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# RATIONAL EXTRACTION TECHNOLOGY OF FINE VEIN GOLD ORES USING SELF-PROPELLED MACHINES

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## ABSTRACT

The article discusses about an effective system development for mining of thin deposits using small-sized self-propelled machines for high efficiency and completeness of mineral extraction. Furthermore, in this research work the results are given for development of fine vein lodes by using sublevel system and high-performance, compact self-propelled machines. The developed technological scheme of ore extraction and delivery by self-propelled VSD is recommended to use in mining enterprises, which develop vein deposits with varying thickness of ore and a wide range of occurrence angles.

**Key words**: Mining, Ore, Gold, Production, Development system, Delivery, Transportation, Self-propelled machines.

## INTRODUCTION

Kazakhstan is one of the largest mining regions in the world. Gold mining has important role in the mining industry of Kazakhstan, however small part of the deposits which are strategic resource of the country is in exploitation. The research shows that in the most vein-type gold ores of Kazakhstan are about 40-50% of deposits are defined in inclined and steeply inclined deep areas with intense fracturing of the ore and host rocks and variable deposit items.

Vein deposits in Kazakhstan have significant distribution. The majority of ore minerals, such as gold, tin, tungsten and rare metals are in a vein structure[1-3].

Complex geological conditions of lode occurrence (thickness of ore bodies vary from

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a few centimetres to 1-2 m or more, the incidence angle from 0 to $90^0$, the nature of the mineralization is unseasoned, a lot of tectonic faults, irregular distribution of minerals and so on) caused to derivation of a great variety systems, lode development technologies and their mining difference from other types of ore deposits. The high value of the ores requires reduction of the thickness of the groove and improvement of the quality of the produced vein mass, which is still an important problem. Thus a radically improvement of the systems and mining processes are required for increasing the effectiveness of vein deposits.

One of the main directions of economic development of the Republic of Kazakhstan is the rational management of natural and labour resources[4]. Economic development plan of the Republic of Kazakhstan will provide a dramatic increase of the ore extraction and processing of rare and precious metals, many of them are represented by vein structure. Complex geological conditions of vein structure deposits result in a high laboriousness and low mining intensity. Development of vein deposits are characterized by complex geological conditions: most vein deposits have unseasoned thickness, unstable host rocks and tectonic faults, intermittent mineralization, changeable incidence angle. Thus, there are used various mining ways as a result of diversity and complexity of geological conditions.

Impossibility of the use of existing machines and the self-propelled high-performance equipment for the cleaning space with small width cause of slight thickness of ore bodies (1.0-1.5 m) makes laborious and expensive development of this type of deposits[5-7].

Thus, there was a need for intensification of the vein ore mining technological processes by innovative technologies using modern high-performance equipment at all stages of the mining industry.

## Mining technology of thin lode of mining camp "Akbakai"

Gold deposit "Akbakai" is one of the largest deposits of "Akbakai" ore field and is the basis of the resource base of Akbakai cluster.

The geological structure of the ore field[8] participate clastic sedimentary rocks of Ordovician - interbedded sandstone thickness and Cenozoic sediments are represented by clays, brackish and eluvial-diluvial formations. Intrusive bodies are presented by granitoid and gabbrodiobretic complexes of Devonian age. Post-Devoniansub volcanic and dike complexes are represented by small bodies of quartz porphyry, granite porphyry dikes and granodiorite, diorite and diabase porphyry, lamprophyre.

"Akbakai" refers[8] to the fields of gold-quartz-sulphide formation.

Main composition of the ore veins are quartz and secondary compositionsare non-metallic minerals which are calcite, sericite, and chlorite.

Pyrite and arsenopyrite are dominated among the minerals (more than 75% of the sulphides in the ore bodies). Other ore minerals are chalcopyrite, sphalerite, galena, antimonite, gray ores, and marcasite. The amount of sulphides decreases depending on depth (from 7-10% in the upper levels to 1.5-5.0% in the lower levels, mainly due to the reduction in the number of arsenopyrite).

According to the degree of distribution and weight there are 4 groups of minerals and elements:

- Pyrite, arsenopyrite - first percent;
- Gray ores - tenths of a percent;
- Chalcopyrite, galena, sphalerite, stibnite, marcasite - hundredths of a percent;
- Gold, silver, bismuth - thousandths of a percent.

The main valuable ore components are gold and silver. The main part of the gold (80-85%) is in a free form; remaining part is in finely divided form and contained in sulfides (mainly arsenopyrite). The finely divided form of minerals is more suitable for steeply dipping veins (17-18%) than for shallow lode (5-6%). The size of 50-70% of free gold particles is about 0.1 to 1.0 mm. The gold form is lamellar and isometric.

Earlier for the development of the deposit has been applied chamber-pillar mining method with ore extracting from the sublevel drifts depending on geological and mining conditions. This system was used for developing inclined lodes with $45^0$ incidence angle and supporting pillars were leaved in production areas in the checkerboard pattern (Fig. 1).

The ore was mined from the end of sublevel drift in receding order. The 2.6 $m^2$ supporting pillars are left inside the block to provide the necessary stability of the cleaning space roof. In the top sub-stage is left sub-drift pillar with thickness up to 3.0 m, in order to maintain the upper-vent and haulage drifts of horizon 370 m.

Between haulage drift of horizon 310 m and the last lower sublevel drifts are left pillars with thickness of 5 m, which are worked out after horizon mining.

Scraper winches type 17 LC-2s and 30LC-2s were used for transportation in production areas. The deflecting and snatch blocks type BL-300 were set up.

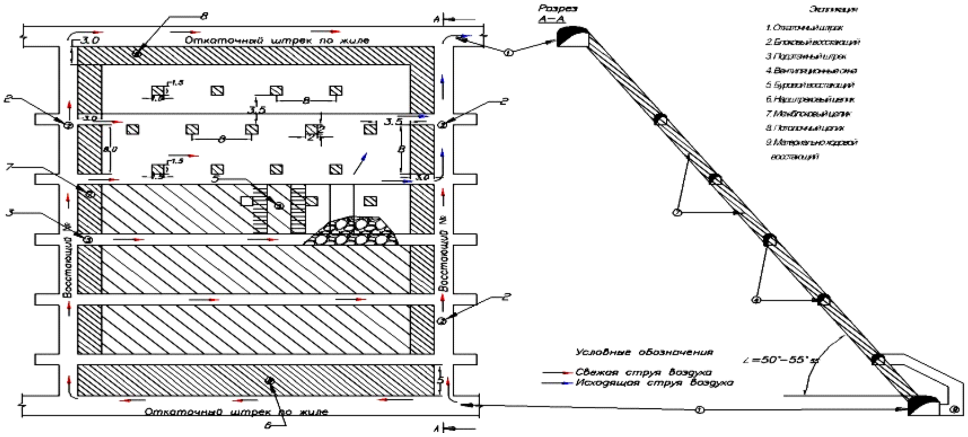

**Fig. 1: Previous chamber- pillar mining method from the sublevel drifts of the mine camp "Akbakai"**

Further, the rock mass unloaded to the central ore pass, through which the ore was loaded on a trolley type UVB-2.5 $m^3$ and stood out to the surface.

After drilling and blasting works about 50% of broken ore is remained in the block and it is not reached to scrape sublevel drift due to the shallowness of the incidence angle of the ore body. The delivery of the broken ore to scraper drift is intractable. Therefore, the exploded ore is delivered mechanically by using scraper winches.

In 2011, the company's management decided to reconstruct the factory to increase the productivity up to 1 million tons. Thus, it has been tasked to increase the productivity of the mines to supply factories. However, previous mining system was not satisfied to the new criterion because of low productivity and laboriousness. Thus, there was a need to intensification the vein ore mining technological processes by innovative technologies using modern high-performance equipment at all stages of the mining industry.

Consequently a new mining system of the thin flat dipping ore deposits of the mine camp "Akbakai" has been developed and implemented by using high-performance, compact self-propelled machines.

## The developed mining technology using small-sized self-propelled machines

Ore bodies of the Akbakai industrial area are represented by thin quartz veins[8-10], located in the resistant host rocks and only at the conjugations of inclined and dipping areas can be observed weakened zones. The stability of rocks and ores in these areas is average.

The vein thickness of Akbakai deposits is low and ranges from 0.5 m to 3.0 m. The average thickness is about 1.7 m.

In the corners of falling, the vein can be divided into two groups:

- Steeply dipping with $55^0$-$85^0$ incidence angles;
- Inclined with $25^0$-$55^0$ incidence angles.

The steeply dipping veins are "Glavnaya", "Frolovskaya" and "Yuzhnaya", which operating reserves are up 40%. The inclined veins are "Glubinnaya", "Pologaya -1", "Yubeleinaya" and "Pologaya -6", which reserves are 60%.

The "sublevel chamber system with layered ore mining by deep wells and delivery by explosion force" was established for mining of inclined veins (Fig. 2). This system provides mining of 2 types of veins in the corners of the fall:

- Inclined up to 35°;
- Inclined from 35 to 50°;

The thin vein thickness is from 1.51 m to 1.92 m.

The system is provided to mine the following veins:

- "Yubileynaya" with the incidence angle - 40°-55°, and an average thickness - 1.51 m;
- "Glubinnaya" with the incidence angle - 35° - 55°, and an average thickness - 1,61 m;
- "Pologaya-1" with the incidence angle - 45° -50°, and an average thickness - 1,92 m;
- "Pologaya-6" with the incidence angle - 30° -35°, and an average thickness - 1,74 m.

On this system the veins are divided into the groups depending on following parameters:

- The length of the block along vein strike – 100 m;
- The height of the block along the strike of the ore fall with breaking into sub-stages - (camera) L-10,0 m.

The block development is carried out from the centre to the flanks of veins, and the cameras development is carried out on uprising, in descending order.

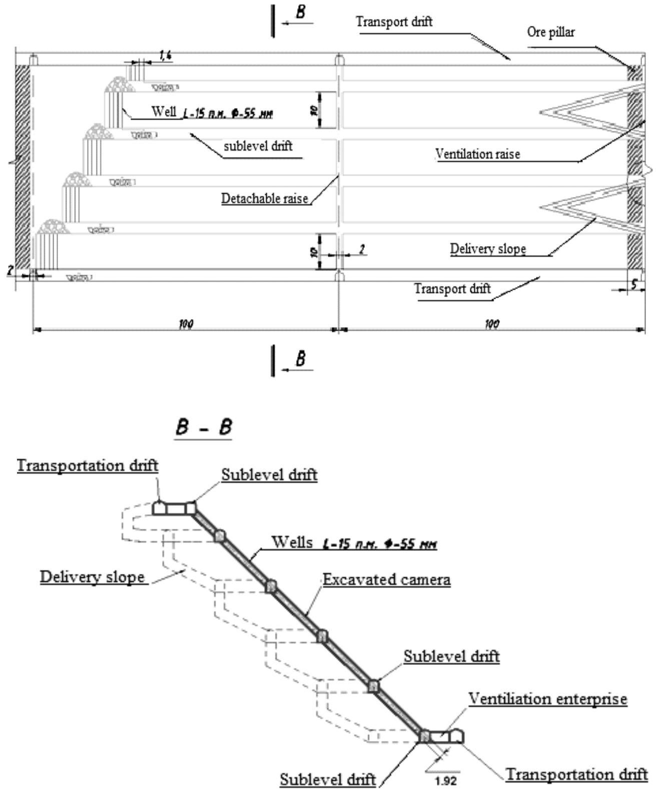

**Fig. 2: The developed mining system of the vein with an incidence angle $30^0$- $55^0$**

The preparatory works of the excavation block consist of mining of transport drift, undercutting the exploration drift (sublevel drift), which traversed on vein at the level of the horizon for refining the contour of the ore body within the boundaries of the block (Fig. 3).

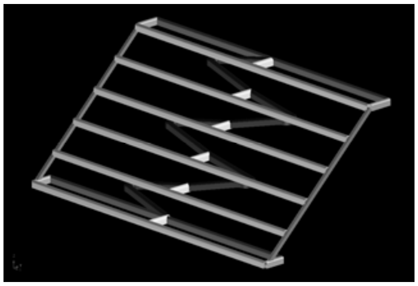

**Fig. 3: The extraction of block by inclined races and preparation by sub level-method**

The winch niche is passed through the hanging wall of the exploration drift sweeps for mining the inclined cutting raise by using scraper winch 30LC-2CM and scraping 0.25-0.3 $m^3$. Cutting raise extends to the overlying sub-stage every 50 m. The width of raise increases to thickness of the chamber and serves as a compensation space (cough) for working out and transporting ore from sublevel drifts. The distance between the sublevel drifts (roof-soil) is 8-10 m. These excavations are worked out from the block slope that extends at an angle of $10^0$ every 200 m along the vein. In this, the preparatory works are finished[8,9,11-13].

According to technical and economical basis for the mining of "Akbakai" deposit was offered the option of inclined transport unit (ITU) at an angle of $\alpha = 10^0$ from eastern flank, with the use of underground self-propelled equipment (SPE) and shaft deepening of "Glavnaya" and RESH-1 to horizon -104 m (580).

The worked out rock mass and ore will be produced by the combined method - through the elevator in the shaft of the "Glavnaya", RESH-1 and dump truck through the ITU-1 and ITU-2.

The rock mass of the central part of the deposit which is above of horizon + 296 m (180) will be transported through the ITU-1 dump trunk. The rock mass of the eastern flank of the deposit which is above horizon +136 m (340) will be transported through the ITU-2 dump trunk. Thus, the capacity of the ITU-2 is going to be 200 thousand tons per year. The remaining 300 thousand tons ore is going to be transported through the shaft "Glavnaya" and RESH-1.

The use of SPE for drilling and transportation of rocks significantly reduce the cost and increase productivity. Furthermore, it can reduce the period of construction and operation of the mine by increasing the speed of tunnel works.

## The influence of rock delivery to the basic technical and economic production figures

A lot of research was made on improving the efficiency of the self-propelled VSD and the development of rational ore mining technologies. Those researches have been studied development system parameters by using self-propelled equipment in underground mines. However, despite the significant contribution to the theory and practice of improving the development system parameters by using self-propelled equipment in underground mines and experience, the ore delivery process still remains imperfect and contains a number of little-known issues related to the specific conditions of the mining enterprises.

Therefore, there is a need to identify the nature and level of the influence of ore delivery scheme parameters on the technical and economic performance of the self-propelled

VSD and establish the relationship of mining technological processes parameters with its delivery by self-propelled machines. There is a possibility to use small-sized machines such as Scooptram ST-3, 5, TORO-6 for delivering ore and for delivering rock mass Scooptram ST- 2D. The parameters of these machines are given on the Table 1.

**Table 1: The technical characteristics of VSD**

| Index | Unit | The VSD index value | | |
|---|---|---|---|---|
| | | **Scooptram ST-3.5** | **Scooptram ST-2D** | **TORO-6 LH307** |
| 1 | 2 | 3 | 4 | 5 |
| Bucket capacity | $m^3$ | 3.6 | 1.5 | 3.0 |
| Carrying capacity | t | 6.0 | 3.6 | 6.7 |
| Loosening coefficient | - | 1.6 | 1.6 | 1.6 |
| The coefficient of bucket fullness | - | 0.9 | 0.9 | 0.9 |
| Density: - Ore | $t/m^3$ | 2.73 | 2.73 | 2.73 |
| - Rock mass | | 2.7 | 2.7 | 2.7 |
| Loading duration | min | 0.8 | 0.5 | 0.75 |
| Unloading duration | min | 0.5 | 0.4 | 0.5 |
| Duration of additional operations | min | 0.8 | 0.7 | 0.8 |
| Preliminary and final operations | min/shift | 17 | 17 | 18 |
| Workplace service | min/shift | 17 | 16 | 20 |
| Technological delays | min/shift | 27 | 27 | 30 |
| The coefficient of use per shift | - | 0.83 | 0.83 | 0.85 |

The analysis of the companies, which use VSD to deliver the rock mass from the worked out block to the ore pass by scooptrams (VSD) showed that the most significant influencing factors are the loading, transportation and unloading of the rock mass.

According to the technological projection of underground transport union norms[14], the calculated shift performance of VSD defined by the relationship

$$Q_{см} = \frac{60 \cdot T_c \cdot Z_p \cdot K_{вс}}{T_Д \cdot K_н}, \ \ T/shift, \qquad \ldots(1)$$

Where $T_c$ - The duration of the shift, hour;

$Z_p$- Estimated loading of the machine, ton.

$Z_p = \rho K_к V_к / K_p,$

Where $\rho$- ore density in the massif, t/m$^3$

$K_к = 0,8 \ldots 0,90$ - loadcoefficient of the VSD bucket;

$V_к$ – VSD bucket capacity, m$^3$

$K_p$- Ore loosening coefficient;

$K_{вс}$- Coefficient of VSD use per shift (К = 0,7…0,75);

$T_д$- The VSD trip duration, min.

$T_д = t_p + t_з + t_м + t_г + t_п,$

Where $t_p$ - Duration of unloading of VSD (≈1…1, 5);

$t_з$– Duration of VSD bucket loading (≈2,0…2,5 min);

$t_м$- Time spent on manoeuvres (≈3…4 min);

$t_г$– Duration of full machine movement, min.

$t_г = L_p / K_{ср.с} V_{ср.гр}, \ min,$

where $L_p$ – The distance between chamber and ore pass, m;

$K_{ср.с}$– Coefficient of average speed ($K \approx 1$);

$V_{ср.гр}$– Average speed of full machine ($V \approx 7,5 кm/h = 125 кm/h$);

$t_п$ - The duration of the empty machine movement, min;

$t_п = L_p / K_{ср.с} V_{ср.п}, \ min,$

where $V_{ср.п}$ – The average speed of the empty machine ($V_{ср.п}$= 12 Km/h = 200 m/min);

$K_н$- Coefficient of the work irregularity ($K_н$= 1,25).

The results of VSD shift productivity calculations on conditions of mine camp “Akbakai" are presented in Table 2.

**Table 2: The dependence of estimated VSD productivity per shift from the delivery distance**

| Delivery distance (m) | The estimated VSD productivity per shift (t/shift) | | |
|---|---|---|---|
| | Scooptram ST-3,5 | Scooptram ST-2D | TORO-601 LH307 |
| 100 | 221.7 | 84.5 | 233.6 |
| 200 | 192.9 | 68.7 | 211.2 |
| 300 | 173.1 | 57.3 | 182.8 |
| 400 | 160.7 | 51.9 | 177.3 |
| 500 | 151.0 | 48.7 | 164.2 |
| 600 | 139.8 | 45.2 | 152.8 |
| 700 | 121.0 | 43.0 | 142.9 |

The dependence of calculated VSD shift productivity on delivery distance is shown in the Fig. 3.

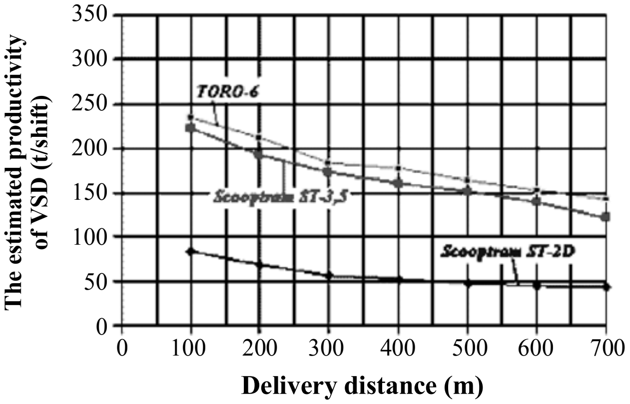

**Fig. 3: The dependence of estimated VSD productivity per shift from the delivery distance**

According to the analysis, the VSD productivity decreases by increasing of distance delivery. Mining conditions have significant impact on the VSD loading efficiency: intense zone depth of ore bulk, density of loosened ore, and the coefficient of loosening, ores, and angle of essential slope. Besides, characteristics of the VSD bucket have a significant impact on the loading.

Bucket implementation effort in bulk rock mass can be calculated by the formula considering mining-technical and construction parameters of VSD bucket:

$$F_{вн} = \frac{10 \cdot B \cdot h_о \cdot l_{вн} \cdot \rho_р}{K_р \cdot K_\alpha \cdot K_ф \cdot K_{тр} \cdot tg\varphi \cdot m \cdot tg\gamma}, \quad N, \qquad ...(2)$$

Where $B$ – Width of VSD bucket;

$h_o$ – Intense zone depth of ore bulk, m;

$l_{вн}$ – Penetration depth of the bucket in the ore bulk, m;

$\rho$ – Density of the loosened ore, kg / m3;

$K_p$ – Coefficient of ore loosening;

$K\alpha$ – Coefficient depending on the inclined plane angle of the bucket and ore bulk slope angle;

$K_{ф}$ – Coefficient depending on the form of bucket;

$K_{mp}$ – Coefficient depending on digging trajectory;

$Tg\varphi$ – The angle of repose;

$m$ – Coefficient for taking into account the effect of surface non-uniformity;

$tg\gamma$ – Internal friction coefficient.

The delivery duration, which depends on the delivery distance and the parameters of the track has a great practical interest. After statistical processing of the chronometer observations this value can be written as –

$$t_д = \left(K_1 \cdot K_2 \cdot L_д\right) \cdot f_1 \cdot f_2 \cdot f_3 \qquad …(3)$$

Where $t_д$ – Delivery time, min,

$K_1$u$K_2$ – Empirical coefficients which taking into account the impact of delivery distance ($K_1$= 40,32 u$K_2$= 1,01);

$L_д$ – delivery distance, m;

$f_1$ – Coefficient which taking into account the road condition of the delivery excavation;

$f_2$ – Coefficient which taking into account the slope angle of excavation;

$f_3$ – Coefficient which taking into account the curvature of excavation.

The calculation method of the coefficients $f_1$, $f_2$, $f_3$ is fully described in[15,16].

The dependence is graphically shown in Figure 4.

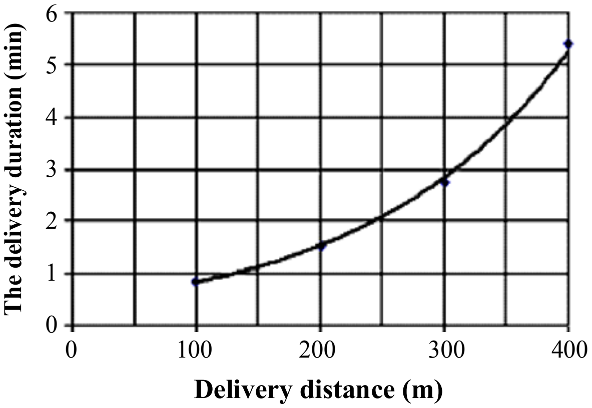

**Fig. 4: The dependence of ore delivery duration from the distance**

The unloading time of VSD in ore pass depends on the size of the transported rock mass and the presence of oversized pieces which size is more than 600 mm. Ore passes are usually equipped with a bang with a mesh of 400 ... 500 mm. Therefore, the oversized pieces have to be loaded into the bucket again and transported in a niche for secondary crushing or exploding. It means an extra time is required for the additional manoeuvres of VSD.

The analysis of chronometer observations allowed establishing an empirical relationship between VSD unloading duration and the pieces of broken ore within 200 mm $\leq d_{cp} \leq$ 600 mm and it is given below:

$$t_p = (0{,}023\ d_{cp} - 2{,}77)\ K_y,\ \text{min} \quad ...(4)$$

where $d_{cp}$ – The average diameter of the ore piece, determined by known methods, mm.

$K_y$ – Coefficient which taking into account the VSD unloading condition influence to its duration ($K_y \approx 1$ in case of the breaker availability in ore pass and $K_y \approx 1{,}5$ - in the absence of the breaker in the ore pass).

The graphical dependence of the VSD unloading time from the piece of the rock mass is given in the Fig. 5.

The analyses of the dependence show that the unloading time of ore increases dramatically, if any oversized pieces are presented.

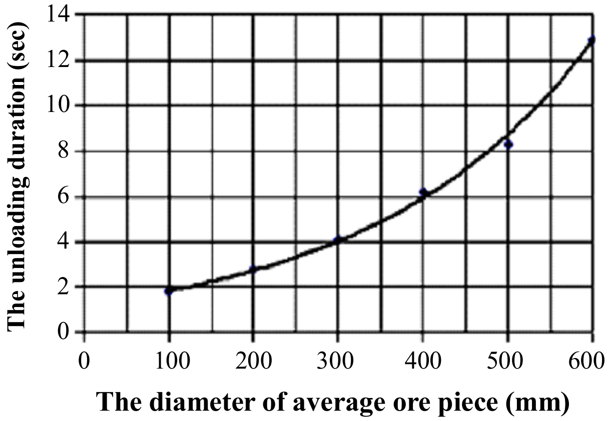

**Fig. 5: The dependence of unloading time from the rock mass lumpiness**

There was mentioned that the productivity is one of the main technical and economic indicators of using self-propelled equipment in underground mines. In the scientific literature, the productivity of mining equipment are divided into three types. They are theoretical, technical and operational productivities. The use of completeness of potential ability of VSD can be estimated by single index:

$$K_{п.в}= Q_э/Q_p \qquad ...(5)$$

where $Q_э$ – Operational productivity of VSD, t/shift;

$Q_p$ – Calculated productivity of VSD, t/shift.

The operational performance of VSD depends on mining and technical conditions, such as the delivery distance of the worked out rock mass, its lumpiness, presence of oversized pieces, the construction parameters of delivery schemes and roads condition. These conditions have a significant impact on the performance of VSD such as speed, the loading and unloading duration, and also determination of the duration of the operating cycle of the machine.

It should be noted that these factors have an unequal impact on calculated and operational performance of VSD. For example, the delivery distance shows unequal impact on calculated and operational performance of VSD and, consequently, on the value of $K_{п.в}$. The unloading conditions of VSD are not considered in determining of the calculated performance, but they have great influence on operational performance.

The coefficient $K_{п.в}$ can be used to identify the most efficient delivery schemes of the rock mass by VSD, the development level of the operational performance of VSD in various mining and geological conditions, and in different delivery schemes and its grain size distribution. This indicator also allows identifying the relevant parameters of rock mass delivery schemes. The relation of this coefficient with the VSD specifications and lumpiness of the rock mass makes it possible to use in prediction the efficiency of the machines, computation need of VSD and in distribution them to the slaughtering.

The researches have shown that to increase the effectiveness of the self-propelled VSD in underground mines is necessary to create the most favourable conditions for their work, which would allow full use of all the potential of machines and creates the conditions to use maximum performance of VSD. In consequence, there will be payback, growth of rock mass delivery intensity and the creation of conditions for the safe performance of the main production processes of ore extraction.

The use of self-propelled machines on the loading and delivery of ore is one of the intensification directions of the underground mining. The effectiveness of the ore delivery is largely dependent on the applied technological ore delivery schemes in the excavation blocks. The mismatch of technological delivery schemes parameters with parameters of self-propelled VSD leads to a significant reduction in machine performance and, consequently, to an increase in the cost of ore production. Thus, the development of the most efficient ore delivery schemes using modern methods of research and projection is necessary for optimum solutions.

In the modern mining industry, the ore delivery schemes with the use of VSD is characterized by variety of elements and parameters, multi-link between them, the presence of the general and local goals of the system. The appropriate simulation method is the best solution for optimization ore delivery schemes from excavation block to ore pass.

It should be noted that the simulation of the ore delivery is quite difficult process due to the large number of interconnections between the influencing factors. The basic technical processes of ore extraction; mining and geological conditions have a direct or indirect impact on the efficiency of ore delivery schemes. In turn, these schemes have a significant impact on the operational performance of the VSD, the ore extraction cost and mining efficiency.

A block diagram of the ore delivery schemes for problem solution optimization by simulation is shown in Fig. 6. It includes a number of limitations such as providing the necessary capacity of the mines, VSD payback, and their potential ability, allowable losses and dilution, safe and effective mining of the remaining ore reserves.

The criteria for the implementation of the simulation model are the sum of the discounted profits, as well as completeness and comprehensive utilization of mineral raw materials. These issues require a special study using modern mathematical methods.

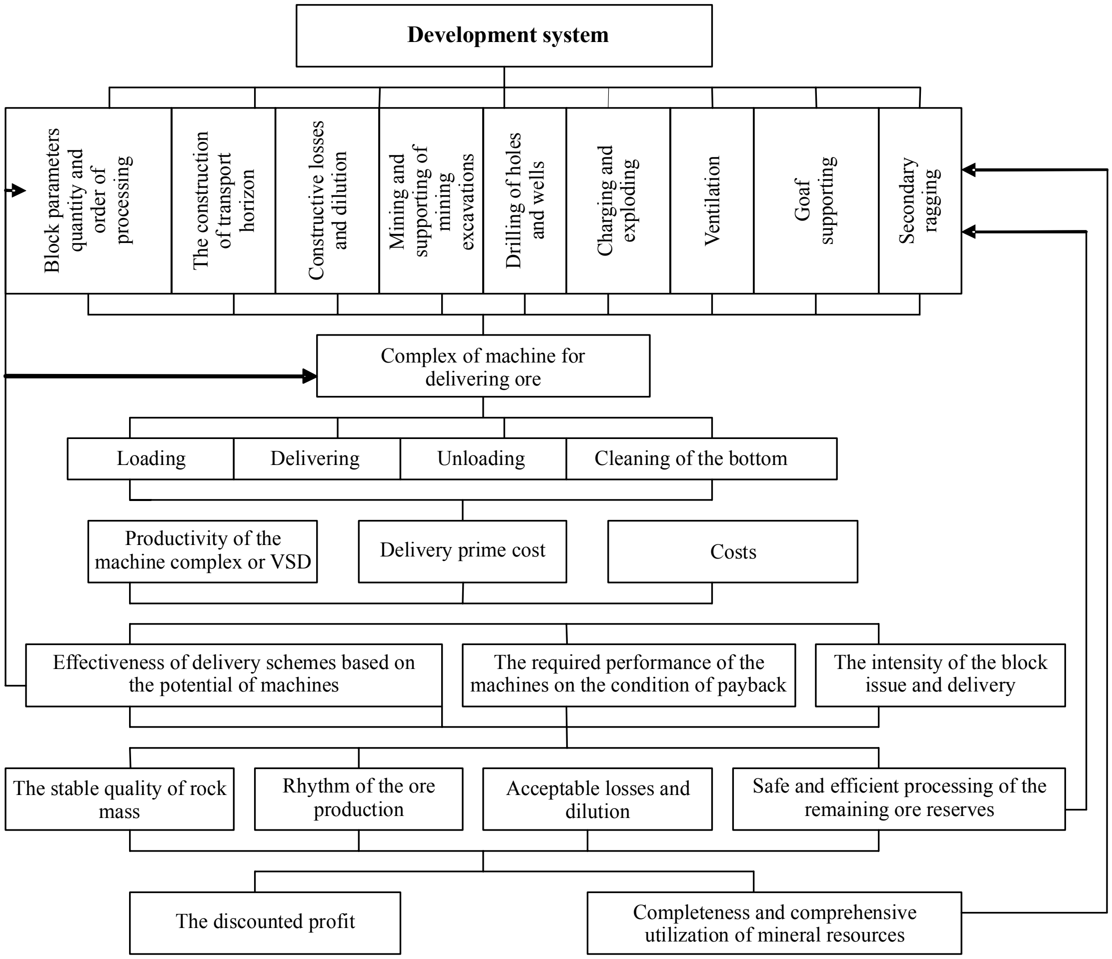

**Fig. 6: The optimization structure of the ore delivery schemes by simulation**

In consequence of the research was decided that the transportation, loading and unloading of the ore in ore pass would be done by VSD. The high productive, compact, self-propelled VSD "Scooptram ST-2D, 2G, 3,5, 7", differing from each other by size, bucket volume, and volume of the combustion engine, were recommended to use. These VSD are equipped by two-stage exhaust gas cleaning system and a firefighting system. The dump trucks type «Minetruck MT2010, 416», «PAUS UNI-50-2» are used for transportation of the rock mass to the surface. The rock mass unloading process on dump truck will be produced in the unloading chamber (Fig. 7). The technological productivity of the VSD was tested (Tables 3, 4, 5).

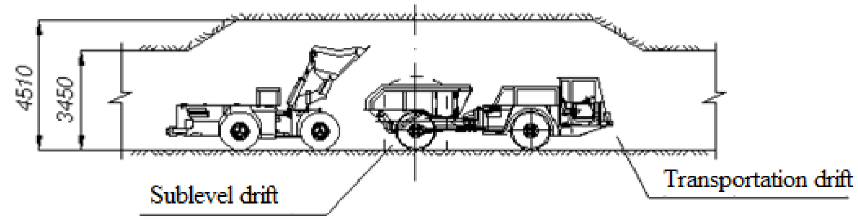

**Fig. 7: Layout of equipment in the unloading chamber**

**Table 3: Input data for calculation of VSD productivity**

| Indicator | Type of work | Symbol | Unit | Value of VSD | |
|---|---|---|---|---|---|
| | | | | **Scooptram ST-3,5** | **Scooptram ST-2D** |
| Carrying capacity | | $P_{\text{п}}$ | t | 6.0 | 3.6 |
| Optimal bucket capacity | For rock | $W_{\text{ков}}$ | $m^3$ | 3.6 | 1.5 |
| | For ore | | | - | - |
| Coefficient of loosening | | $K_{\text{раз.}}$ | pt. unit | 1.6 | 1.6 |
| Coefficient of bucket fullness | | $\varphi_{\text{ков.}}$ | pt. unit | 0.9 | 0.9 |
| Density | rock | $\gamma_{\text{п}}$ | $t/m^3$ | 2.7 | 2.7 |
| | ore | $\gamma_{\text{р}}$ | | 2.73 | 2.73 |
| The bucket loading duration | rock | $t_3$ | min/trip | 0.7 | 0.5 |
| | ore | | | 0.8 | 0.5 |
| The bucket unloading duration | | $t_{\text{р}}$ | min/trip | 0.3 | 0.3 |
| Duration of additional operations | | $t_{\text{в}}^{\text{ПД}}$ | min/trip | 0.8 | 0.7 |

Cont…

| Indicator | Type of work | Symbol | Unit | Value of VSD | |
|---|---|---|---|---|---|
| | | | | Scooptram ST-3,5 | Scooptram ST-2D |
| Average speed | | $V_{ср.}^{ПД}$ | km/hr | 12.25 | 7.95 |
| Shift duration | | $T_{см}$ | min/cm | 480 | 480 |
| Preliminary and final operations | | $T_{пз}^{ПД}$ | min/cm | 17 | 17 |
| Workplace service | | $T_{об}^{ПД}$ | min/cm | 17 | 17 |
| Time for personal need | | $T_{лн}$ | min/cm | 10 | 10 |
| The distance between the garage and bottom of excavation | Excavation | $L_{отс}$ | m | 500 | 500 |
| 1 | 3 | 3 | 4 | 5 | 6 |
| Technological delays | Excavation | $T_{тпп}$ | min/cm | 27 | 27 |
| Standards of rest | | $t_{отд.}^{ПД}$ | % | 10 | 10 |
| Coefficients of the rest | | $K_{отд.}^{ПД}$ | pt. unit | 0.90 | 0.90 |
| Number of shift per day | | $N_{см.}$ | shift per day | 3 | 3 |
| Number of working days in a year | | $N_{сут.}$ | shift per year | 340 | 340 |
| Coefficient of use per shift | | $K_{ис}^{ПД}$ | pt. unit | 0.83 | 0.83 |
| Coefficient of irregularly mining works per year | | $K^{ПД}_{нгр.}$ | pt. unit | 0.80 | 0.80 |

**Table 4: Summary calculation table of the VSD productivity**

| Transportation distance L,м | Technical productivity $A_m^{ПД}$, $m^3$/hr | | Productivity per shift $A_{см.}^{ПД}$, $m^3$/cm (8 hrs) | | Productivity per year, $A_y^{ПД}$, thousand $m^3$/year (340 days) | |
|---|---|---|---|---|---|---|
| | VSD type | | | | | |
| | ST-3,5 | ST-2D | ST-3,5 | ST-2D | ST-3,5 | ST-2D |
| 50 | 53.1 | 22.5 | 268.3 | 112.8 | 273.6 | 115.0 |
| 100 | 43.7 | 16.8 | 221.0 | 84.5 | 225.4 | 86.2 |
| 150 | 37.2 | 13.4 | 187.9 | 67.6 | 191.7 | 68.9 |
| 200 | 32.3 | 11.2 | 163.4 | 56.3 | 166.7 | 57.4 |
| 250 | 28.6 | 9.6 | 144.6 | 48.2 | 147.5 | 49.2 |
| 300 | 25.6 | 8.4 | 129.6 | 42.2 | 132.2 | 43.0 |

The analysis of the table of the VSD productivity shows:

(i) The VSD ST-3, 5, which used in excavation of inclined block and production unit with an average length of transporting L = 200.0 m from the bottom (distance between reloading arrivals - 200.0 m), carries 32.3 $m^3$of ore per hour.

(ii) Under the same operating conditions, VSD ST-2D carries -11. 2 $m^3$ per shift.

Therefore the bottom (V = 27.8 $m^3$) will be removed in 52 minutes by ST-3,5, and in 2 hours 28 minutes by ST-2D.

However the power of others negatively affects to the ventilation and thus, the VSD ST-2D (84 l.) are more attractive.

The ITU is chosen for excavation and the VSD "ScooptramST-2D" was selected for transportation.

**Table 5: Input data for calculation of productivity of dump trucks UNI-50-2 for excavation inclined units**

| Name | Symbol | Measurement unit | Value |
|---|---|---|---|
| The distance between parking and bottom of excavation | $L_{отс}$ | linear metre | 400 |
| Average speed of UNI-50-2 | $V_{гр}$ | m/min | 100.0 |
| | $V_{пор}$ | | 333.3 |
| Bucket capacity of UNI-50-2 | $V_{куз}$ | $m^3$ | 6.5 |
| Volume of the rock mass per cycle | $Q_{ц}$ | t | 75.05 |
| Density of rock mass in array | $\gamma_{пор}$ | $t/m^3$ | 2.7 |
| Coefficient of loosening | $K_{раз}$ | | 1.6 |
| Loading time of UNI-50-2 | $T_{заг.}$ | min | 5 |
| Unloading time of UNI-50-2 | $T_{разг.}$ | min | 0.5 |
| Shift duration | $T_{см}$ | min/cm | 480 |
| Preliminary and final operations | $T_{пз}$ | min/cm | 20 |
| Service of the workplace | $T_{об}$ | min/cm | 15 |

Cont…

| Name | Symbol | Measurement unit | Value |
|---|---|---|---|
| Time for personal need | $T_{\text{лн}}$ | min/cm | 10 |
| Rest standards | $t_{\text{отд}}$ | % | 7 |
| Coefficient of rest | $K_{\text{отд}}$ | | 0.93 |
| Number of shift per day | N | Shift per day | 3 |
| Number of working days in a year | $N_{\text{сут}}$ | Days per year | 340 |
| Coefficient of filling machine body | $K_{\text{зап}}$ | | 0.9 |
| Coefficient of use of UNI-50-2 | $K_{\text{исп}}$ | | 0.75 |
| Coefficient of shift use | $K_{\text{см.ис}}$ | | 0.83 |
| Coefficient of irregularity | $K_{\text{н}}$ | | 1.1 |
| Coefficient of additional reserve trip | $K_{\text{а}}$ | | 1.15 |
| Coefficient of reserve | | | 1.2 |

Total: for ore mass transportation is required 1 unit of UNI-50-2.

The increase of the number of dump truck requires the increase of the fresh air. It is provided by stowage of the rock mass from excavation to the developed chamber of the horizons +376 m (100), +296 m (180) and +216 m (260) and +136 m (340).

Total number of SCE per excavation of ITU and production block would be 2 units, including VSD Scooptram ST-2D - 1 unit; dump truck PAUSUNI-50-2 - 1 unit.

## The technical and economical effectiveness of the developed system by using self-propelled machines

The comparative technical and economic substantiationof the use of the sublevel chamber development system by using self-propelled machines is done as a result of research.

Comparison of the two mining options of the excavation block "Glubinnaya" of the mine camp "Akbakai" was made.

The main technical and economic indicators of mining blocks in two variants are shown in Table 6.

**Table 6: Main parameters of block excavation by 2 options**

| Name | Measurement unit | In block mining | | Comparison of the options in % |
|---|---|---|---|---|
| | | Sublevel camera system using the SCE (mechanically) | Sublevel drifts development system (manual method) | |
| | | Option 1 | Option 2 | |
| 1 | 2 | 3 | 4 | 5 |
| Balance reserves of the block | | | | |
| | Ton | 126235.2 | 15759.68 | |
| | Au, g/t | 5 | 5 | |
| | Metal, Kg | 631.176 | 78.798 | |
| The height of the block along the fall | m | 85 | 85 | |
| The height of chamber along the strike | m | 67 | | |
| The block width | m | 400 | 47 | |
| The average incidence angle of ore | Degree | 45 | 45 | |
| The average thickness of ore | m | 1.445 | 1.445 | |
| Shipment ore | | | | |
| | Ton | 174589.7 | 15392.673 | |
| | Au, g/t | 3.43 | 3.977 | |
| | Metal, Kg | 599.617 | 61.227 | |
| Including from the cleaning works | ton | 127419.2 | 11467.95 | |
| | Au, g/t | 3.83 | 3.925 | |
| | metal, Kg | 488.058 | 45.015 | |
| From preparatory and rifled work | ton | 47116.1 | 3924.709 | |
| | Au, g/t | 2.879 | 4.13 | |
| | metal, Kg | 135.844 | 16.211 | |
| Dilution | | | | |
| | % | 28.53 | 20.45 | 139.51% |
| | Ton | 49809.1 | 3147.26 | |
| Including from the cleaning works | % | 23.4 | 21.49 | |
| | Ton | 29807.5 | 2464.83 | |
| In preparatory and rifled work | % | 42.4 | 17.38 | |
| | Ton | 20001.6 | 682.43 | |

Cont…

| Name | Measurement unit | In block mining | | Comparison of the options in % |
|---|---|---|---|---|
| | | Sublevel camera system using the SCE (mechanically) | Sublevel drifts development system (manual method) | |
| | | Option 1 | Option 2 | |
| 1 | 2 | 3 | 4 | 5 |
| Loss | % | | | |
| | % | 5 | 22.3 | 22.42% |
| | Ton | 6311.76 | 3514.27 | |
| | Kg | 31.558 | 17.571 | |
| Preparatory works | | | | |
| | Linear metre | | 183 | |
| | $m^3$ | 9243 | 700.4 | |
| Rifled works | | | | |
| | Linear metre | 2272 | 312 | |
| | $m^3$ | 17088 | 780 | |
| Cleaning works | | | | |
| | Linear metre | | | |
| | $м^3$ | 46795 | 4210.751 | |
| Total rock mass | | | | |
| | Linear metre | | | |
| | $m^3$ | 73126 | 5691.15 | |
| Mining rifled works/cleaning works | $m^3$/thousand ton | 52.9 | 45.5 | |
| Mining preparation works/cleaning works | $m^3$/thousand ton | 97.9 | 50.67 | |
| Фактически затраченное время на отработку блока включая ГПР ГНР ОР (время простоя не учтено). The time spent on block mining including ODA PLR OR (down time is not taken into account) | | | | |
| | Days | 304 | 322 | |
| The average daily productivity per block | | | | |

Cont…

| **Name** | **Measurement unit** | **In block mining** | | **Comparison of the options in %** |
|---|---|---|---|---|
| | | **Sublevel camera system using the SCE (mechanically)** | **Sublevel drifts development system (manual method)** | |
| | | **Option 1** | **Option 2** | |
| **1** | **2** | **3** | **4** | **5** |
| | t/day | 574.13 | 47.773 | |
| | Kg Au/day | 1.972 | 0.19 | |
| Ore mining prime cost including | $/t | 40.4 | 52.23 | 77.35% |
| | | 365.763 | 492.094 | 74.327% |
| Personnel costs | $/t | 2.1 | 10.1 | 20.79% |
| Main and additional materials cost | $/t | 19.2 | 21.2 | 90.57% |
| PPEandtoolscost | $/t | 0.9 | 1.1 | 81.82% |
| ServicecostsofSCE | $/t | 1.5 | 1.23 | 121.95% |
| Costs for fuel and tires | $/t | 6.7 | 5.0 | 134.00% |
| Amortization costs | $/t | 6.0 | 4.98 | 120.48% |
| Cost of general mining | $/t | 4.08 | 8.38 | 48.68% |
| Profits from processing the mined ore at a cost $ 1300oz., prime cost of processing $ 14 and removing 70%<br>gross income - (production costs + processing costs) | | | | |
| | $ | 8 048 388 | 588 076 | 1368.6% |

The table 6 shows that the dilution of the 1st variant is more for 39.51% than the 2nd variant, while the loss of the 1st variant is less for 77.58% than the second variant.

The average daily ore mining productivity of the first and second variants including whole cycle are 574.13 tons per day or 1.972 Kg of gold per day and 47.77 tons per day or 0.19 Kg of gold per day, respectively.

The production costs of ore were $ 40.4 per ton for the first variant against $ 52.23 per ton for the second variant. In terms of an ounce, they are $ 365.763 oz. and $ 492.094 oz., respectively. Based on the above mentioned calculations can be concluded that the vein mining with an incidence angle of $30^0$-$55^0$ is should be done by sublevel camera system with layered mining by deep wells.

Currently gold mine "Akbakai" is mined by our developed technology (Fig. 8). The annual output of the mine has tripled, with 220-250 thousand tons up to 600-650 thousand tons due to the implementation of the new development systems and full mechanization of mining operations in thin vein deposits mining conditions from 2011 to 2014.

**Fig. 8: The current state of delivery and transportation of the ore deposit "Akbakai"**

The delivery of worked out rock mass to the ore pass is done by machine with a further issuance of ore and rock through the inclined transport unit.

Preparation of stocks carried by ore drifts andraise. Crosscuts and roundabout excavations are located on the rock. The ore warehousing is in the ore stockpile of the crushing mill complex.

The ore losses in blocks consist of pillars which left to save the vertical and horizontal workings. Some losses are formed from interblock pillars, upper-drift pillars and intra-block supporting pillars[17].

# CONCLUSION

The research shows that the development of new innovative technologies with new technics which provides high completeness of mineral extraction, ensuring high stability of extracted rock mass quality, increase productivity and safety of mining operations is necessary for increasing the productivity of the gold mining enterprises.

The inclined vein deposit mining systems and technologies using high productive equipment and deep well with small diameter allow mining the vein in variable geological and morphological conditions of deposit.

Sublevel development system of inclined vein deposits using high-performance equipment and deep wells with small diameter can be effectively used in a sudden change of thickness, incidence angle and strength of the rocks - along strike, raiseand fall veins.

The dependence pattern of the technical and economic performance of the VSD from the lumpiness of the worked out ore and loading and unloading time of the machine are identified. It allows finding rational schemes and calculating the delivery distance of the ore.

It is found that when choosing the rational self-propelled VSD must be strived to achieve a rational productivity of VSD on conditions of merchantability and completeness of their potential abilities.

The economic and practical effectiveness of the proposed technology are based on scientific and experimental substantiation of rational parameters of sublevel-chamber system development with the delivery of ore by explosion force with the use of a small-size and other high-performance equipment, and deep wells of small diameter in all kinds of processes and works in blocks.

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