



Risk Assessment Of Surface Miner for Estonian Oil-Shale Mining Industry

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The paper deals with risk assessment of a high-selective oil-shale mining technology using surface miner Wirtgen 2500SM. This study addresses risk associated with productivity and cutting quality on example of Estonian oil shale deposit in areas with complicated layering conditions. The risk assessment method allows choosing relevant technology with friendly environment and economic value. For risk estimation the event tree is used. The results of the risk assessment are of practical interest for different purposes.

1 Introduction

About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Mining sector faces challenges to increase the output of mines and to minimize the environmental impact of mining at the same time. Continuous mining and milling techniques for the hard rock industry are up to now limited through the hardness of rock material. The application limits for the future technique will be placed above the limits of bucket wheel excavating systems with a diggability of normal up to 10 MPa of uniaxial compressive strength (UCS). This can be expanded with special designed excavators for frozen hard coal or soft limestone (Wilke at al. 1993). Horizontal and vertical ripping techniques are currently used for materials up to 50 MPa UCS, sometimes combined with in-pit crushing systems.

Surface mining is carried out in open casts with maximum overburden thickness of 30 m. Draglines with 90 m boom length and 15 m³ bucket size are used for overburden removal. Hard overburden consists of limestone layers and is blasted before excavation. Oil shale layers are blasted as well or broken by ripping (semi-selective mining). Disadvantage of ripping is excessive crushing of oil shale by bulldozer crawlers. Excavated rock is transported with 32-42 or 60 tonnes trucks (Belaz and Euclid) to the processing or crushing plant depending on opencast.

Aim of the research and in-situ SM testing is to introduce continuous mining technology on example of Estonian oil shale deposit in areas with arduous layering conditions. The results of in-situ testing can be used to improve existing situation in mining fields with complicated geological conditions and in densely populated regions.

Continuous surface miners can find their natural applications in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Besides they offer further advantages less mineral loss and dilution, improved mineral recovery especially in areas sensitive to blasting, less stress and strain on trucks due to minimum impact of the excavated material, primary crushing and fragmentation of mineral rock, reduced capacity requirements for preparation plants.

The high-selective oil-shale mining technology introduced by surface miner (SM) Wirtgen SM2500 and the first 9 months of testing results at "Narva" open-pit in Estonia. The technology allows to decrease oil-shale losses from 10-15% up to 5-7% on in-situ conditions. Mining process of the surface miner has a lower disturbing impact, which is topical in open casts and quarries especially in densely populated areas. The low level of dust and noise emissions and also very low vibration are arguments to mine oil shale with surface miner instead of drilling-blasting operations. (Nikitin at al., 2007)

The most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2-7 cm) with deviations about one centimeter. It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. It means, that oil-shale losses on the case of SM technology can be decreased from conventional 12 up to 5 percent

2 Risk analysis of surface miner Wirtgen 2500M technology

Continuous surface miner, which are designed to cut softer rock materials like sandstone, clay, bauxite, hard coal, phosphate, gypsum and marl are operating between 10 MPa and 70 MPa compressive strength. Nowadays, road cutting machines are working materials up to 100-110 MPa compressive strength. The very recent developments show that there is a need for investigations to enlarge the mentioned application limits.

The Wirtgen 2500SM design with a mid-located cutting drum (diameter 1.4m, cutting width 2.5m) was expected to be more promising for hard rock (80-110 MPa) applications than the front-end designs. Here, the whole weight of the machine (100 t) is available for the penetration process and only a smaller torque resulting from the cutting process (cutting depth up to 0.6m) has to be counterbalanced. Besides, the surface miner with middle drum concept moves during the winning process. Due to this great moved mass, much more dynamic mass forces are possible than during the movement of the small mass of the cutting organ mounted on a boom.

Modifications and development work for the tested SM focused mainly on the corresponding cutting drums (number of cutting lines) and specifications of the cutting tools, different loading technologies (windrowing or direct truck loading) also (Figure 1 a, b).

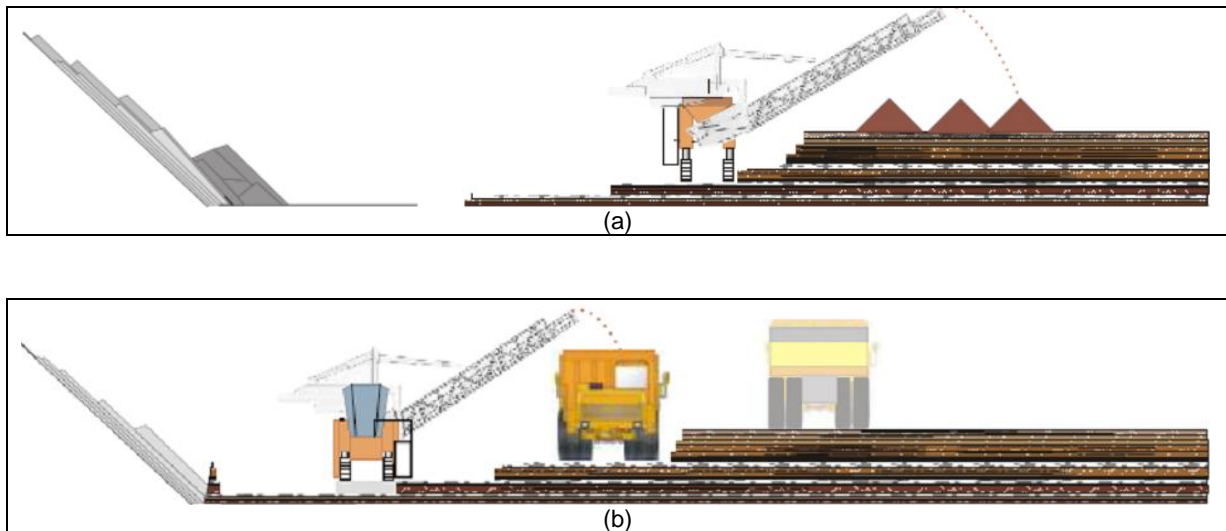


Figure 1. Different loading technologies: windrowing (a) and direct truck loading (b)

2.1 Rock Breakability Results

To be able to transfer the achieved results to other EU rock mines, it is necessary to identify the SM and cutting rock parameters responsible for the breakability factor of a deposit. The development of such a generalised classification system is therefore an important objective of the project as well.

Applying statistical distribution according to Weibull, the function of size distribution of oil-shale particles may be assumed as follows:

$$W = 1 - \exp[-(d/d_0)^m] \quad (1)$$

where $d_0 = d_{0.63}$ is diameter of screen opening to pass 63.2% of broken oil shale; m is breakability factor.

The results from sieving analysis made for limestone and oil-shale layers show that for "Narva" open pit test site conditions breakability factor $m = 1.1$. Hence, the share of oil shale δ passing the 25×25 -mm screen in the total mine-run shale equals to

$$\delta_{-25} = d_{-25} = 1 - \exp[-(25/d_{0.63})^{1.1}] \quad (2)$$

where, $d_{0.63} = 20.0 + 2.16S'$ for SM up-cutting direction (see Figure); S' is cross-section of cut, cm^2 .

In 1968 E. Reinsalu had proposed an approximate relationship between energy consumption by different methods of breaking and average size of mined oil-shale particles, which was later completed with the present investigation data (Figure 2).

Concentratibility and trade oil shale grade depend on sizing extracted oil shale, which, in its turn, is closely

related to energy consumption and the selected method of oil shale breaking. Equation (3) and Figures 3 a, 3 b demonstrates the correlation of the distribution law parameters and specific energy consumption with the parameters of oil-shale and limestone particles sizing. The tested SM sizing parameters are inside the areas with number 7 and 8 (Figure 2 a).

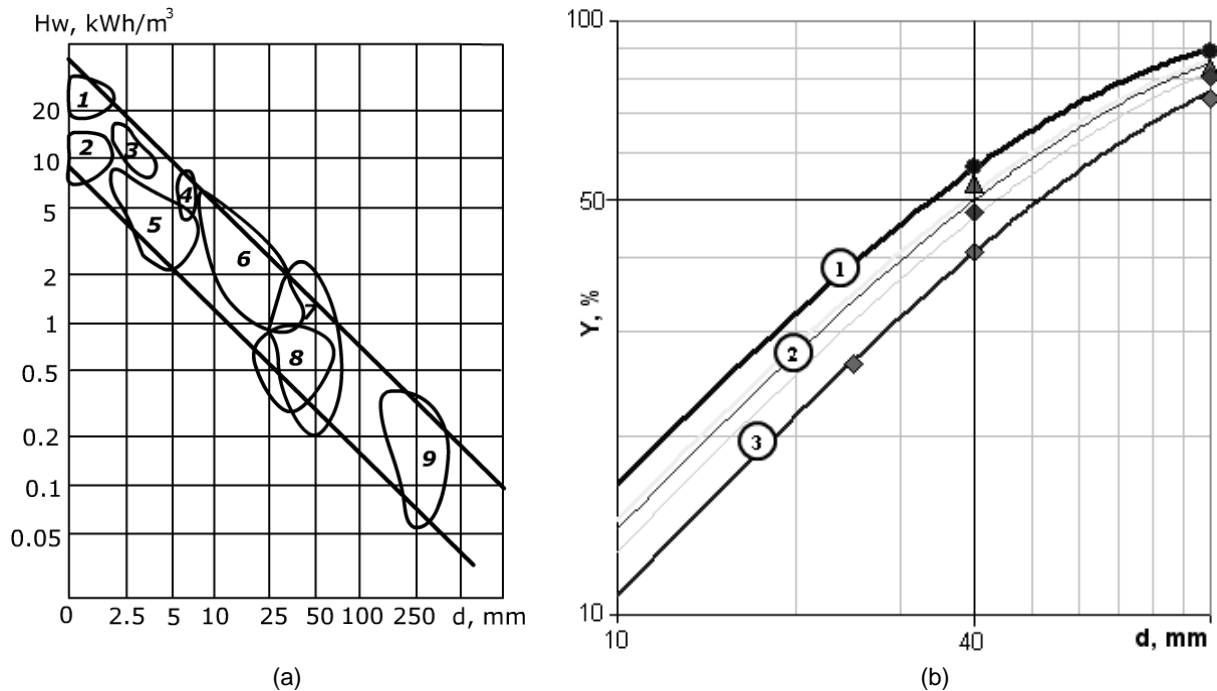


Figure 2. Effect of method of breakage on specific energy consumption (A.) and the resulting average oil shale and limestone sizing (B.)

Where, 1 – drilling in limestone; 2 – drilling in oil shale; 3 – cutting machine in limestone; 4 – cutting machine in oil shale; 5 – cutting of layer B with shearer loader UKR-1; 6 – cutting with shearer; 7 – cutting with DKS (a mean for measuring cuttability) in limestone; 8 – cutting with DKS in oil shale; 9 – breaking with ripper (surface mining); Wirtgen 2500SM sizing data (up-cutting direction): ①– cutting in oil-shale complex EF (0.43m); ②–cutting in limestone seams A/B (0.18m) and C/D (0.25m); ③– cutting in oil-shale complex CB (0.36m).

3 Risk estimation of surface miner testing results

The Wirtgen 2500SM was delivered to AS Eesti Põlevkivi at the end of 2006. The testing of SM was beginning at “Narva” oil-shale open cast. The SM testing was held from 01.01.2007 to 30.09.2007 and was estimated by four testing phase (Figure 3). The machine was operated in two or three-shift systems.

During the first testing phase (I) 145 total operating hours from 200 available (9.4 m/min) and during the second testing phase (II) 151 from 208 available shift-hours (9.0 m/min) the SM with direct truck loading was tested. But the real cutting time was 35 and 41% from available shift-hours for the each period correspondingly. During the third testing phase (III), 4130 total operating hours from 5416 available shift-hours the SM with about 26% of windrowing. For the fourth testing phase (IV) 111 total operating hours from 112 available shift-hours the SM windrowing achieved 100%. The average cutting speed during the real cutting time was 11.5 m/min. For the while period real cutting time is about 46%, where on average during the shift-time 33% SM operated on oil-shale layers and 13% on limestone (layers C/D and B/A). The Figure 3 illustrates the shift-hours distribution graphics for the testing phases.

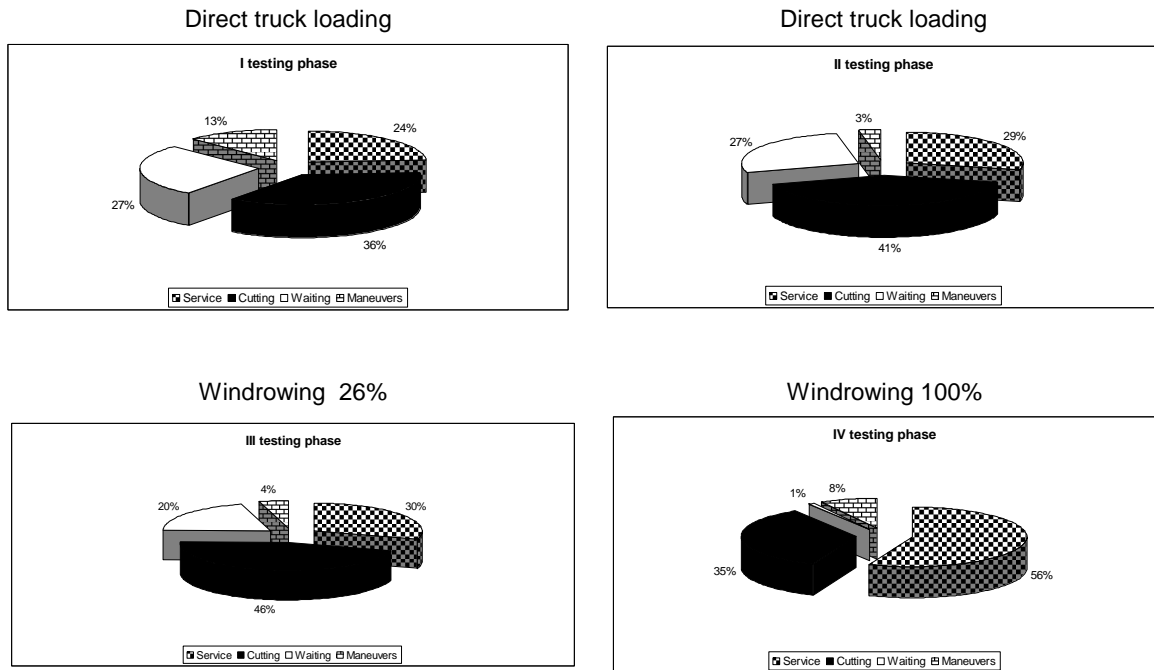


Figure 3. The shift-hours distribution graphics for the while testing period.

During the testing phase registered “waiting” is about 27%. Obviously, the main reason is direct truck loading method. Analysis has shown that by direct truck loading method, truck-waiting downtime decrease real cutting time by 1.0-1.5 hour per shift and average cutting speed by 20-25%. The percent of “waiting” include about 7% of time loses for trucks exchanging, about 6% for SM upper conveyor manoeuvres, then about 6% for spade-work (SM controlling before and after the shift) and up to 10% time loses due to the ground water problems.

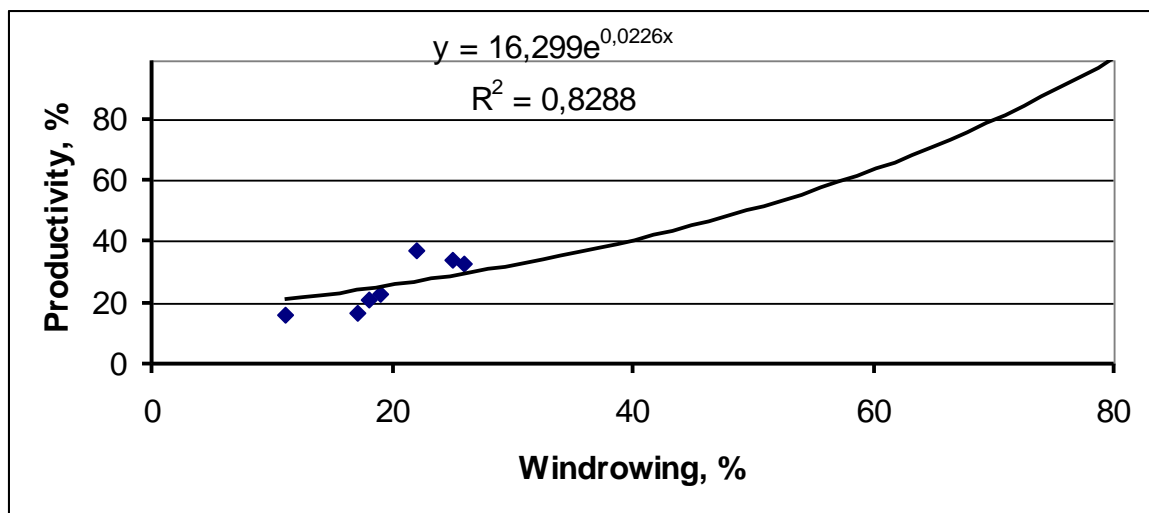


Figure 4. Dependence of SM productivity on windrowing percentages

As you can see from the graph (Figure 4), there is a great SM productivity potential when windrowing percent is growing. The additional LHD-machine operating and SM depreciation costs greater oil-shale excavation rate is coating. As a result the oil shale operating cost can be reduced up to 10-15%.

Main aspects influencing the efficiency of the combine work concern the duration of the processes. Cutting

different layers, track dumper loading (waiting), manoeuvres and maintenance processes are the most important factors. Investigations have shown that duration of the processes influence on productivity. The main quantitative approach used in risk estimation is the event tree method (Calow, P. 1998). This method was selected as the most appropriate one for the risk estimation of the SM. In the first stage of the project time factor was taken into consideration. For probability determination the empirical approach was used (Williams at al. 2004). The event tree indicating the probabilities of the SM processes and spent time. It is possible to select different variants and to determine the probability of one.

The event tree allows determining time deviations from average value (Figure 5). Four different testing phases (I-IV) of the SM were observed. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Application of the fault tree is presented in Table 1. Selected variant of the tests give different value of the probabilities and deviations from the average value. For determination the higher productivity is necessary to give attention on processes with positive value and improve it quality (Figure 5).

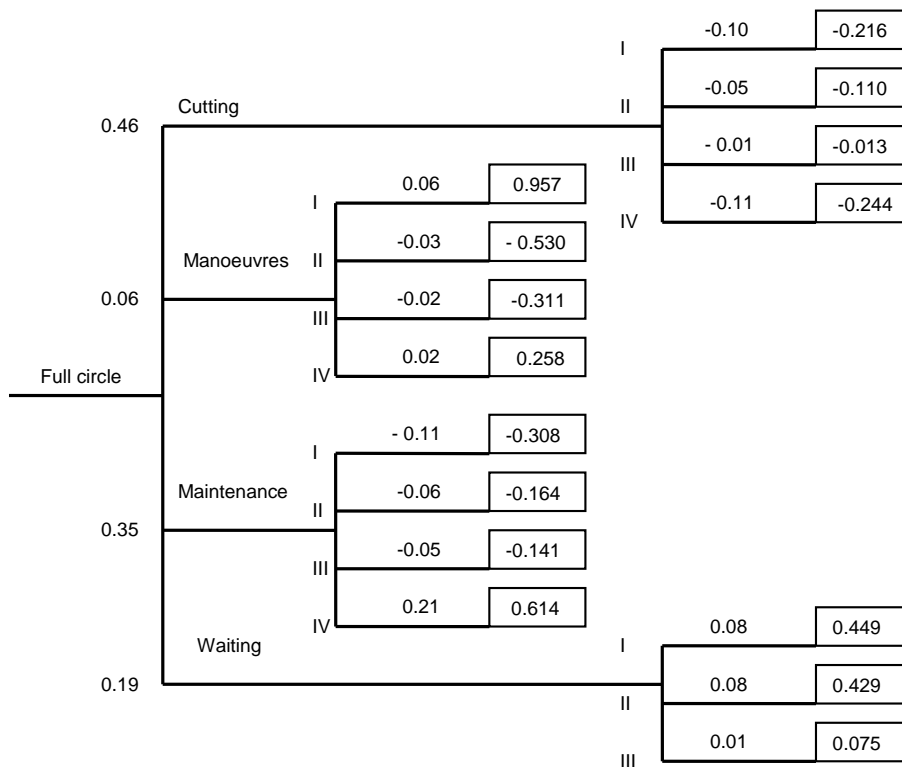


Figure 5. Event tree of different processes

In case of excluding complicated geological condition higher productivity can achieve owing to the windrowing method.

Table 1. Time deviations from the average value

Testing phases	I	II	III	IV
Maintenance	-0.308	-0.164	-0.141	0.614
Cutting	-0.216	-0.110	-0.013	-0.244
Waiting	0.449	0.429	0.075	-
Maneuvers	0.957	-0.530	-0.311	0.258

4 Risk evaluation

The thickest and harder limestone seam "C/D" (60-80 MPa) has sufficient quality to produce aggregate for road



building and concrete. Separately extracted limestone (C/D and A/B) can be left directly in mine, which reduces haul costs and increase run-out oil shale heating value without additional processing.

The oil yield increase by 30%, up to 1 barrel per tone during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning in power plants because of less limestone containing in oil shale. Its results higher efficiency of boilers, because up to 30% of energy is wasted for limestone decompose during the burning process. Positive effect would result in lower carbon dioxide and ash emissions (Adamson et al 2006).

Another perspective of surface miner would apparent in places with relative small overburden thickness (less than 10 m) and near the towns where the removal of hard overburden with SM should be considered as well instead of overburden blasting. On these cases the SM would "cut" considerably operating costs of stripping and possibility mine out reserves near the densely populated areas.

Another problem is the oil-shale bed geological characteristics. Estonian oil-shale bed consists from oil-shale and limestone seams with different thickness and compressive strength. Oil shale is relatively soft rock with UCS 15-40 MPa but limestone is 40-80 MPa. There are also places near the karsts zones with 100-120 MPa compressive strength. During the cutting process the loads in cutting tools vary greatly due to the differences in rock physical and mechanical parameters, which lead increased loading of the cutting drum.

The applicants have recently encountered many situations where manufacturers cutting drum/head designs could be significantly improved upon, as they were not tailored to the actual geotechnical conditions predominant at the mine. However, without more user-friendly tools, the opportunity to make such improvements in practice has been limited. Improved designs have the potential to increase cutting speed and efficiency, reduce pick replacement costs, reduce machine down time through gearbox failure and pick changing, improve machine reliability by reducing excessive vibration during cutting, improve loading efficiency and reduce fine oil shale and dust production. Research program to develop design of cutting tools/drums to minimise cutting tools consumption and machine down time on the basis of testing data will be develop. New design of cutting drums will lead to improved tool cutting (pick) loading efficiency with less fine rock and dust production. The result of this work will be taken into account for the next SM design.

Development of mining machinery and mining technology by the way of selective mining will improve environmental situation in Europe and Baltic Sea region. Effect can be achieved in decreasing CO₂ emission, ash and water pollution.

Selective mining enhances the quality of oil shale. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower. The disturbing impact of drilling-blasting operations in quarries and open casts next to densely populated areas causes vibration, dust and noise emissions which are arguments to stop operations where blasting is used. Surface miner high-selective technology has perspectives due to reduced dust and noise, non-existent vibration and dust emission levels also.

By extending the applicability of the surface miner/road cutting technology from soft material into semi-hard and hard rocks with UCS of up to 110-120 MPa, an economically and environmentally acceptable alternative to drilling and blasting could be available. By taking into account the rock-mechanical and mine planning aspects of the test application, an evaluation of the overall economical feasibility and the transfer of the results to other hard rock mines can be ensured.

5 Conclusions

Event tree allow determining suitable variant of different processes for continuous surface miner. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Surface miner higher productivity in testing phase (IV) was achieved on account of 100 % windrowing method. The high cutting performance can be explainable absence of waiting time. This information allows finding adequate decision to improve quality of the processes and avoid negative influence.

Results obtained by this project can be using in different industrial sectors. The main applications will be found in the surface mining and road construction sectors. New usage could be in zones where rock soils will transformed into zones with agricultural capacities.

There is a couple of direct and indirect effects which reduce oil shale cost prise on 20% due to less mineral losses, loading method (windrowing) can optimize fuel consumption when high-selective mining technology with surface miner is applied. The result of this work will be taken into account for the next surface miner design.

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