https://doi.org/10.31713/m1219

DEVELOPMENT STRATEGY FOR UNDERGROUND MINING OF RICH IRON ORES CONSIDERING LAND ALIENATION BY KRYVBAS UNDERGROUND MINES

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Abstract

According to preliminary estimates, by 2050, about 70% of mining enterprises in Kryvyi Rih iron ore basin will have exhausted their balance reserves of naturally rich iron ore or reached the maximum economically feasible depth of mining at current production volumes and with the current level of mechanization. Mining enterprises can prolong their performance by mining naturally lean iron ores (magnetite quartzites) which amount to over 5.0 B t. Mining magnetite quartzites by systems with bulk caving of ore and overlying rocks requires abandoning a significant amount of iron ore reserves (over 60%) in protective pollars, or expanding mining and land allotments. Land has to be alloted towards residential and industrial sites of Kryvyi Rih. Land allotment expansion results in increased costs for compensating losses to enterprise owners and for land reclamation. Thus, it is advisable to mine magnetite quartzites applying systems that leave the daylight surface undisturbed, improve the quality of the extracted mineral, increase extraction indicators and reduce disturbed land areas. The research findings can be used in underground mining of naturally lean iron ores at all mines of Kryvyi Rih iron ore basin when working out reserves to a depth of 500 m.

Keywords: underground iron ore mining, sheart zone, land plot alienation, investments, time factor, discounting, discounted capital investments.

Introduction

The mining industry is of strategic importance for economic development and ensuring Ukraine's competitiveness in the global market. The lands provided for subsoil use are the spatial and operational basis for geological exploration of subsoil and location of mining enterprises. Proper organization of land use makes an important area of ensuring performance of a mining enterprise.

The issue of land use for underground mining has been studied by various scholars [1-6], but they mostly consider problems of legal regulation and protection of land provided for subsoil use within the legal regime of industrial land, while specifics of land allocation and use for underground mining remains unaddressed.

The use of land by mining enterprises is characterized by certain specific features due to the fact that the right to use land plots is inextricably linked to the right to subsoil use. These features include, in particular, acquisition of land rights.

The size and configuration of land allotment are determined by the structure of the mining enterprise and parameters of mining allotment in compliance with the state regulations and design documentation approved in accordance with the established procedure. They should be comprehensively justified and minimum required.

Currently, almost all Ukraine's land is assigned to certain owners or users of various categories. The land necessary for subsoil use is not a single land plot falling into the category of industrial land only, but it is located within areas of other categories as well [7-10].

In this regard, in order to carry out almost any work on prospecting, exploration and mining of mineral resources, it is necessary: first, to alienate (buy out, expropriate) a relevant land plot (territory) from its owner or user; secondly, to transfer it to a relevant subsoil user.

Thus, at present, the institution of land alienation from owners and users of land of various categories in favor of mining enterprises for prospecting, exploration and development of mineral deposits is one of the most topical and important.

Alienation of lands of various categories by mining enterprises from owners and users results in new land uses that form the enterprises' land allotment.

Therefore, the enterprise has to allot the newly formed land use for subsoil use needs in order to formalize the right to use it on a lease basis. To do this, the enterprise is first of all to plan the process of land alienation from their owners and users. Further safe and efficient performance of the enterprise depends on its effective implementation.

Analysis of researches and publications

The JSC *Kryvyi Rih Iron Ore Plant* (*Kryvbaszalizrudcom*) is one of Ukraine's largest underground iron ore mining enterprises. The *Ternivska* mine is one of four underground mines that are part of the JSC *Kryvbaszalizrudkom* and was commissioned in 1963 [11].

The mine works out a deposit of naturally rich ores and magnetite quartzites located in the north of Kryvyi Rih iron ore basin and is administratively part of Ternivkyi district of Kryvyi Rih, Dnipropetrovska oblast.

The *Ternivska* underground mining allotment covers 426,5 hectares, and its boundaries (Fig. 1) run along those of Ordzhonikidze mining allotment (the PrJSC *Central GZK*) in the south and on the territory of T ernivkyi district of Kryvyi Rih in the north, east and west.

The mining allotment contains mine shafts and complexes of industrial facilities, a caving and shear zones, dumps, and *Gorky* residential area in the northern part.

The ore deposit is opened in the center of the mine field by one ore-hoisting shaft of the *Ternivska* mine currently sunk to a depth of 1425 m, and two ventilation shafts on the flanks: the *Flanhova* mine in the south and the *Pivnichna-Ventyliatsiyna* mine in the north. The *Flanhova* shaft is sunk to 1350 m, and the *Pivnichna-Ventyliatsiyna* one – to 1200 m.

At the *Ternivska* mine, the ore deposit is mined applying level (sub-level) induced caving systems, mainly a level-room system with a level height of 75 m and many options of sub-level caving.

Currently, the *Ternivska* mine extracts iron ore from the 1275-1350 m level. Mining is performed by double levels with a total height of 150 m, of which the level 1275 m is intermediate and the level 1350 m is the main one [12-15].

The mine's industrial site has a full range of technological buildings and facilities for receiving and processing raw ore, producing and shipping commercial products.

Fig. 1. Surface plan of the Ternivska mine of the JSC Kryvbaszalizrudkom: *1* – mining allotment; *2* - land allotment

As of 2022, the mine's annual production capacity is 1,161 Mt.

The mine has also started introducing imported high-performance mining equipment.

The land allotment of the *Ternivska* mine consists of three separate land plots, see. Fig. 1, located in the industrial and production zone of Ternivskyi district of the city within the mine's mining allotment. The land plots are not a single area, they are separated from each other by common use roads that are access ways to other users' plots located within the mining allotment of the *Ternivska* mine. The total area of the land allotment is 244,5516 hectares.

Extraction of large volumes of rocks from the subsoil and their movement to another territory change the stress-strain state of rocks, [16-20]. And this, in turn, affects the processes of rock mass displacement which can reach the surface and cause strains and destruction of industrial and civilian facilities located in this zone, Fig. 2.

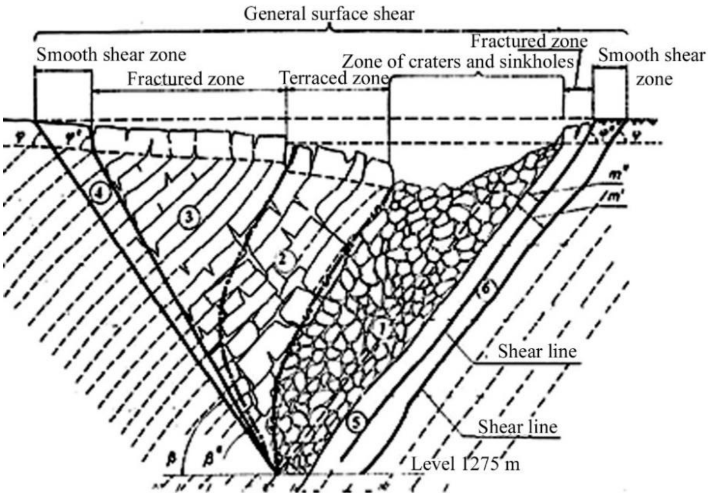

Fig. 2. Areas and zones of various strains of the massif and the earth surface in the across the strike section of the sheet-like deposit: *1* – the caving area; *2* - the shear area; *3* – the fractured area; *4* – the area of smooth deflection; *5* - the area of the layer shear; *6* - the area of smooth shear of layers

Depending on the specific combination of mining, geological and technological factors, the process of rock displacement can be localized at depth or, having reached the surface, manifest itself in various forms such as craters, sinkholes and other disturbances of the surface.

Thus, underground mining operations and extraction of millions of tonnes of rock mass from the subsoil using systems with induced caving of ore and country rocks result in significant man-made disturbances of the geological structure of the subsoil in the form of cavities within the mine's mining allotment. Gravity makes the rocks surrounding such cavities move, thus causing development of rock displacement which leads to formation of a general shear zone on the earth surface consisting of areas of various strains.

Ore deposit mining is accompanied with shears and the threat of sudden sinkholes that cannot be predicted timely. Therefore, all industrial and public surface and underground facilities, artificial and natural reservoirs that fall within the zones of influence of underground workings are subject to changes, damages, destructions and complications that disrupt their normal operation mode.

According to technological design standards of mining enterprises [21], facilities that fall within the design zone of dangerous strains should be relocated beyond this zone or protected from deleterious effects of mining operations.

When designing underground mining operations, it is necessary to determine feasibility of developing new areas of deposits at depths below the hoisting capabilities of mine shafts [21,22].

According to the "Rules for protection of structures and natural objects from the temporary impact of underground mining operations in Kryvyi Rih iron ore basin" [23], the feasibility study identifies the design zones of earth surface shear caused by iron ore deposit mining to the level 1500 m in two options:

- option I – working out all reserves to the 1500 m level;
- option II - mining the reserves with part of ore abandoned in pillars to protect the surface of the residential area.

The design boundaries of the earth surface shear zones of the two reserve mining options are shown in Fig. 3.

According to *option I*, when mining all reserves up to the level 1500, the design shear zone includes a significant part of *Gorky* residential area and the ponds, see Fig. 3. This option provides for relocation of residential buildings and utilities that fall within the shear zone caused by rich ore mining to the level 1500 m. Thus, according to option I, the following are subject to relocation: 302 private households, 2 shops, a school, a kindergarten, a gas distribution point, an Orthodox church, housing and utility buildings and the ponds.

Option II involves mining the deposit reserves while abandoning part of ore in protective pillars to prevent disturbances of the residential area surface, see Fig. 3. For this purpose, pillars within surveying axes 70-78 and 109-117 are mined from the 1350 m level with an extension to the 1500 m level by planes inclined at 85° to the level. The width of the pillars along the strike is 94 m on the 1350 m level and 120 m on the 1500 m level.

Fig. 3. Formation of the shear zone and the new land use within its boundaries for subsoil use needs at the *Ternivska* mine, the JSC *Kryvbaszalizrudkom*: *1* – boundaries of the mining allotment of the *Ternivska* mine; *2* – boundaries of the land allotment of the *Ternivska* mine; *3* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores without leaving pillars, level 1350-1500 m, the *Ternivska* mine (option I of the feasibility study); *4* – design boundaries of the earth formation according to option II of the feasibility study accepted for further deposit mining, the *Ternivska* mine

The mentioned pillars on the 1350-1500 m level along with the existing ones on the 1200-1350 m level ensure localization of the shear zone on the earth surface within the shear zone resulted from mining the deposit to the 1500 m level. The earth surface beyond the shear zone resuled from mining the deposit to the 1500 m level remains undisturbed. The residential area and the ponds are preserved. That is, according to option II, only 109 private households and a shop that fall within the design shear zone are subject to relocation.surface displacement zone when mining naturally rich iron ores with pillars left, level 1350-1500 m, the *Ternivska* mine (option II of the feasibility study); *5* – protective pillars (option II of the feasibility study); *6* – the area of a new land use

Thus, the area of land to be alienated under option II of the deposit mining is much smaller compared to that under option I, see Fig. 3.

The areas of the earth surface shear zones caused by iron ore mining to the 1500 m level of the *Ternivska* mine of the JSC *Krybaszalizrudkom* under the mentioned two options are shown in Table 1.

Land plots are alienated as the shear zone develops.

Table 1

Areas of shear zones caused by mining the naturally rich iron ore deposit to the 1500 m level

Zone	Area, hectares	
	Option I	Option II
Shear zone	269	153
including:	-	-
zone of probable crater formation	120	92
fractured zone and shear zone (boundaries coincide)	149	61

Based on the feasibility study [24], for further ore reserves mining on the 1350-1500 m level of the *Ternivska* mine, option II of mining rich iron ores is accepted. According to it, part of ore is abandoned as protective pillars. The option ensures localization of the shear zone on the earth surface within the shear zone resulted from mining the deposit to the 1500 m level, and prevention of part of *Gorky* residential area, which will then be beyond the zone, from earth surface disturbances.

According to the second option of the feasibility study, the design boundary of the shear zone caused by mining on 1350-1500 m level dermines the boundary of the mine's new land use area which is to be allocated for subsoil use needs of the JSC *Kryvbaszalizrukom*, Fig. 3.

To ensure the timely and efficient implementation of the process of alienation of private land plots that will fall into the earth surface shear zone during further deposit mining at the level 1350-1500 m, the enterprise should first address the issue of its effective planning.

Purpose

The *research aims* to ensure the further safe and efficient performance of a mining enterprise applying the underground mining method by improving the planning of the process of alienating land plots of the shear zone during further iron ore reserves mining at the *Ternivska* mine of the JSC *Kryvbaszalizrudkom* through determining the optimal scenario for investing in the alienation process, considering its dynamics conditioned by spesifics of the deposit mining technology.

For this, the following *tasks* should be solved:

1. To study the dynamics of the land alienation process in space and time, considering spesifics of the technology for mining the deposit at the *Ternivska* underground mine
2. To plan the enterprise's investments in land alienation by developing investment scenarios for the alienation process, considering its dynamics in space and time conditioned by spesifics of the mining technology.
3. To assess economic efficiency of the developed investment scenarios for the alienation process, considering the time factor, and in accordance with the established optimality criterion, to determine the cost-effective (optimal) investment scenario for the alienation process.

Metods

A wide range of general scientific methods, including traditional ones of empirical and theoretical knowledge, are used to conduct research into land management uses. The empirical research methods include observation, description, experiment, comparison, measurement, questionnaire-based survey, testing, etc. In addition to these specific methods, at the empirical level of scientific knowledge methods that are general (general logical) for both the empirical and theoretical levels are used such as abstraction, induction and deduction, generalization, analysis and synthesis, analogy, modeling, etc [25].

The methods of analysis and synthesis are associated with division of the land management object under study into its constituent elements and their combination into a single whole, respectively. A more complex mathematical analysis, as a rule, is applied to determine the influence of certain factors (values, arguments) on the dependent variable (function, result).

1. Methods of monetary valuation of land plots

For all categories of land in settlements (except for agricultural land and water fund land plots used for fish farming), the normative monetary value of one square meter of land is determined by the formula

$$C_n = \frac{B \times H_n}{H_k} \times K_f \times K_m, \quad (1)$$

where C_n is the normative monetary value of 1 m^2 of land, UAH; B is the cost of developing and arranging the territory per 1 m^2, UAH; H_n is the profit margin (6%); H_k is the capitalization rate (3%); K_f is the coefficient describing the functional use of a land plot (for residential and public buildings, industry, transportation, etc.); K_m is the coefficient describing the land plot location.

The coefficient describing the land plot location (K_m) is determined by three groups of regional, zonal and local rent-forming factors and calculated by the formula

$$K_m = K_{m1} \times K_{m2} \times K_{m3}, \quad (2)$$

where K_m is the coefficient describing the land plot location; K_{m1} is the coefficient describing regional factors of the land plot location, in particular: population and administrative status of the settlement, its place in the settling system; location within settlements in the suburban areas of large cities; accommodation within settlements with the status of resorts; K_{m2} is the coefficient describing zonal factors of land plot location within settlements, in particular: distance to the settlement center, concentrated workplaces, and recreation places; location in the core of large cities and other settlements of particular historical importance, in the coastal zone of settlements; K_{m3} is the coefficient describing local factors of the land plot location in terms of territorial planning, engineering and geological, historical and cultural, natural landscape, sanitary and hygienic conditions and the level of territory arrangement.

Normative monetary valuation of land in settlements is carried out in three stages [26,27].

At the first stage, the average (basic) cost per square meter of land in a settlement, which depends on location of the settlement in the national, regional and local production and settling systems and the level of development and arrangement of the territory, is determined by the formula

$$C_{nm} = \frac{B \times H_n}{H_k} \times K_{m1}\,. \tag{3}$$

At the second stage, within a settlement, the base value of one square meter of land is differentiated by economic and planning zones, which are established on the basis of an economic assessment of the settlement territory, considering heterogeneity of functional and planning qualities of the territories that influence the amount of rental income; accessibility to the settlement center, labor activity centers, public service and recreation centers; the level of engineering support and landscaping; development of the public service sector; environmental qualities and attractiveness of the territories. The cost of one square meter of land in settlements by economic planning zones is calculated by the following formula

$$C_{nz} = C_{nm} \times K_{m2}\,. \tag{4}$$

At the third stage, the monetary valuation of individual land plots is carried out. The value of one square meter of a land plot of a certain functional purpose is determined considering the territorial-planning, engineering and geological, historical and cultural, natural landscape, sanitary and hygienic, engineering and infrastructure features of its location within the economic planning zone according to the formula

$$C_n = C_{nz} \times K_f \times K_{m3}\,. \tag{5}$$

The normative monetary value of a land plot is subject to indexation. The general procedure for indexation of the normative monetary value of land is established by Art. 289 of the Tax Code of Ukraine [28], according to which the State Service of Ukraine for Geodesy, Cartography and Cadastre annually calculates the indexation coefficient of the normative monetary valuation of land based on the consumer price index for the previous year, by which the normative monetary valuation of agricultural land, land of settlements and other non-agricultural land is indexed as of January 1 of the current year.

Thus, considering indexation of the normative monetary value, (5) takes the following form

$$C_n = C_{nz} \times K_f \times K_{m3} \times K_i\,, \qquad (6)$$

where K_i is the coefficient of indexation of the normative monetary value of land, which is applied cumulatively depending on the date of the normative monetary value of land.

2. Economic and mathematical method of research

Capital investment planning at an enterprise involves calculating the required amount of production investments for the calculation period and determining sources of capital financing.

Development of an enterprise's investment strategy is a necessary condition for its efficient investment activity and includes the following:

- formulating investment activity directions and a system of long-term goals;
- deciding on the most effective ways to achieve the goals.

The official methodology for assessing the economic efficiency of production investments (capital investments) involves determining their overall (absolute) or comparative (feasibility assessment) economic efficiency.

An indicator of the comparative efficiency of capital investments is the *discounted costs minimum* (B_{pr})

$$B_{pr} = C_i + E_n \times K_i \rightarrow min\,, \qquad (7)$$

where B_{pr} is the discounted capital expenditures (investments), UAH; C_i is the cost of annual output under the *i*-th investment option, UAH; E_n is the normative coefficient of capital investments efficiency; K_i is investments under the *i*-th option, UAH.

Thus, when developing possible scenarios for investing in the process of land alienation, its dynamism in time and space should be considered. In order to assess economic efficiency of capital investments and determine the optimal investment scenario, it is advisable to use the comparative efficiency of capital investments under each scenario, considering the time factor, accepting the discounted capital expenditures minimum as the optimality criterion.

The difference in the time of capital investments is considered by discounting them to the same period of time using the *discount factor e*, which is determined by the expressions:

a - to discount earlier expenditures to any later year

$$e_p = (1 + E_n)^{t_k}, \tag{8}$$

b - to discount later expenditures to any earlier year

$$e_n = \frac{1}{(1 + E_n)^{t_k}}, \tag{9}$$

$$t_k = t_d - t_i, \tag{10}$$

where E_n is the discount rate, or the normative coefficient of capital investment efficiency (considers the degree of entrepreneurial risk, in a typical methodology for determining economic efficiency of capital investments for a mining enterprise, it equals 0.08 [28, 29]); t_k is the indicator of the power of the discount factor, which is equal to the time interval between the year of discounting and the year of investment, years; t_d is the serial number of the year of capital expenditures discounting; t_i is any *i*-th year of capital expenditures, which is counted from the beginning of the alienation process and varies from 1 to *t* years.

Practical application of discounting to determine the discounted current value of cash flows requires appropriate financial and mathematical formalization of the discounting model - determining the absolute value of the discount.

In a typical methodology for determining economic efficiency of capital investments for ferrous metallurgy enterprises, the size of the discount rate varies within 0,08÷0,15 [28, 29].

Thus, efficiency of capital investments is significantly influenced by inflation and risk, considering the fact that the discount rate takes these factors into account.

Capital investments can be made in several stages with different implementation periods. Any year from the beginning of the investment project can be taken as the moment of assessing efficiency of capital investments within the life of the project. Thus, considering (8) and (9), the total discounted capital expenditures are calculated by the following formulas

$$K_{pr.p} = K_1 (1 + E_n)^{t_d - 1} + ... + K_i = \sum_{1}^{t} K_i \, (1 + E_n)^{t_d - t_i}, \tag{11}$$

$$K_{pr.n} = \frac{K_1}{(1 + E_n)} + \frac{K_2}{(1 + E_n)^2} + ... + \frac{K_i}{(1 + E_n)^{t_1 - t_i}} = \sum_{1}^{t} \frac{K_i}{(1 + E_n)^{t_d - t_i}}, \tag{12}$$

where $K_{pr.p}$, $K_{pr.n}$ are the discounted capital investments (expenditures) from the earlier to any later year and the later to any earlier year, respectively, M UAH; t is total duration of the investment project, $t=t_I+t_{II}+\ldots+t_N$, years; t_I, $t_{II},\ldots$, t_N are duration of the first, second, ..., N-th period of the investment project, years; K_i is initial capital expenditures of any i-th calendar year of the investment project, UAH;

Thus, using the discounting method, future capital expenditures (investments) are discounted to the current value, resulting in comparable absolute values of the cost of future capital expenditures.

Results

According to the feasibility study [24], for further working out at the 1350-1500 m level of the *Ternivska* mine, the second option of mining rich iron ores is accepted which provides for abandoning part of ore in protective pillars and determines the design boundary of the earth surface shear zone. The design boundary of the shear zone determines the boundary of the area for formation of a new land use of the mine, which is to be alienated for the needs of subsoil use by the JSC *Kryvbaszalizrudkom*.

Thus, due to necessary forced abandonment of disturbed land (earth surface shear zone), a new land use is being formed on part of the territory of *Gorky* residential area between the design boundary of earth surface shear zone caused by mining to the 1500 m level (according to the second option of the feasibility study) and the boundary of the mine's current land allotment - the fourth component of the *Ternivska* mine's land allotment.

Within the newly formed land use there are lands of two forms of ownership - private (land of the residential buiding area – citizens' personal land plots) and communal land (public lands that are free from development, not provided for ownership or permanent use).

The design boundary of the shear zone caused by deposit mining to the 1500 m level (according to the second option of the feasibility study), which determines the boundary of the territory for a new land use of the *Ternivska* mine, runs accross the area of some land plots on Bakinska, Tychyna, Shchelhunov and Heroiv Brestu streets, dividing them into parts. That is, it is not the total area of these land plots that is subject to alienation, but their parts that fall within the shear zone.

The boundaries of the design land use shown in Fig. 4 coincide with actual boundaries of the land plots in the north, east and west, and run along the boundary of land plot No.1 of the current land allotment of the mine [30].

Fig. 4. Designed new land use of the *Ternivska* mine: *1* – boundaries of the mining allotment of the *Ternivska* mine; *2* – boundaries of the land allotment of the *Ternivska* mine; *3* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores without leaving pillars, level 1350-1500 m, the *Ternivska* mine (option I of the feasibility study); *4* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores with pillars left, level 1350-1500 m, the *Ternivska* mine (option II of the feasibility study)

The total area of the newly formed land use within the designed boundaries (see Fig. 4) makes 20,1724 hectares.

Thus, our research considers the generalized areas of individual land plots within their design boundaries at certain addresses and the design total area of residential development land under the land plots to be alienated, which is 16,6652 hectares.

Due to mining operations, the process of land alienation is dynamic in space and time. Its dynamics in space is described by *se-*

quence (alienation of a certain number of land plots in the corresponding land use area), and in time - by *duration* of alieniation. These characteristics are the basis for planning the alienation process.

Given the iron ore mining technology of the *Ternivska* mine, the sequence and duration of the process of alienating privately owned land plots should be established.

According to the feasibility study [24,30], alienation of all privately owned land plots within the designated area of land use under residential development is planned for the time of completion of the mine reserves up to the 1350 m level, i.e. before starting operations at the level 1350-1500 m.

The sequence of land alienation consists in determining certain parts of the land use area with the corresponding number of land plots within them to be alienated in the first and second place.

As mentioned above, the mine is currently producing iron ore at the 1275-1350 m level. Therefore, further mining of the deposit to a depth of 1500 m involves creation of two levels - 1425 m and 1500 m, which form two floors - 1350-1425 m and 1425-1500 m, respectively, with each of them creating the corresponding boundaries of the shear zones on the earth surface.

Thus, first, the 1425 m level is worked out and a shear zone is formed from the 1350-1425 m level, then the 1500 m level creates a shear zone of the 1425-1500 m level, Fig. 5.

Fig. 5 displays the boundaries of the shear zones caused by mining 1350 m, 1425 m, and 1500 m levels on the surface plan. They determine development of the earth surface shear process with further increase of the deposit mining depth up to 1500 m and establish the sequence of land alienation by shear zones within which they fall.

The land use area beyond the shear zones is conditionally divided into *alienation zones*. Fig. 6 shows that each of them includes a certain number of land plots subject to alienation.

Alienation zone I is created between the boundary of the current land allotment and the design boundary of the shear zone when mining the 1350-1425 m level. Its boundaries run along the boundary of the current land allotment and boundaries of land plots, and its area makes 4.2089 hectares;

Alienation zone II is created between the design boundaries of the shear zones during mining 1350-1425 m and 1425-1500 m levels. Its boundaries run along those of land plots and its area makes 12,4563 hectares.

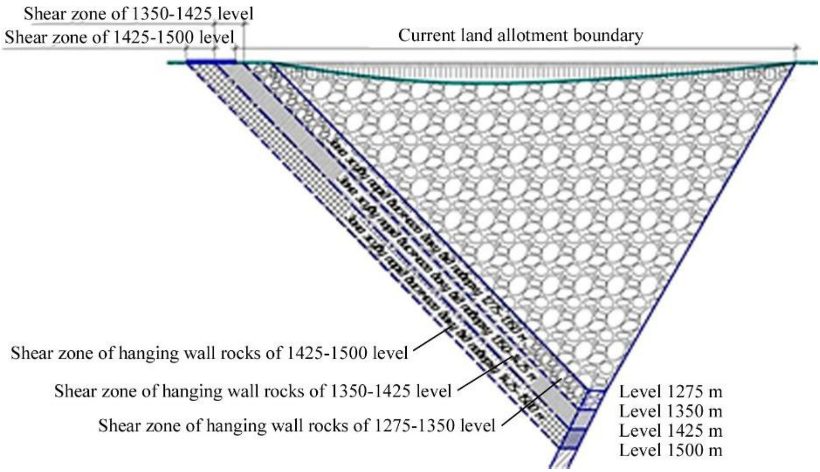

Fig. 5. Rock and earth surface shear zones caused by mining the 1350-1425 m and 1425-1500 m levels on the across the strike section of the *Ternivska* mine deposit of the JSC *Kryvbaszalizrudkom*

Thus, the sequence of land plot alienation is determined by the technological sequence of mining levels and development of the shear zone with further increase in the mining depth and shoud be as follows.

To work out the 1350-1425 m level, it is necessary to alienate the first zone at the time of completion of the 1350 m level and the beginning of creation of the 1425 m level (before completion of the 1275-1350 m level).

To work out the 1425-1500 m level, it is necessary to alienate the second zone at the time of completion of the 1425 m level and the beginning of creation of the 1500 m level (before completion of the

1350-1425 m level), Fig. 7.

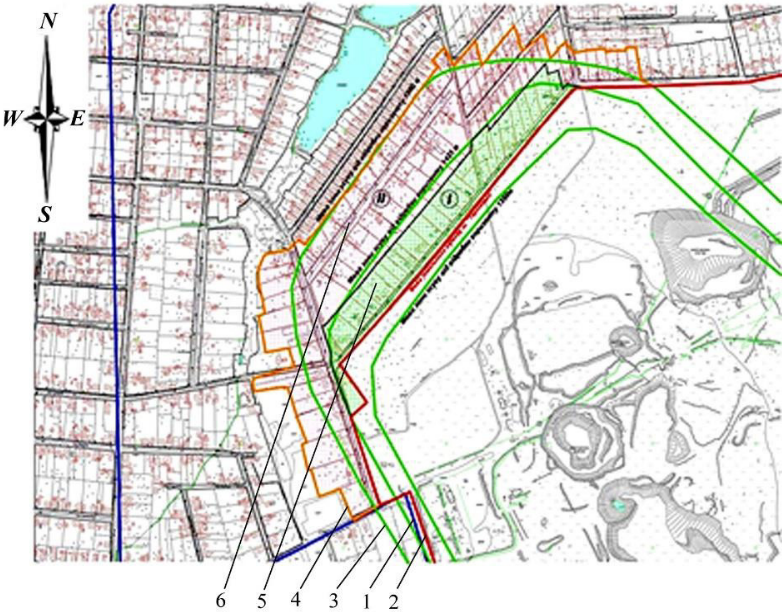

Fig. 6. Division of land use of the *Ternivska* mine into alieniatinon zones corresponding to the shear zones caused by mining the respective levels: *1* - the boundary of the mining allotment of the*Ternivska* mine; *2* - the boundary of the current land allotment of the*Ternivska* mine; *3* - the newly created land use between the design boundary of the share zone (feasibility study option II) the boundary of the current land allotment of the*Ternivska* mine; *4* - boundaries of the shear zone caused by mining levels 1350, 1425, 1500 of the*Ternivska* mine; *5* - alieniation zone I – land plots that fall within the shear zone when mining the level 1350-1425; alieniation zone II – land plots that fall within the shear zone when mining the level 1425-1500

At the same time, it follows from the above that duration of alienation of land plots of each zone within the shear zone caused by mining the corresponding level is limited to the period of mining the previous (higher) level.

Thus, duration of alienation of land plots in zone I (the shear zone caused by mining the level 1350-1425 m) is limited to duration of mining the level of 1275-1350 m, and zone II (the shear zone caused by mining the level 1425-1500 m) - to duration of mining the level 1350-1425 m.

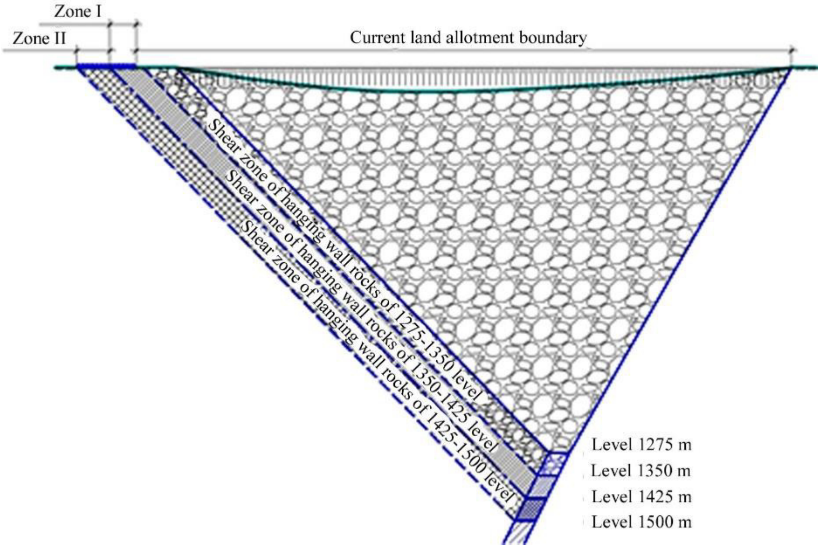

Fig. 7. Land alienation zones on the across the strike section of the *Ternivska* mine deposit of the JSC *Kryvbaszalizrudkom*

Duration of zone alienation can be found by the formula for determining duration of level mining [29]

$$t_v = \frac{Q}{A} + t_r + t_e \quad , \tag{13}$$

where $t_{в}$ is duration of zone alienation (duration of mining the level), year; Q is the amount of reserves in the level, Mt; A is the annual productivity of the enterprise, Mt; t_r is the period of the level creation, years; $t_{з}$ is the period of completion of mining the level, years; $t_r = t_e = 1{,}5$ years, since a new level is created simultaneously with completion of the previous one.

For the purpose of calculations, the year 2017 is taken as the beginning of the mining period for the level 1275-1350 m. The amount of reserves in the levels 1275-1350 m and 1350-1425 m makes 11,923 Mt and 11,359 Mt respectively [30]. According to the JSC *Kryvbaszalizrudkom* data, the annual productivity of the *Ternivska* mine is 1,161 Mt.

Let us study the dependency of alienation duration for land plots of each zone on the change in the volume of commercial production when mining reserves of the levels 1275-1350 m and 1350-1425 m. Based on calculations by (13), a diagram can be built to demonstrate the dependency of land alienation duration on the mine's annual productivity, Fig. 8.

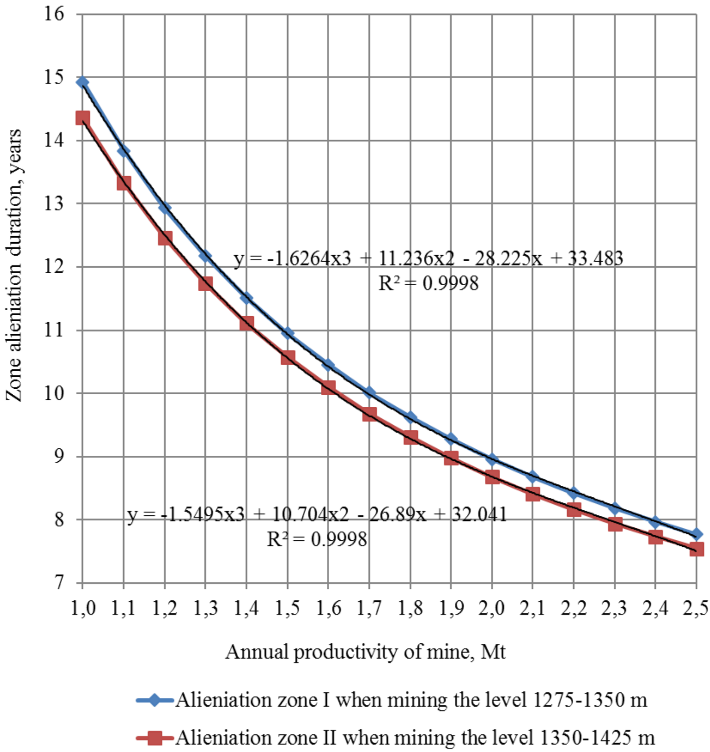

Fig. 8. Dependency of land alienation duration for two zones on the annual mine productivity and the amount of reserves in levels

Fig. 8 shows that with an increase in annual productivity of the mine from 1,0 to 2,5 Mt, duration of zones I and II alienation period decreases from 14,9 to 7,8 years and from 14,4 to 7,5 years respectively.

The obtained calculated values of duration of each zone alienation depending on commercial production volumes described by annual productivity are well approximated by polynomial curves of the third power. The latter are determined by the following equations

$$t_v = -1{,}6264A^3 + 11{,}236A^2 - 28{,}225A + 33{,}483, \quad (14)$$

$$t_v = -1{,}5495A^3 + 10{,}704A^2 - 26{,}895A + 32{,}041 \quad (15)$$

Equations (14, 15) enable determining duration of the process of land plot alienation for zones I and II when mining the levels 1275-1350 m and 1350-1425 m with the corresponding amount of reserves in them with different annual productivity.

Thus, we have established that the dependency of land plot alienation duration for each zone on the annual productivity of the mine can be approximated with a high probability by a polynomial curve of the third power. The reliability of the R^2 approximation for the diagnosed curves is determined as well, see. Fig. 8.

Thus, alienation duration for zone I (the shear zone caused by mining the level 1350-1425 m) is equal to duration of working out the level 1275-1350 m; alienation duration for zone II (the shear zone caused by mining the level 1425-1500 m) equals duration of working out the level 1350-1425 m.

Land plots included in zone I must be alieniated during 13 years within the period of 2017-2029, and those of zone II – during 13 years within the period of 2030-2042. The total duration of privately owned land plot alienation for the two zones of the land use under study makes 26 years and covers the period of 2017-2042.

Despite the fact that the land plots to be alienated are not similar in terms of their main characteristic – availability and condition of real estate objects (built-up or vacant), they are similar in terms of administrative and territorial location and the engineering and transport infrastructure.

The redemption normative value of land plots is calculated by areas of alieniation zones they belong to; the total initial investment required by the JSC *Kryvbaszalizrudkom* to carry out the alienation process is determined as well. The redemption value of a land plot (normative value) is found by the following formula

$$B_d = C_n \times S, \quad (16)$$

where B_d is the redemption value of the land plot (normative value), UAH; C_n is the normative monetary value of 1 m^2 of the land plot, UAH; S is the area of the land plot, m^2.

To apply (16), the normative value of 1 m^2 of the land plot (C_n) of residential land should be found first.

Thus, the enterprise should invest 19,448 M UAH to alienate land plots in zone I and 57,554 M UAH in zone II. The total amount of initial investment required by the enterprise to alienate the total area of land plots is 77,002 M UAH.

Given the dynamism of the land alienation process in space and time, when planning this item of capital investment, an enterprise should consider several investment scenarios and perform economic assessment of their efficiency.

At an enterprise applying the underground iron ore mining method (underground mine), the minimum specific discounted costs for extraction of 1 t of ore are used as a criterion for its optimal productive capacity [29,30]

$$B_{pr} = C + E_n \times K \rightarrow min, \tag{17}$$

where B_{pr} is the specific discounted value cost per 1 t of ore mined, M UAH/t; C is annual operating specific costs, M UAH/t, E_n is the normative capital investment efficiency coefficient; K is specific capital expenditures, M UAH/t.

To decide on the best investment scenario, comparative economic efficiency indicators are used, which consider only those cost parts that change in comparable options.

In our case, we believe that the operating and other capital expenditures of the mine, except for the cost of land alienation, are fixed.

Therefore, under our conditions, (17) is adaped and the criterion of the optimal investment scenario for land alienation is determined as the specific discounted capital investment minimum by the formula

$$B_{pr.i} = \frac{K_{pr.i}}{Q} \rightarrow min, \tag{18}$$

where $B_{pr.i}$ is the specific discounted value of capital investments (costs) for land alienation, UAH/t; $K_{pr.i}$ is the discounted value of capital investments (expenditures) for alienation of land plots, M UAH; Q is the amount of reserves in the level to which capital investments for alienation of land plots of the corresponding zone are attributed, M t.

The initial amount of investment is assumed to be the same for each scenario of investing in land alienation and estimated at 77,002 M UAH. The spatial division of the land use under study into alienation zones determines their compliance with stages of investment in the alienation process, and periods of capital investment correspond to those of zone alienation.

Given the above indicators and conditions of their application, let us consider *two scenarios* of investing in the process of alienation of privately owned land plots, which differ in terms of their implementation:

1. *Simultaneous investment* in the process of alienation of land plots of zones I and II during 13 years (2024-2036). When mining the 1275-1350 m level, we invest in alienation of land plots in zones I and II during 13 years.

2. *Staged investment* in the process of alienation of land plots in zones I and II during 26 years (2024-2049). At the first stage of the scenario, when mining the level 1275-1350 m, funds are invested during 13 years (2024-2036) for alienation of land plots of zone I, at the second stage - during the next 13 years (2037-2049) in mining the level 1350-1425 m - zone II.

For each investment scenario, even and uneven (with increased and decreased funding) options for distribution of capital investments by years are provided for.

We consider it expedient to discount capital investments in alienation of land plots at the time of zone I alienation completion (late 2036 - early 2037), which corresponds to the period of completion of mining the level 1275-1350 m and the beginning of mining of the level 1350-1425 m, since it determines the space and time distribution of the alienation process.

The item of capital expenditures for alienation of land plots of zone I refers to capital expenditures for mining the level 1350-1425 m, and the item of capital expenditures for alienation of land plots of zone II refers to capital expenditures for mining the level 1425-1500 m.

For the first investment scenario, we need to invest in alienation of zone I and zone II simultaneously, i.e. earlier, when the level 1275-1350 m is mined, so we need to make earlier investments and discount them to a later year. Thus, the capital investment for the simultaneous alienation of land plots of zones I and II is discounted to the end of this investment scenario implementation - late 2036 (the 13th year).

For the second scenario, the investment is made in two stages:

- at the first stage, we discount earlier investments to a later year of investment - capital investments for alienation of land plots of zone I are discounted to the end of the implementation period of this investment stage - late 2036 (the 13th year of the investment stage);

- at the second stage, we discount later investments to the earlier year of investment - capital investments for alienation of land plots of zone II are discounted to the beginning of the implementation period of this stage of investment - at early 2037 (the 1st year of the investment stage).

Thus, for each of the studied options of by-year distribution of capital investments for the two scenarios of investing in land alienation, we discount different time periods of capital investments to the same period of 2036-2037 through the normative indicator of their efficiency (discount rate) of 0.08 and obtain comparable absolute values of future capital investments, the analysis of which enables an adequate management decision on investing in the alienation process.

Based on the determined values, diagrams of dynamics of the discounted capital investment amounts can be built according to different options of their distribution by years for two scenarios of investment in the process of land alienation (Fig. 9, 10).

Comparison of the total values of the initial and discounted capital investments in alienation of privately owned land plots under two investment scenarios with different options for distribution of capital investments by years, demonstrates that, considering the time factor, the amount of capital investments changes. This dynamics is plotted in Fig. 11.

Thus, at even distribution of capital investments by years, the total amount of the discounted value of capital investments under the first scenario (simultaneous investment in two alieniation zones during 13 years) increases from 77,002 M UAH to 127,321 M UAH, and under the second one (staged investment in each zone during 26 years) decreases from 77,002 M UAH to 67,150 M UAH.

Uneven distribution of capital investments by years is considered in two options: with increased and decreased funding. The total amount of the discounted value of capital investments under the first scenario increases from 77,002 M UAH to 106,561 M UAH and 148,080 M UAH respectively, under the second one it decreases from 77,002 M UAH to 59.983 M UAH and 74,310 M UAH respectively.

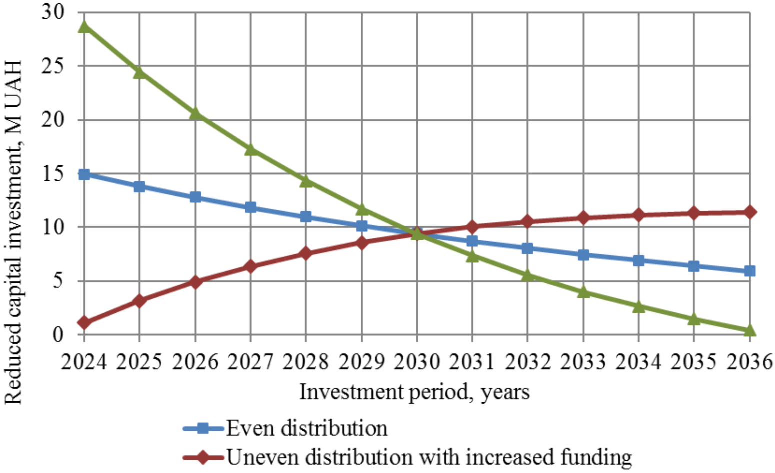

Fig. 9. Dynamics of the discounted capital investments by different options of their distribution by years of the first scenario of investment in land plot alienation

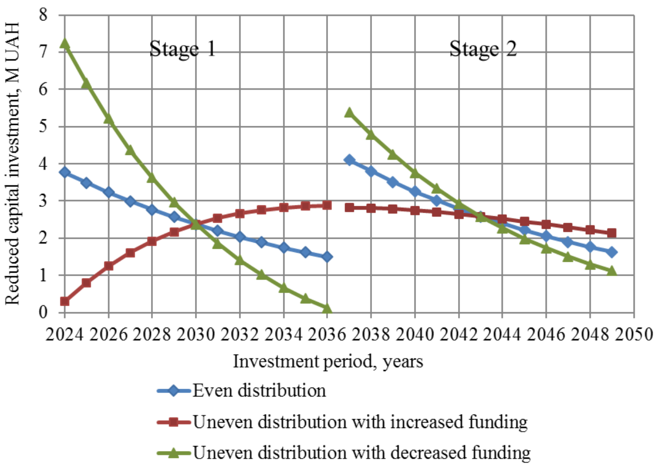

Fig. 10. Dynamics of the discounted capital investments by different options of their distribution by years of the second scenario of investment in land plot alienation

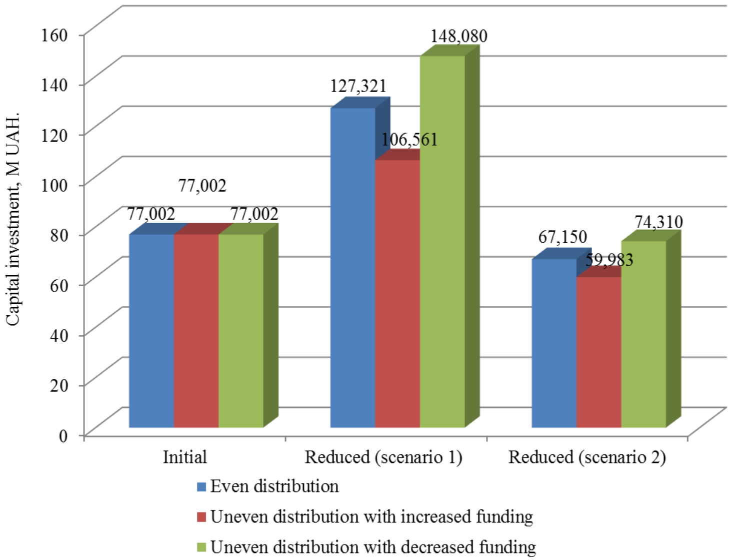

Fig. 11. Comparison of amounts of the initial and discounted capital investments by two investment scenarios for the process of land alienation under different options of their distribution by years

Thus, the amount of the discounted value of investments for alienation of land plots depends on the term of their implementation and the selected value of the normative indicator of their efficiency (discount rate).

Comparison of the calculated total values of the discounted capital investments in alienation of privately owned land plots under two investment scenarios with different options for distribution of capital investments by years, demonstrates that for all options of distribution the amount of the discounted capital investments under the second scenario is less than the first one, see. Fig. 11.

Thus, at even distribution of funds by years, the amount of the discounted value of capital investments under the first investment scenario (simultaneous investment in alieniation of zones during 13 years) equals 127,321 M UAH and under the second one (staged investment in each zone during 26 years) - 67,150 M UAH, i.e. 60,171 M UAH less.

At uneven distribution of capital investments by years considered in two options with increased and decreased funding, the amount of the discounted value of capital investments under the distribution options for the first scenario is 106,561 M UAH and 148,080 M UAH respectively. For the second one it makes 59,983 M UAH and 74,310 M UAH, which is less by 46,578 M UAH and 73,770 M UAH respectively.

Thus, the research enables establishing that it is advisable to plan investments in alienation of privately owned land plots that fall into the zone of earth surface shear during further mining of the *Ternivska* mine's iron ore deposit to a depth of 1500 m according to the second scenario, which is more cost-effective than the first one and consists in staged investment in land alienation: at the first stage of the scenario, when mining the level 1275-1350 m, funds are invested in alienation of zone I land plots during 13 years (2024-2036), and at the second stage - during the next 13 years (2037-2049), when mining the level 1350-1425 m of zone II. Investments within the timeframe of each stage should be distributed unevenly, their volumes increasing by years.

Conclusions

The research conducted enables the folloing main conclusions:

1. It is advisable to develop investment scenarios that differ not only in terms of their implementation, but also in terms of options for distributing capital investments by years (even and uneven with an increase and decrease in funding), which allows for more thorough investment analysis and planning.

2. Consideration of the time factor (discounting capital investment days to one period through a discount coefficient that takes into account inflation and business risks) when performing a comparative economic assessment of efficiency of capital investments in land alienation enables obtaining their comparable absolute values (current value of future investments), which in turn enable making adequate management decisions on investing in alienation in market economy conditions.

3. For the *Ternivska* mine of the JSC *Kryvbaszalizrudkom*, it is established that efficiency of the land alienation process is ensured

by applying its optimal investment scenario, which provides for staged investment in the alienation process: stage 1 - alienation of zone I during 13 years (2024-2036) when mining the 1275-1350 m level, stage 2 - alienation of zone II during 13 years (2037-2049) when mining the 1350-1425 m level, applying uneven distribution of capital investments within the timeframe of each stage with an increase in the amount of funding by years.

Acknowledgments

The work was supported by the Ministry of Education and Science of Ukraine within the framework of the state scientific theme «Investigation and scientific and practical substantiation of technological means for raw material control in mining ores on deep levels» (State registration 0122U000843).

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