

<https://doi.org/10.32056/KOMAG2023.2.1>

## The method for preliminary estimation of expenditures and time necessary for liquidation of a mining plant

Received: 07.04.2023

Accepted: 02.06.2023

Published online: 31.07.2023

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Abstract:

A comprehensive scientific approach will facilitate rationalization processes and minimization of mine liquidation costs. The study, based on a statistical analysis of liquidation processes in 19 mining plants from 2015 to 2023, proposes a method for preliminary estimation of costs and time of potential liquidation of hard coal mines.

The method can be used for preliminary estimation of mine liquidation costs and as a cost management tool. The method does not refer directly to the liquidation processes used in SRK S.A. therefore, it can also be used by any entity in mine liquidation process as a comparative tool for detailed and multi-criteria estimation of the costs of planned mine liquidation.

Keywords: costs management, restructuring of mining plants, liquidation of a hard coal mine



## 1. Introduction

Life of a mine is not only the time of mining, but also its liquidation period [1-3]. Revitalization and restructuring of post-mining areas are realized by Spółka Restrukturyzacji Kopalń S.A. ([www.srk.com.pl](http://www.srk.com.pl)). The mine liquidation project is very complicated and expensive due to the large scope of work required. One of the reasons limiting the improvement of liquidation efficiency is the lack of instruments and tools supporting the cost management. In hard coal mines, comprehensive solutions adapted to the specificity of the industry have not been developed so far. The developed solutions concern only the selected issues related mainly to the efficiency of the mining process or preparatory work [4-7].

## 2. Research work problem

Rational expenditure on restoring the post-mining areas to society has not been the subject of comprehensive scientific research work so far [8-11]. Available studies in this area are few and concern only the selected issues [12-17]. The article presents the results of the next stage of research work on tools to support the management of the costs of liquidation processes [8, 11]. A method of preliminary estimation of the time and expenditure necessary in liquidation of the mining plant, which will support the company planning the mine liquidation, has been suggested.

## 3. Research work method

The aim of the research work was to develop and propose a tool for a preliminary estimation of time and expenditure necessary for the planned liquidation process based on a small group of parameters characterizing the liquidated mines. The research plan was implemented based on the analysis of updated mine liquidation programs completed or still carried out by Spółka Restrukturyzacji Kopalń S.A. (SRK) in the years 2015 to 2023.

After analyzing the available literature and statistical analysis of the mining plant restructuring processes broken down into subsequent years, a list of potential evaluation parameters was proposed and their real impact on the estimation of the final cost and time of mine liquidation was checked. Questionnaire surveys among the experts (people designing the liquidation and people managing the liquidation processes) allowed for the selection of a list of the most important assessment parameters.

The correct operation of the proposed assessment tool was verified for the hypothetical mining plants. The verification of the method consisted in comparing the estimates of the method with the experience gained by SRK S.A. Consultations in the form of interviews with the experts managing the liquidation processes confirmed correctness of the results and allowed to explain the reasons of more significant deviations from the expected values.

## 4. Results of the research work

### 4.1. Determination of the assessment parameters

Programs and liquidation plans for 19 mines or their parts from 2015 to 2023 were analyzed. The surveyed group included 9 already closed mines and 10 currently liquidated mines grouped in 5 Departments of SRK S.A. Each case of liquidation of a mining plant is individual, however, there are certain regularities [18-20]. Liquidation process at SRK S.A. lasts from 2 to 8 years (in average 5 years). The cost of liquidation is also very diverse and, for example, for the largest mine it is forty times higher than the cost of liquidating the smallest mine. The average cost of liquidation a mine is 300 to 400 million PLN (calculated to the costs from the first quarter of 2023). This is due to the large scope of work necessary during the task realization.

For better consistency in the cost ratio, it was proposed to divide the liquidated mines into 5 groups due to the amount and structure of their liquidation costs. The mines were divided into Large Mines (KD), Larger Medium Mines (KSW), Smaller Medium Mines (KSM), Small Mines (KM) and a group of Micro Mines (KMikro) [8, 10, 11].



The intention of the method was to link several parameters characterizing the mine with the final cost and time of its liquidation. The determined evaluation parameters were to be easy to read, not requiring major calculations and easy to understand. When selecting the parameters, a certain functional similarity of the analyzed mining plants was assumed. It was assumed that each of the analyzed mines has a similar set of objects, differing only in scale.

In accordance with the adopted assumptions, potential parameters were determined, the analysis of which would make it possible to initially determine the scope of costs and the duration of the mine liquidation processes. During the analysis, the size of analyzed parameter was assigned to the corresponding reference group. In the calculations, the analyzed parameters were treated as "de-stimulants", and then as "stimulants". The standardized values of the assessment parameters were calculated in accordance with formula 1. Based on the analysis, it was found that in the analyzed research problem, the following three parameters read at the time of the decision to liquidate the mine are best correlated with the costs and liquidation time (Table 1):

- the total length of excavation gates, regardless of their size, structure and the fact whether they are to be liquidated or remain as the skeleton of the left pumping station,
- volume of all mine shafts, regardless of their number and regardless of whether they will be liquidated or developed as a pumping station,
- the number of all facilities of the mining plant, regardless of their volume, technical condition or intended for liquidation or development.

**Table 1.** Single-criterion analysis of the assessment parameters

Assessment parameter		Conformity
1.	Total length of excavation gates	73.68%
2.	Volume of all mine shafts	52.63%
3.	The number of all objects of the mining plant	68.42%

The proposed parameters describe all processes related to the task of physical liquidation. Parameters less correlated with the costs and time of mine liquidation were not included in the analysis.

At the next stage of the research work, the determined parameters were correlated in pairs. As before, the standardized values of the assessment parameters were calculated in accordance with the quotient transformation. The analyzed parameters were adjusted to the corresponding group of mines by changing the weight assigned to the partial assessment and changing the range of final assessments, so as to match the parameters and groups of mines as precisely as possible [21]. The results are presented in Table 2. When all parameters are "stimulants", the multi-criteria evaluation using the quotient transformation has the following form:

$$FC_{jmax} = \sum_{i=1}^n \frac{h_{ij}}{h_{imax}} \quad (1)$$

where:

$FC_{jmax}$  - multi-criteria value of assessment parameters for the mine "j",

$i$  - number of assessment parameter,

$j$  - number of analysed mine,

$h_{imax}$  - maximum parameter "i",

$h_{ij}$  - assessment parameters for the mine "j".



**Table 2.** Multi-criterion analysis of the assessment parameters “in pairs”

Assessment parameter		Weight of the parameter	Conformity
1.	Total length of excavation gates	0.833333333	68.42%
	Volume of all mine shafts	0.166666667	
2.	Total length of excavation gates	0.265251989	73.68%
	The number of all objects of the mining plant	0.734748011	
3.	Volume of all mine shafts	0.639423077	73.68%
	The number of all objects of the mining plant	0.360576923	

Due to the fact that the compliance coefficient was too low, another attempt was made to compare the correlation of assessment parameters with the total costs of mine liquidation. This time, three assessment parameters were compared using multiple criteria, also using the quotient transformation (formula 1). The analyzed parameters were adjusted to the corresponding group of mines by changing the weight assigned to the partial assessment and changing the range of final assessments, so as to match the parameters to the appropriate group of mines as precisely as possible [8, 10, 11]. The results are presented in Table 3.

**Table 3.** Multi-criterion analysis of all assessment parameters

Assessment parameter	Weight of the parameter	Conformity
Total length of excavation gates	0.315789474	84.21%
Volume of all mine shafts	0.421052632	
The number of all objects of the mining plant	0.263157895	

Analysis of three parameters significantly improved the correctness of assigning the analysed mines to the corresponding reference groups. Adding another evaluation parameters no longer increased the conformity, and sometimes worsening the already obtained result.

#### 4.2. Method for preliminary assessment of time and costs of mine liquidation

The tool was proposed for the proposed method. The tool interface pattern is presented in Fig. 1÷4. There are fields with a white background in the interface. These fields are descriptive fields. The fields marked in light gray are the input fields, i.e. the values of the original assessment parameters. The fields marked in dark gray are the result fields, where the method reports the estimated results of the analysis.

The proposed method, based on previously determined parameters, estimates the foreseeable time and cost of liquidation. The liquidation time is assessed on the basis of a single-criteria analysis, separately for each of the assessment parameters, and a multi-criteria analysis, for three parameters at the same time. In a single-criterion analysis, a reference group is determined for the analyzed assessment parameter. Then, already within the reference group, the value of the parameter is assigned to the mine liquidation time. The tool presents the results by inserting an "x" in the column corresponding to the designated time interval.

At the next stage, the method in the multi-criteria analysis of three parameters jointly, in accordance with formula 1, classifies the analyzed set of parameters to the corresponding reference group of mines. Already within the reference group, the method estimates the foreseeable liquidation time. The results are given in the same way as in the single-criteria analysis. The "x" is bolded.



The analysis of the assessment parameters is also the basis for determining the preliminary estimated value of the mine liquidation cost. After classifying the analyzed set of assessment parameters to a specific reference group of mines, the cost of liquidating the entire mine is assigned to this set in a multi-criteria manner. The estimated preliminary liquidation cost is presented in the lower right corner of the interface. In addition, the method provides in the last line the name of the assigned reference group and the maximum, minimum and average cost of mine liquidation in this group. Based on the estimated time and cost of liquidation, the method provides the estimated average annual cost of a mine liquidation, determined for the entered set of assessment parameters.

### 4.3. Verification of the proposed method

The method was verified in two stages. At the first stage, all 19 analyzed mines were tested in terms of compliance of the calculated results with the values obtained in liquidation practice. In three cases out of 19, the results were very different from reality. Documentation analysis (liquidation plans and programs), statistical evaluation and interviews with experts (persons in charge of liquidation processes) indicated that these 3 cases are the specific cases. According to the experts, these three mining plants were excluded from the verification of the method as unusual examples. After excluding them from the analysis, according to the experts, a satisfactory estimation of liquidation costs was obtained. The method tends to slightly overestimate the liquidation costs. In most reference groups, the average overestimation of costs does not exceed 5%, only in the group of smaller medium-sized mines (KSM) it is about 16%. In extreme cases, the method overestimates the costs by up to 30% and underestimates up to 24% for larger mines (KD and KSW) and up to 13% for smaller mines (KSM and KM). For micro mines (KMikro), over 99% compliance of the forecast with the value determined by the method was obtained.

When estimating the liquidation time, in two cases the forecast indicated a much shorter liquidation time. According to the analysis of documents and the opinion of experts, this concerned the mines for which, for reasons of protection of neighboring active mining plants, the time of liquidation was artificially extended. This was the case for one of the larger medium-sized mines (KSW) and the "micro" mine (KMikro). The accuracy was considered to be sufficient for this stage of potential designing work. In the case of one of the atypical mines, the liquidation time was extended.

At the second stage of verification, four hypothetical examples of mine liquidation were analyzed. The first of the analyzed hypothetical mines was the mine marked "K1", for which the smallest parameters obtained in the entire analyzed group of 19 liquidated mines were selected. This mine turned out to be smaller than the micro mine (KMikro). The second one was the K2 mine with the shortest length of excavation gates so far, the average volume of shafts and the maximum number of mining facilities. The third analyzed example was the K3 mine with average values of assessment parameters for the group of medium-sized smaller mines (KSM). The last analyzed mine, K4, is one of the mines previously called atypical, belonging to the group of small mines (KM).

Evaluation parameters	Enter data	Expected time of liquidation [years]				
Total length of excavation gates [km]	6425					x
Volume of all mine shafts [m <sup>3</sup> ]	2310					x
Number of all minig plant facilities [items]	14					x
Multi-criteria						<b>x</b>
Average cost of mine liquidation per year [mIn PLN]	6,5	6 -	5-6	4-5	3-4	2-3
Cost of mine liquidation	Maximum	Minimum	Medium	Expected cost of mine liquidation [mIn PLN]		
"micro"	20,7	18,6	19,6			<b>13,1</b>

**Fig. 1.** Results of the preliminary assessment of liquidation time and costs of K1 mine

The analysis of the K1 mine (Fig. 1) classified it as expected as a micro mine (KMikro). For this mine, which is smaller than the smallest micro mine (KMikro), the liquidation cost is lower than the minimum cost for this group of mines. The mine liquidation time determined by the method in the single-criteria and multi-criteria analysis was from 2 to 3 years. Comparing the average liquidation cost with the expected liquidation cost of the K1 mine, it can be seen that the method indirectly

suggests a two-year liquidation time. In practice, such time is usually planned for liquidation processes for the analyzed set of assessment parameters.

Evaluation parameters	Enter data	Expected time of liquidation [years]				
Total length of excavation gates [km]	6425	x				
Volume of all mine shafts [m3]	10039	x				
Number of all minig plant facilities [items]	393	x				
Multi-criteria		x				
Average cost of mine liquidation per year [mln PLN]	76,6	6 -	5-6	4-5	3-4	2-3
Cost of mine liquidation	Maximum	Minimum	Medium	Expected cost of mine [mln PLN]		
"medium larger"	602	326,1	434,3	liquidation	460,4	

**Fig. 2.** Results of the preliminary assessment of liquidation time and costs of K2 mine

As expected, the multi-criteria method classified the K2 mine (Fig. 2) to the group of medium-large mines (KSW) and indicated a 5 to 6-year liquidation period, determining the liquidation cost of PLN 460.4 million. This value slightly exceeds the average value for the indicated reference group. The single-criteria analysis of the liquidation time also, as expected, determined the minimum time of liquidation of excavation gates (from 2 to 3 years), the maximum time of liquidation of facilities (over 6 years) and the time of liquidation of shafts resulting from the scope of tasks (from 5 to 6 years). Comparing the cost of liquidation with the cost of one year of mine liquidation indirectly suggested a 6-year liquidation time. Also the experts (persons managing liquidation processes) confirmed the compliance of the results with the current practice.

Evaluation parameters	Enter data	Expected time of liquidation [years]				
Total length of excavation gates [km]	22931	x				
Volume of all mine shafts [m3]	7320	x				
Number of all minig plant facilities [items]	71	x				
Multi-criteria		x				
Average cost of mine liquidation per year [mln PLN]	49,6	6 -	5-6	4-5	3-4	2-3
Cost of mine liquidation	Maximum	Minimum	Medium	Expected cost of mine [mln PLN]		
"medium smaller"	252,6	170,4	198,3	liquidation	213,3	

**Fig. 3.** Results of the preliminary assessment of liquidation time and costs of K3 mine

The analysis of the model object which is the K3 mine (Fig. 3) did not differ from the assumptions. According to the assumptions, the method classified the mine to a group of medium-sized smaller mines (KSM). The liquidation cost of the mine was set at PLN 213.3 million, which is 107.55% of the average value in this reference group. A discrepancy of this order at such an initial stage of cost estimation is not significant. The single- and multi-criteria analysis of the assessment parameters unanimously indicated 4 to 5 years of liquidation. Comparing the cost of liquidation with the cost of a year of a mine liquidation indirectly points to a 4-year liquidation time. Statistical analysis and expert opinions in this case also confirmed the correctness of the method assessment.

Evaluation parameters	Enter data	Expected time of liquidation [years]				
Total length of excavation gates [km]	32235	x				
Volume of all mine shafts [m3]	8125	x				
Number of all minig plant facilities [items]	102	x				
Multi-criteria		x				
Average cost of mine liquidation per year [mln PLN]	76,6	6 -	5-6	4-5	3-4	2-3
Cost of mine liquidation	Maximum	Minimum	Medium	Expected cost of mine [mln PLN]		
"medium larger"	602	326,1	434,3	liquidation	441,1	

**Fig. 4.** Results of the preliminary assessment of liquidation time and costs of K4 mine

The assessment of the K4 mine pointed it to medium-sized larger mines (KSW) as a reference group and assigned a liquidation cost of PLN 441.1 million (Fig. 4). In the single-criteria analysis, the method suggested, due to the total length of the excavation gates and the total volume of the shafts, 5 to 6 years of liquidation time, and due to the number of surface objects, 4 to 5 years. The multi-





criteria assessment confirmed the assessment of the first two assessment parameters. Comparing the cost of liquidation with the cost of one year of mine liquidation indicated a period of 6 years. In the opinion of experts, if this example of the mine is a typical one, the assessment of the method would be correct.

## 5. Discussion

Based on the analysis, it was found that when estimating the preliminary cost and time of liquidation, the length of excavation gates, the volume of the shafts and the number of surface objects should be taken into account. The parameters adopted for the assessment represent the components of the processes of shafts liquidation, excavation gates and surface objects, for which a statistical liquidated mine spends about 11% of the amount allocated for its liquidation. The remaining part of the cost ensures the correct mine liquidation processes, requiring additional spending of the remaining approximately 89% of the costs [8, 9, 10, 11].

When verifying the correct operation of the method, at the first stage, the scope of loosening and management of hypothetical mines was assessed, with the exception of K4, which has its liquidated counterpart. The real mine corresponding to the analyzed parameters belonged to small mines (KM) and was liquidated for 4 years. The liquidation cost assigned in the method is as much as 317.73% of the true value. The prototype of the K4 mine was a mine merged several times, consisting of many small surface objects, many short shafts and a simple network of long excavation gates. Therefore, unexpected results of the analysis were obtained. This confirmed the fact that the method gives correct results only for typical mine conditions.

At the second stage of verification, hypothetical examples of mine liquidations were presented for assessment to the people who manage the SRK S.A. Branches. Experts confirmed the correct operation of the method with the accompanying software.

## 6. Conclusions

The proposed method of preliminary assessment of the time and costs of mine liquidation can be used as a tool for estimating time and costs in the planned processes of liquidation of mines or their parts. The method can be used by any mine liquidation company, because it only requires the acquisition of a few basic parameters of the liquidated mining plant and it does not refer to the structure of liquidation processes developed by SRK S.A.

The described method is based on a statistical analysis of costs broken down into years of the ongoing liquidation processes. The tool allows optimization independent of the scale of the liquidation task.

Estimation of time and costs of liquidation, also taking into account the cases of untypical main processes of liquidation of a mining plant is an unresolved problem. Only unsystematized knowledge of practitioners is used.

The proposed method requires further research work, but already in its current form it can be a very useful auxiliary tool in an engineering work and in the initial design work of restructuring post-mining assets.

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