extracting enterprises to ensure the inflow of investments. The construction of a new mine will always be more costly than the maximum involvement of the operating mine stock in operation (Bondaletov 2012, Liu *et al.* 2017).

1. Literature review

The article examined the works that consider the techno-economic justification of the effectiveness of involving in the development of complex reserves of coal deposits (Liu *et al.* 2017).

It should be noted two main areas of development of scientific research on the problem of justifying the optimal design options for the development of the mine fund:

- development of rational schemes for opening, preparation and testing of minefields under construction and operating mines, the main purpose of which is to justify compatible optimal technological solutions that take into account the features of the occurrence of seams, as well as the opening schemes, conditions and possibilities for reconstruction of the technological complex of the surface with an assessment of the prospects for involving new mine Fields; The task was to reduce to a minimum the period of construction or reconstruction of mines, to ensure a minimum period of recoupment of capital investments; This direction is devoted to a number of fundamental works of A.S. Burchakov, M.I. Ustinov, A.S. Malkin, L.A. Puchkov, A.M. Kurnosov, A.S. Saginov, V.M. Eremeev, P. V. Bgorova, G.I. Kozovoy, V.G. Lavrik, V.A. Fedorin, K.K. Adshgov, S.S. Kvona and others;
- development of methods for optimizing the quantitative parameters of technological schemes, as well as the parameters of technological processes based on the construction of economic and mathematical models of mines; This problem, which was especially acute at the time when the use of new technological equipment (for example, narrow-cut cleaning technology and partial or complete conveyorization of transport) required the search for methods for the formation and justification of optimal solutions that would improve the efficiency of coal mining; A great contribution to the development of this problem area was made by N.I. Ivanov, A.V. Starikov, E.I. Rogov, V.N. Vyshegzhanin, M.A. Revazov, K.N. Trubetskoi, A.A. Peshkov, Yu. N. Kuznetsov, *etc*.

To increase the economic efficiency of new and reconstructed enterprises in Russia and abroad, the methodology of integrated (parallel) design and development of enterprises is intensively developed through a purposeful change in their structure, including in the process of their operation or reconstruction (Kapitonov *et al.* 2017). In the coal industry, the scientific foundations of this promising methodology have not yet been developed and are not brought to practical implementation. In the development of scientific foundations for the design of coal-mining enterprises, a significant contribution was made by A.S. Astakhov, A.S. Burchakov, B.M. Vorobiev, V.M. Eremeev, V.E. Zaydenvarg, Yu.N. Kuznetsov, A.S. Malkin, V.V. Agafonov, V.V. Melnik, V.S. Muchnik, M.E. Pevzner, L.A. Puchkov, A.D. Ruban, A.S. Saginov, A.G. Salamatin, M.I. Ustinov, V.A. Kharchenko, L.D. Shevyakov, V.D. Yalevsky, V.P. Zubov, and other scientists.

2. Materials and methods

The Program for the Development of the Coal Industry for the period up to 2030, adopted in the Russian Federation, (The Energy Strategy of Russia for the period up to 2030... 2009) is aimed at intensifying the development of exploited deposits. The dynamics of development of new coal deposits is insignificant, which is due to their location both in relation to the main consumers of coal, and underdevelopment of the infrastructure of the regions. This implies the need to implement design solutions aimed at maximizing the extraction of reserves and involving in the development of previously abandoned reserves.

Of all the projects presented in the Program, projects of mines with a capacity of 2.5 to 4.5 million tons predominate. The ten largest construction projects that are due to be commissioned during 2015-2030 with a total capacity of more than 39 million tons will require investments in the prices of the implementation period of about 146 billion rubles. Due to the simultaneous implementation of projects, it is not possible to compare single value indicators, but these data characterize the scale of systemic changes in the coal industry whose purpose is to ensure the competitiveness of coal as energy and chemical raw materials, increase the investment attractiveness

of the industry and the activity of potential investors. It is assumed that the labor productivity of workers employed in the coal industry will grow 5 times. Such an increase, most likely, will be provided due to growth of extraction by the open method. In underground works such an increase is unlikely. The average annual production capacity of the mines remains low, within the limits of 1300-1500 tons. The increase in the depth of mining, the condition of mine layers on the risk of emissions, high gas content does not allow using high-efficiency equipment with maximum efficiency in the main processes. A retrospective analysis showed that the unpreparedness of the Russian industry to produce high-performance cleaning and tunneling combines is also related to the fact that in most mines their use is largely limited by the gas content and explosiveness of the seams. Currently, the share of imported equipment in the main underground processes is 49.6%, including 75.1% of harvesters (The Energy Strategy of Russia for the period up to 2030... 2009). The experience of mines with the use of high-performance equipment has shown that it is possible to provide high productivity provided the degassing of the pit is prolonged by boreholes drilled from the surface and also in the horizontal plane of the formation. Such training should last 9-12 months, which allows increasing the load on the cleaning face by 30% or more.

Analysis of the state of the reserves of the mines of the leading Russian basins showed that the prevailing conditions of occurrence, characterized mainly by the high degree of disturbance of the beds, the instability of the enclosing rocks, watering and the presence of erosion, the localization of a large number of reserves in areas limited by intransitive tectonic disturbances, require an integrated approach in justifying Expediency of involving them in working off. The state of the reserves of the mine fields of the Kuznetsk Basin, for example, is currently as follows:

- in the last decade of the exploitation of the basin, reserves with favorable geological and geological conditions were involved in development, which led to the abandonment of a large number of local sites;
- a large amount of reserves is left in the seams of small and medium power, as well as in coal packs when working out powerful strata;
- in conditions of growing deficit of coking coals, the problem arises of developing rational technological schemes for opening, preparing and working out these reserves;
- in the construction of new mines in the explored areas, it is possible to create high-performance new-generation mines using the latest technical and technological solutions to maximize the involvement of discovered reserves in testing;

The excavation fields of the operating mines of the Kuznetsk basin can be divided into two groups: Group I – excavation fields, the dimensions of which are not more than 3.5-4.5 km along the strike, not more than 1-1.5 km in the dip, called the fields With limited dimensions; Group II – excavation fields, the extent of which is up to 6 km along the strike, 1-1.5 km in the fall, called the fields with optimal dimensions; Reserve fields of mines.

Structural changes in the consumption of energy resources, an increase in the share of gas consumption, as the most environmentally friendly and cheap energy resource, require coal producers to seek reserves to improve the competitiveness of their products. Russia expects to increase coal supplies to the countries of the Asia-Pacific region by 13%, and to the domestic market – by 32%. Such plans require the implementation of a number of measures to reduce production costs, improve the efficiency of investment. According to Rosinformugol (Shulyatieva 2015), the price of coking coal after the fall significantly increased and is 167.8 dollars. The deepening of mining operations in the developed fields, a number of social obligations, an increase in the prices of equipment and materials significantly reduce the internal reserves of increasing the efficiency of production. For many years there has been a controversy about whether to create enterprises on the principle of mine-lava or high-performance modern enterprises with an annual production of 10 million tons or more. The construction of the mine requires significant initial capital investments, which must be self-depreciated for the coal mined. The establishment of enterprises on the principle of mine-lava is advisable in areas of deposits, limited coal reserves, or located in zones of significant tectonic disturbances. Justification of the design capacity of new mines in fields that do not have such limitations should be carried out taking into account the maximum use of the main opening workings and maximum involvement in the development of stocks. Ensuring a high level of concentration of production requires the

development of a mathematical tool for justifying the parameters of technological schemes of mines, which would make it possible to significantly reduce the specific capital costs.

The bulk of capital investments in the mining of mine fields fall at their opening and preparation. Amortization deductions for opening and preparing workings refer only to the extracted part of the reserves and are the returnable financial resources forming the depreciation fund of the mine, which refers to own funds or share capital. Considering the terms for the construction of new mines in place of those who have left retired, and even taking into account the annual revaluation of fixed assets, there is a depreciation of the investments at the time of their return, and new construction requires additional capital investments, replenishing the depreciation fund.

Studies have established that within the mine potential for excavation are the reserves in the security pillars under the buildings and structures, as well as in the mines of the mine workings (Korshunov *et al.* 2016, Alabyev *et al.* 2017). On average, coal reserves in security lobbies under buildings and facilities can be about 12.5 million tons per mine, and about 20 million tons of protective mine workings. In addition, significant losses of reserves can be associated with a loss for the excavation of plots Thin and disturbed layers.

Large losses of reserves take place in the fields of extinguished mines. This is due both to the imperfection of the technology and technology of coal mining in the past, and to a sharp decline in production in the republic in the 1990s, which led to the closure of a number of mines. According to preliminary calculations at the mines of the Kuznetsk Basin, about 31% of all abandoned coal reserves are located in the lintels near horizontal excavations, about 8.5% of the inclined workings. 57% of losses are localized in other parts. The period of closure of most of these mines is 15-20 years, that is, these reserves are currently in the zone of settled rock pressure, the geological and geological characteristics of these mines are quite accurate. Their development in the future will significantly extend the life of the basin. However, an effective mechanism is needed to assess the appropriateness of extracting these stocks. In the 1990s, mines were closed in the basin, which developed layers with complex bedding conditions and low qualitative characteristics of coal. Nevertheless, the abandoned fields of previously operating mines, as a rule, opened, represent a significant potential for further development of coal mining. The main trend for overcoming the deconcentration of mining operations and reducing the technical and economic performance of the mines of the basin, caused not only by the objective factors of the deterioration of mining and geological conditions, but also by a number of miscalculations in the adoption of design decisions for the development of individual coal enterprises, can serve as a series of measures to consolidate them.

If we consider the problem of the development of the coal industry from the point of view of state, national interests, then the mining of reserves should be carried out taking into account the maximum completeness of their seizure. In the 1980s, the program for merging adjacent mines was developed and partially implemented, which made it possible to significantly reduce the number of main opening workings, to simplify the ventilation and underground transport schemes, to maximally involve previously abandoned reserves already subject to degassing.

Thus, the urgency of the problem lies in the fact that in the context of the exhaustion of natural energy resources and the increasing complexity of their extraction, it is necessary to develop such a mechanism to comprehensively justify the expediency of extracting them, which will increase the competitiveness of these resources in the market, and to extractive enterprises to ensure the flow of investment. The construction of a new mine will always be more costly than the maximum exploitation of the existing mine fund.

3. Results and discussion

Technological and economic justification of rational design solutions for involving complex reserves in development. The economic efficiency of the implementation of project solutions is assessed by calculating the effectiveness of the investment project, when options are not only these solutions, but also options for financing the project. This determines the basis of its investment attractiveness and competitiveness. Increasing the economic efficiency of investment projects can also be achieved by reducing the loss of coal during the mining of open mine fields by applying rational technological schemes of opening and preparation. The expediency of reducing losses due to the abandonment of reserves in the subsoil may also be justified by the fact that the specific costs for opening and preparing the mine fields can largely compensate for the additional costs of excavating complex sites.

Investigation of the problem of investment efficiency due to the maximum extraction of open stocks and the reduction of specific capital costs has the ultimate goal: the creation of a mechanism and a mathematical apparatus to justify the expediency of involving reserves in complex mining conditions, which should provide a significant socio-economic effect from increasing the efficiency of subsoil use. The competitiveness of coal in the market and the investment attractiveness of coal mining companies.

As the analysis has shown, the basic capital investments at mining of mine fields fall on their opening and preparation. Depreciation charges for opening and preparing workings refer only to the extracted part of the reserves and form the depreciation fund of the mine, which refers to own funds or share capital. However, given the time frame for the construction of new mines in place of those who have left retired, and even taking into account the annual revaluation of fixed assets, there is a depreciation of the investments at the time of their return, and new construction requires additional capital investments.

The amount of additional investment in capital construction (opening and preparation of stocks) for the reconstruction of a similar facility will be (Shulyatieva 2006):

$$I_{ad} = \sum_{t_0}^{T} A_t \times k_d - \sum_{t=1}^{T} A_t \times k_d \times (1+i)^{-t}, \quad (1)$$

where: t is the year of operation of the mine; a - coefficient that takes into account the decrease in the real value of depreciable assets due to inflation and the risk of production fluctuations in the t-th year.

For the period up to the time of recovery (), which amounts to, the amount of compensation will be

$$\sum_{i=t_0}^{\tau} A_i = \sum_{t_0}^{\tau} A_t \times k_d - \sum_{t=1}^{T} A_t \times k_d \times (1+i)^{-(\tau-t)} \quad (2)$$

This amount represents that part of the investment capital, which will be necessary in addition to replenishment of reserves in the volume equal to the spent ones. This will lead to an increase in the payback period, which will be:

$$T_{OK} = \frac{\sum_{t_0}^{t} IC_t \times (1+E)^t}{\sum_{t_0}^{\tau} [Q_t \times (p_t - VC_t) - FC_t] \times (1 - \Delta H_n) \times (1+i_t)^{-t} + \sum_{t_0}^{\tau} A_t \times (1+i_t)^{-t}} \quad (3)$$

where: τ is payback time ($\tau \in T$); T – service life of the mine; t_0 – initial moment of project implementation; t – step number of the investment project implementation ($t \geq t_0$, $t \leq \tau$); ΔH_n – coefficient that takes into account the income tax rate; p_t – the price of coal sales in the t-th year; VC_t – specific variable production costs in the t-th year; FC_t – total costs are constant without taking into account the amortization of capital investments for opening and preparation of reserves associated with coal mining in the t-th year.

The formalized presentation of the investment payback period allows to conclude that even insignificant losses of coal during the development of stocks multiply the losses of the value of the invested investments. This leads to a permanent rise in the cost of coal mining due to the growth in the specific volume of workings per ton of coal mined. Without taking into account other factors that may lead to an increase in production costs, the coefficient of increase in the cost of mining 1 ton of coal can be as follows:

$$\Delta p_t = \frac{A_t \times K_d - A_t \times K_d \times (1+i)^{-t}}{Q_t} \quad (4)$$

where: K_d is conversion factor of the book value of fixed assets permitted by law.

Mathematically, this can be represented as the more:

$$\sum_{t_0}^{T} Q_t \rightarrow Z_{np}, \text{ the less } \sum_{t_0}^{T} \Delta p_t \quad (5)$$

Specific financial losses due to losses due to abandonment of reserves in the subsoil in the t-th year will be

$$\Delta f p_t = \frac{\sum_{t_0}^{T} IC_{p_t}}{\sum_{t_0}^{T} Q_t} - \frac{\sum_{t_0}^{T} IC_{p_t}}{Z_{np}} = \sum_{t_0}^{T} CI_{p_t} \left(\frac{Z_{np} - \sum_{t_0}^{T} Q_t}{Z_{np} \times \sum_{t_0}^{T} Q_t} \right) \quad (6)$$

where: IC_{p_t} is the amount of invested capital in the construction of a new horizon (mine) at the time *t*.

Thus, investors, solving the immediate problem of reducing the costs of coal mining, incur significant losses due to the growth of specific capital investments per 1 ton of coal produced.

The maximum amount of the additional benefit from the full development of industrial reserves can be determined as (6). However, the complexity of the occurrence of coal seams, as well as the decrease in the quality of coal mined, do not allow achieving an equality between the size of industrial reserves and those suitable for excavation. This is due to the fact that complex conditions of occurrence lead to an increase in direct costs.

$$\Delta C = \frac{\sum_{t_0}^{T} \Delta f p_t}{T} \times Z_{dir} - \sum_{t_0}^{T} Q_t \times \Delta f p_t \quad (7)$$

The substantiation of the influence of mining-geological and mining technical conditions on the cost of production is given in (Shulyatieva 2006, Shulyatieva 2011). Therefore, without giving a general calculation algorithm that is based on the fact that the change in the conditions of the excavation reduces the load on the cleaning face (the laboriousness of the work, the costs of maintaining the workings, because of the slowing down of the extraction sections), we give a general view of the extraction costs model at the time

$$D_{d_t} = 1210 \times n_c \times r \left(0{,}977 m_{r_t} - 0{,}624\right) \times \left[\frac{V_{aw_t}}{0{,}557 V_{ap_t} + 2{,}479}\right] \times \times \left(1{,}46 - \frac{61{,}464}{L_{l_t}}\right) \times (1{,}014 - 0{,}0092 \times \alpha_a) \times k_h \times k v_t \times k_m \quad (8)$$

where: V_{av} is the average working speed feeder; α_l is the angle of incidence of lava, degree; m_r is the removable bed capacity; *r* is the width of the grip of the executive body; L_l is the length of the face; $k_h$is a coefficient that takes into account the tectonic disturbance of the formation.

$$k_h = 0{,}571 + 0.053 \times \left(\frac{h}{m}\right)^{-1} \quad (9)$$

where: $h/_m$ is the ratio of the amplitude of the tectonic disturbance and the extractable thickness of the reservoir, m; k_{vl} – coefficient taking into account the effects of variability in the angle of incidence of the formation in the bottom face (Δα):

$$k v_t = (1{,}014 - 0{,}0092 \alpha_l) \times (0{,}955 - 27{,}19 \Delta\alpha \quad (10)$$

Variations of the index along the length of the face form the convexity or concavity of the sections and affect the load on the cleaning face. They are defined as the ratio of the standard deviation of this indicator within the excavation field to the total area of the excavation field accepted for design or within which the influence of the indicator (*S*):

$$\Delta\alpha = \frac{\delta_\alpha}{S}, \delta_\alpha = \frac{\sum(\alpha_{0_i} - \bar{\alpha}_0}{n} \quad (11)$$

where: α_i is the observed i-th value of the indicator, deg., *i* = 1, 2,…, *n*;

ᾱ is the average of the observed indicators.

Accounting for this factor is necessary, since it determines the quality of the coal to be extracted, and, consequently, its value. When analyzing this information, it is established that if the fluctuation of the angle of incidence of the formation in the cleaning face occurs within the limits of its withdrawable capacity, this does not affect the speed of slaughter movement, since the resistance of coal to cutting does not change (Chiroma *et al.* 2017). In accordance with these, the ratio parameter of the total (m_f) and removable (m_r) reservoir thickness ($K_r = \frac{m_f}{m_r}$) and the effect of this parameter on the load on the cleaning face ($K_{мв}$). As a result, the following dependence is obtained:

$$K_{MB} = (1{,}74 - 0{,}817\ K_m)^{-1} \quad (12)$$

Justification of the expediency of involving in the development of reserves and increasing investment income, and, consequently, investment attractiveness can be expressed as follows: you can involve reserves in workings until the increment in costs for their extraction is less than the increase in additional income from a decrease in specific investments. That is, if in the i-th section the inequality.

$$\Delta I_i - Q_i \times C_{0_i} > 0 \quad (13)$$

Then this area is advisable to involve in development. Intensification of industrial production is predetermined by an increase in the demand for energy raw materials, including the need for coking coal, coals for energy and for household needs. If the growth rate of the demand for coal continues, then by 2020 it will amount to about 500 million tons, including 160-180 million tons by underground. Uncovered demand, in case of conservation of their production at the current level, will reach a value of about 40 million tons.

Conclusion

If during the last five years coal enterprises have carried out their activities, relying on the potential laid in the development of mines prior to privatization, now this potential has been worked out. To carry out further activities, it is necessary to search for technical, technological and organizational solutions aimed at the rational use of mining workings, the concentration of mining operations, the most complete extraction of open stocks, which will ensure more efficient use of investments in the development of enterprises. The main task of modern investment projects in the industry should ensure the receipt of competitive products based on the search for optimal design solutions that ensure the creation of more sophisticated technological complexes and shorten their payback periods.

In accordance with the above, the problem of developing design solutions has the following directions:

- design solutions aimed at developing reserves of low-power and complex structure strata;
- design solutions aimed at developing local sites at operating mines;
- design solutions aimed at testing the margins of the excavation fields depending on their size and configuration.

If we consider the problem of the development of the coal industry from the point of view of state, national interests, then the mining of reserves should be carried out taking into account the maximum completeness of their seizure. The incentive for such technological decisions to be made by subsoil users in this direction should be an effective taxation system.

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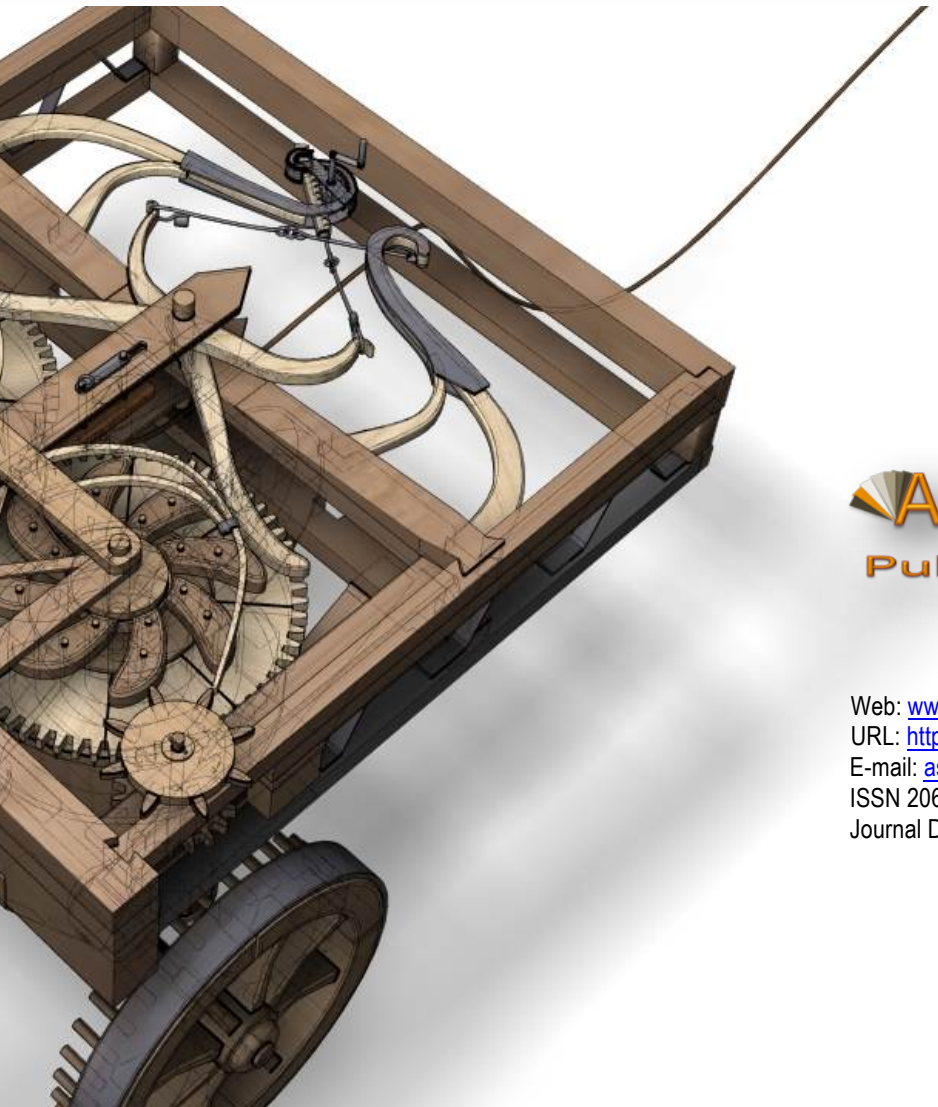

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