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Modified method for assessing the required expenditures and estimated time of hard coal mine liquidation

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The assessment method is based on an analysis of the mine liquidation costs, divided into successive years of the course of the aforementioned processes. The method does not pertain directly to the specific liquidation processes conducted at SRK S.A., but it can also be employed by any entity conducting mine liquidation as a comparative tool for the detailed and multi-criterial estimation of the costs of planned mine closure.

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Abstract

The restructuring of hard coal mining requires significant budgetary expenditures. A comprehensive scientific approach may facilitate the rationalisation and minimisation of mine closure costs. This study proposes a method for the preliminary estimation of the costs and time required for the potential liquidation of a hard coal mine. In addition to a literature review, a statistical analysis and a case study, personal interviews were conducted with individuals with direct management over the restructuring, reclamation and liquidation processes pertaining to mines undergoing closure.

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1. Introduction

A mining plant’s activity is typically associated solely with its period of extraction, yet it should be remembered that liquidation is the final natural stage of mining activity [1–3]. After active mining is concluded, the abandoned mine infrastructure may hinder the potential repurposing of a mining plant’s assets. Spółka Restrukturyzacji Kopalń S.A. (SRK, www.srk.com.pl) conducts activity related to the closure of mining plants as well as the reclamation and restructuring of mining areas [4,5]. The Company is focused on clearing former mining areas of infrastructure that is redundant and impossible to repurpose as well as on supervising and managing the leftover assets of mining plants undergoing liquidation [6–8]. As per a social agreement, the closure of successive mining plants proceeds according to a schedule. Mine liquidation is a very complex and expensive task due to the wide scope of work that must be accomplished as part of it [9,10]. The average cost of closing a mine is about 75–100 million euros. Reducing the capital intensity of hard coal mines undergoing liquidation is a problem that the mining sector has been struggling with from the moment the industry restructuring processes were commenced at the turn of the centuries [11,12]. The reasons behind the limited improvement in liquidation efficiency can be identified as, for example, the lack of available instruments and tools to support cost management [13,14].

Repurposing the assets of mining plants undergoing liquidation is complex and expensive [15,16]. The issues related to restoring the post-mining areas for the use of the society, as well as the rational financing of mine liquidation processes have not been the subject of comprehensive studies [9,17]. The literature available in this regard is limited and concerns only specific, typically general problems. This publication is a presentation of a modified improved version of a tool for assessing the costs of
liquidation processes [13,14]. It proposes an updated and more accurate method for the preliminary assessment of the time required to close a mining plant as well as the expenditures necessary to conduct the task in question, based on a narrow group of parameters characteristic of mines undergoing liquidation [18,19]. The updated and improved method can be used as a supporting tool by teams planning the liquidation of a mine or its part [15,20]. The obtained information will make it possible to determine the estimated time and financial scope of the planned enterprise already at a very early stage of preparation.

The method presented in the article is applied to identify the potential costs and time required to conduct mine closure based on a number of the most characteristic parameters describing a liquidated mine and simultaneously correlating with the final costs and time of the closure [18,22,22]. The provided assessment parameters are meant to be legible and comprehensible and to require no major calculations. The parameters were selected based on the adopted functional similarity of the analysed mining plants. It was assumed that if each of the analysed mines was designed for the same purpose, i.e., hard coal extraction, then each of them would also exhibit a similar set of facilities, differing only in the scale of the enterprise. Such an assumption at the preliminary assessment stage should have no influence on the applicability of the liquidation cost and time estimation method [23,24].

2. Materials and methods

2.1. Materials

2.1.1. Mine liquidation process characteristics

The research involved the analysis of liquidation plans and programs for 19 mines or their parts over the period of 2015–2023. The studied group included 17 already liquidated mining plants as well as 2 currently undergoing liquidation or their separated parts (www.srk.com.pl). The analysed liquidated mine group is very heterogeneous. Each case of mining plant liquidation is a unique one, though there are certain regularities. The liquidation process lasts 5 years on average (2–8 years). The liquidation cost is also very diverse, ranging from about 5 to 230 million EURO, with an average cost of about 80 million EURO (after conversion to values specific to the 1st quarter of 2023). The reason for this is the broad range of difficult, sometimes dangerous and expensive work that must be accomplished as part of the task. The time to accomplish each of the liquidation processes as well as their costs are typically associated with the number, size and type of the liquidated facilities. The liquidation time is a derivative of the logical mining plant facility closure sequence, the tender procedure duration and the applied demolition technology.

To increase the comparability of costs for such a diverse reference group, per prior studies [19], the mines were divided into groups of Large Mines (LM), Medium-Large Mines (MLM), Medium-Small Mines (MSM), Small Mines (SM) and Micro Mines (MM). Table 1 presents a compilation of the basic parameters characteristic of the adopted mine groups. The liquidation process costs were recalculated based on the financial conditions specific to the 1st quarter of 2023 [15,25].

At SRK S.A., the mine liquidation process is divided into 10 constituent processes — see Table 2. The closure of a mine is typically accomplished

| Table 1. Basic parameters characteristic of the adopted mine groups. |
|-----------------------|--------|--------|--------|--------|--------|--------|
| **Group**             | **Total** | **LM** | **MLM** | **MSM** | **SM** | **MM** |
| Maximum mine liquidation cost, million EURO | 230.8 | 230.8 | 140.2 | 58.8 | 32.3 | 4.8 |
| Minimum mine liquidation cost, million EURO | 4.3 | 139.8 | 76.0 | 39.7 | 18.6 | 4.3 |
| Average mine liquidation cost, million EURO | 82.2 | 182.2 | 101.2 | 46.2 | 25.3 | 4.6 |
| Maximum mine liquidation time, years | 8 | 7 | 8 | 5 | 5 | 4 |
| Minimum mine liquidation time, years | 2 | 5 | 4 | 3 | 2 | 2 |
| Average mine liquidation time, years | 4.9 | 5.5 | 4.7 | 4.0 | 3.6 | 3 |

Source [15,19].

| Table 2. Constituent mine liquidation processes conducted at SRK S.A. |
|------------------|------------------|
| 1 Gallery mining excavations closure and securing |
| 2 Shaft and fore-shaft closure and securing |
| 3 Securing adjacent mines from water, gas and fire hazards |
| 4 Mine infrastructure liquidation |
| 5 Terrain reclamation |
| 6 Securing the facilities to be closed in a sequence ensuring the safe liquidation of the mining plant |
| 7 Work performed from the perspective of hazard protection and prevention with regard to the liquidated mining plant |
| 8 Preparing the necessary designs, documentation, assessments, expert opinions and analyses related to the liquidation |
| 9 Mending damage caused by the mining plant operation |
| 10 General supervision of the tasks performed during the liquidation |

Source: SRK S.A. data.
according to two variants. These variants are related to the structure of the end mine model. Factoring in the safety of adjacent mining plants, a mine can be liquidated in total or with a remaining active pumping system [15,26]. If there is no threat to the safety of neighboring mines, the entire underground infrastructure (excavations and mining shafts) is closed.

Processes 1 and 2 can be performed at the same time. In this model, the mining excavations closure process (Process 1) and the adjacent mine securing process (Process 3) must end before the shaft closure process (Process 2) is concluded. The terrain reclamation process (Process 5) can start only after the underground infrastructure is liquidated (Process 4) and the facilities to be closed are secured (Process 6). The remaining processes (Processes 7, 8, 9 and 10) are conducted throughout the mine liquidation operations [21,25,27].

When a mine is to have an active pumping system after closure, the entire underground infrastructure is liquidated except for the necessary shafts and mining excavations, which are converted into the pumping system. The basic process involves gallery mining excavations closure and securing (Process 1). The adjacent mine securing process (Process 3) must be conducted until the end of all the liquidation operations [28,29]. The closure of redundant shafts (Process 2) can be performed independently from mining excavations closure (Process 1) and may be concluded first, as the mining excavations closure can be conducted by means of the shafts left to ensure the pumping system operation even until the end of all the mine liquidation processes. The terrain reclamation process (Process 5) can start only after the underground infrastructure is liquidated (Process 4) and the facilities to be closed are secured (Process 6), whereas the remaining processes (Processes 7, 8, 9 and 10) are conducted throughout the mine liquidation operations [26,30].

Based on prior research, it was concluded that the parameters exhibiting the highest correlation with liquidation time and costs include [19,28]:

- the total length of the mining excavations, regardless of their size, structure or purpose,
- the size of all the mine shafts, regardless of their number and whether they are to be closed or maintained,
- the number of mining plant facilities to be closed, regardless of their purpose, technical condition or size.

These parameters were assigned corresponding weights that affect the final evaluation (Table 3). The parameters should be determined once the decision to close a mine is taken [19,28].

The adopted partial assessment parameters describe 3 of the 10 constituent mine liquidation processes (Process 1, 2 and 4), but also all the processes involving physical liquidation tasks [31,32]. Parameters close to the adopted ones yielded slightly lower accuracy in the classification of mines to their corresponding reference groups, and were therefore not included in the final analysis [33,34]. Furthermore, factors such as the scope of employment or the area to be reclaimed and repurposed were also not included in the group of assessment parameters [35,36]. Factors whose influence on the mine liquidation time and cost could not be determined mathematically were also not included as parameters in the analysis [37,38].

### 2.2. Methods

The presented work led to improving the accuracy and extending the scope of application of the previously developed tool [19,28] for the preliminary assessment of the time and expenditures necessary to conduct a planned liquidation process. The goal was achieved in two stages (Table 4). The research objective was accomplished based on the statistical analysis of concluded or ongoing examples of chosen mining plant (Branch) liquidation conducted in the years 2015–2023 by Spółka Restrukturyzacji Kopalń S.A. Data related to the mine liquidation tasks accomplished in the years 2015–2021 was derived from periodic reports of Branch activity submitted to the Company Board. Data for the year 2022 was obtained from monthly progress reports for the 12 months of 2022 (the data may undergo minor corrections once the annual report is prepared), whereas the data for the year 2023 constitutes the anticipated values pertaining to the accomplishment of the planned liquidation processes.

A review of the available literature and cost analysis of the mining plant restructuring processes conducted at SRK S.A., divided into successive years of their course, performed in stage I, made it possible to conclude that the 3 previously selected assessment parameters (analysed together using

<table>
<thead>
<tr>
<th>Partial assessment parameter</th>
<th>Parameter weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mining excavations length</td>
<td>0.316</td>
</tr>
<tr>
<td>Total mine shaft size</td>
<td>0.421</td>
</tr>
<tr>
<td>Number of facilities to be closed</td>
<td>0.263</td>
</tr>
</tbody>
</table>

Source [19].
quotient transformation) offer the best correlation with the total liquidation costs and time. At this stage, we additionally performed a statistical analysis of 3-year data and conducted direct interviews (surveys) with experts [9,10].

Stage II verified the correctness of the modified assessment tool based on a hypothetical model and actually conducted mining plant liquidation processes. The method verification consisted in comparing the method’s estimations with SRK S.A.’s experience. After obtaining an acceptable estimation accuracy, the method was presented to experts for another evaluation. The direct interview with experts who manage liquidation processes confirmed the correctness of the obtained estimated values. The research identified new areas and problems that required solving. Figure 1 depicts the entire research method, described in Steps I and II (see Table 4). It illustrates the iterative nature of the modification of the method, depending on mine-specific actual conditions and possibilities.

3. Method for the preliminary estimation of mine liquidation costs and time

The critical element of the proposed method is a tool prepared in Microsoft Excel. The interface of the tool includes white background fields, which are the descriptive fields. Fields marked in light brown are data input fields for the original values of the partial assessment parameters [29,39]. Fields marked in light green are result fields, where the method provides the liquidation cost and time estimation results [40,41]. A template of the tool interface is presented in Figure 2.

The method assigns a mine to one of the adopted mine groups based on the input original values of the assessment parameters [19,42]. It estimates the anticipated expenditures and time for the liquidation process using the cost and time value thresholds relevant to the specific group. The most likely time of mine closure and the estimated costs of conducting the liquidation processes are assigned to

<table>
<thead>
<tr>
<th>Stage of research</th>
<th>Research methods</th>
<th>Research method application results</th>
</tr>
</thead>
</table>
| I                 | - Literature study  
                      - Statistical analysis  
                      - Direct interview | - Statistical analysis of liquidation process costs  
                      - Proposed modification of the prior assessment method |
| II                | - Synthesis       
                      - Case study        
                      - Direct interview | - Verifying the correctness of the updated assessment method  
                      - Identifying the research areas and problems to be solved |

Source: own study.

Table 4. Research methods and the results of their application in the individual development stages of the modified method for assessing the required expenditures and estimated time of hard coal mine liquidation.

![Fig. 1. Block diagram of the research methodology. Source: Own study.](image)

![Fig. 2. Interface of the tool for the preliminary estimation of mine liquidation costs and time. Source: own study.](image)
the specific parameters using statistical analysis, initially separately for each partial assessment parameter [39,43]. The tool first presents the results determined based on a single criterion for each individual partial assessment parameter and then calculates the average value for the single-criterial assessments. Afterwards, using quotient transformation and formula 1, the method assigns the analysed set of partial parameters to its corresponding mine reference group for all three partial parameters combined. Already as part of the reference group, the method estimates the anticipated liquidation time and the expenditures required for the process [40,41]. Furthermore, to compare the expenditure scopes, the method provides the name of the assigned reference group in the final line together with the maximum, minimum and average mine liquidation costs in this group [44,45]. The estimation accuracy was improved by applying a multi-criterial comparison of the input original values with their corresponding liquidation cost and time thresholds within the mine groups, determined based on the scope of the task [42,43].

\[
WK_j = \sum_{i=1}^{3} w_i \frac{h_{ij}}{h_{i,max}}
\]

where:
- \( WK_j \) – multi-criterial value of the partial assessment parameters for a mine \( j \),
- \( w_i \) – weight of a partial assessment parameter \( i \),
- \( i \) – partial assessment parameter ID,
- \( j \) – analysed mine ID,
- \( h_{i,max} \) – maximum value of a partial assessment parameter \( i \),
- \( h_{ij} \) – value of an analysed partial assessment parameter \( i \) for a mine \( j \).

4. Discussion
4.1. Verification of the proposed method

The correctness of the designed method algorithm was inspected in two stages. The first stage compared the actual liquidation costs of all the 19 analysed mines with the values of the costs as estimated by the proposed method. In 3 out of 19 cases, the obtained results were strongly divergent from actual experience. A documentation analysis (liquidation plans and programs), a statistical assessment and interviews with experts (individuals who manage liquidation processes) indicated that these 3 cases were atypical examples for which the adopted method assumptions were not fully valid [46,47]. One of these cases involved an underestimation of the costs by about 60%, while in two there was an overestimation by a factor of two and three. The most overestimated mine included a network of long mining excavations that required disproportionately low expenditures, as well as a significantly high number of facilities that were of small sizes which led to low costs [38,46]. The proposed method classified this mine as a large mine (LM) when it should have actually been classified as a medium-large mine (MLM). In the other two cases, mines that should have been assigned to the small mine group (SM), or rather just their specific parts, were classified by the method as a reference group larger than in reality (MSM) due to the long mining excavations structure and the large number of small facilities (with low liquidation costs). As per the experts’ opinions, these three mining plants were excluded from the method verification as atypical examples [30,48]. According to the experts, after excluding the atypical examples of liquidation from the analysis, the obtained liquidation cost estimation was satisfactory for this stage of the design work. The obtained deviations from actual values within the reference groups are presented in Table 5 and Figure 3.

The method tends to slightly overestimate the liquidation costs. In the medium-sized reference groups (MLM and MSM), the average overestimation of costs is about 20%, and only in the small mine group (SM) it is about 30%. In the large mine group (LM), the method underestimates the liquidation costs by about 6%. In extreme cases, the method overestimates the costs by about 60%, except for one extreme case in the medium-large group (MLM), while underestimating by about 16% for large and medium-small mines (LM and MSM) and by 40% for medium-large (MLM) and small (SM) mines [49,50]. Due to the minor range of liquidation costs for micro mines (MM), the obtained concordance of the values proposed by the

### Table 5. Deviations of values estimated by the method relative to actual values.

<table>
<thead>
<tr>
<th>Mines</th>
<th>All</th>
<th>LM</th>
<th>MLM</th>
<th>MSM</th>
<th>SM</th>
<th>MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated average mine liquidation cost</td>
<td>125.4%</td>
<td>104.3%</td>
<td>120.4%</td>
<td>116.4%</td>
<td>131.4%</td>
<td>104.3%</td>
</tr>
<tr>
<td>Estimated average mine liquidation cost (excluding 3 atypical mines)</td>
<td>105.7%</td>
<td>104.3%</td>
<td>100.7%</td>
<td>116.4%</td>
<td>105.4%</td>
<td>99.4%</td>
</tr>
<tr>
<td>Maximum overestimation</td>
<td>+61.15%</td>
<td>+51.97%</td>
<td>+61.15%</td>
<td>+59.67%</td>
<td>+40.18%</td>
<td>+0.00%</td>
</tr>
<tr>
<td>Maximum underestimation</td>
<td>-43.64%</td>
<td>-15.63%</td>
<td>-39.83%</td>
<td>-5.20%</td>
<td>-43.64%</td>
<td>-0.64%</td>
</tr>
</tbody>
</table>

Source: own study.
method with the real costs of liquidation was over 99%.

In 2 cases of mine liquidation time estimation, the method predicted a considerably shorter time of closure. After analysing documents and obtaining the experts’ opinions, it was concluded that this underestimation happened for mines where the liquidation time was artificially extended to secure the adjacent active mining plants. 2 cases of significant liquidation time overestimation were also noted [34,36]. These included one medium-large mine (MLM) and one small mine (SM). The reason for this was the large number of small facilities to be closed as well as a network of long mining excavations that could be closed with relatively minor effort and expenses. The estimation accuracy obtained for the method was deemed sufficient for the preliminary stages of potential mining plant liquidation planning [51,52].

The next stage of verifying the method consisted in analysing 5 examples of mine liquidation processes, including 3 hypothetical and 2 actually accomplished ones. The examples were selected in such a way so as to inspect the correctness of the liquidation time and cost estimation in the most comprehensive way, and also to investigate the results of applying the method in situations of illogical sets of assessment parameter values. The first of the analysed hypothetical mines was the mine with the mining excavations designation “M1”, which was assigned the highest parameters obtained in the entire analysed group of 19 liquidated mines. As per expectations, this mine turned out to be bigger than the largest mine liquidated thus far [37,47]. The second mine was M2, with average partial assessment parameter values for small mines (SM). The third analysed example was mine M3, with the shortest length of underground mining excavations driven thus far, an average shaft size and the greatest number of liquidated mining plant facilities. This was followed by the analysis of the actual mine M4, for which the multi-criterial assessment indicated the lowest deviation from the costs incurred in practice. The next analysis involved the example of liquidated mine M5, where the required expenditure was overestimated by 130%. This was one of the mines that were deemed atypical before, belonging to the medium-large group [12,53].

As per expectations, the method classified mine M1 as a large mine (LM) — Figure 4. As it was a mine bigger than the largest mine liquidated thus far, the cost of its closure significantly exceeded the maximum liquidation cost for this mine group, by 23%. The mine liquidation time determined by the method was about 8 years in the single-criterial analysis due to the mining excavations length and shaft size, whereas the number of facilities to be closed yielded a liquidation cycle of over 13 years [51,54].

In this case, the average single-criterial assessment value overlapped with the multi-criterial analysis, yielding a liquidation time of about 10 years [45,48]. In practice, no mining plant was ever liquidated for such a long time, but according to the

Fig. 3. Deviations of values estimated by the method relative to actual values. Source: own study.
experts, the scope of work to be carried out for a mine of this size could be feasible.

The analysis of mine M2 as a reference site did not diverge from expectations. As was foreseen, the method assigned mine M2 to the small mine (SM) group both in the single-criterial and multi-criterial approaches, indicating a liquidation time of about 3.5 years, which is an average value for this mine group (Fig. 5). The liquidation cost determined by the method was 23.5–23.8 million EURO. This value is slightly underestimated relative to the average value for the reference group in question.

<table>
<thead>
<tr>
<th>Assessment parameter</th>
<th>Calculated liquidation cost</th>
<th>Share of the actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mining excavations length, m</td>
<td>72.5 million EURO</td>
<td>85.71%</td>
</tr>
<tr>
<td>Total mine shaft cubature, m³</td>
<td>75.0 million EURO</td>
<td>88.71%</td>
</tr>
<tr>
<td>Number of facilities to be liquidated, units</td>
<td>76.4 million EURO</td>
<td>90.31%</td>
</tr>
<tr>
<td>Average single-criterial</td>
<td>74.6 million EURO</td>
<td>88.24%</td>
</tr>
<tr>
<td>Multi-criterial</td>
<td>79.9 million EURO</td>
<td>94.52%</td>
</tr>
</tbody>
</table>

Fig. 4. Preliminary liquidation cost and time estimation results for mine M1. Source: own study.

Fig. 5. Preliminary liquidation cost and time estimation results for mine M2. Source: own study.

Fig. 6. Preliminary liquidation cost and time estimation results for mine M3. Source: own study.

Fig. 7. Preliminary liquidation cost and time estimation results for mine M4. Source: own study.
Fig. 8. Comparison of the liquidation costs of mine M4 calculated based on single and multiple criteria with actual costs. Source: own study.
The method classified mine M3 as a medium-large mine (MLM). As was expected, the single-criterial assessments yielded very diverse liquidation times and costs (Fig. 6). This was the result of the mine’s illogical structure [11,12]. The average single-criterial values for the liquidation time and cost brought these parameters to a slightly more similar level [35,49]. Only the values determined by multi-criterial analysis obtained the experts’ approval. In practice, it is in fact the cost of 122 million EURO, which constitutes 134.61% of the average value in this reference group, that would be adopted for the liquidation processes with the analysed set of assessment parameters.

In the assessment of mine M4, the method classified it as a medium-large mine (MLM), which conforms with its actual state, and assigned it a liquidation cost of 80 million EURO, slightly above the minimum cost for this reference group. The cost calculated in the multi-criterial approach was only 5.5% lower than the one incurred in practice (Fig. 7).

In the single-criterial analysis, the method suggested a liquidation time of 4–13 years based on the total mining excavations length and shaft size, while the number of surface facilities yielded a time of about 3 years.

The multi-criterial analysis confirmed the results of the first two assessment parameters. The determined liquidation time was also similar (slightly longer) to the one obtained in practice [34,53].

A comparison of the actual costs with the liquidation costs calculated by the single-criterial and multi-criterial approaches is presented in Table 7 and Figure 8. A divergence of such an order of magnitude at this early stage of cost estimation is not significant.

The assessment of mine M5, which was evidently impossible to analyse with this method, classified it as a medium-large mine (MLM) and assigned it a liquidation cost of 236.5 million EURO (Fig. 9). A comparison of the actual costs with the liquidation costs calculated by the single-criterial and multi-criterial approaches is presented in Table 7 and Figure 10.

In the single-criterial analysis, the method suggested a liquidation time of 4–13 years. The multi-criterial analysis confirmed the average single-criterial assessment parameter estimation, indicating a liquidation time of about 9 years. A statistical analysis and expert opinions also confirmed the correctness of the assessments by the method in this case.

In the final stage of verification, the hypothetical and actual analysed examples of mine liquidation were presented for evaluation by individuals who manage SRK S.A. branches in practice. The experts confirmed the correctness of the method together with the included software.

The method algorithm correctness was evaluated by comparing the financing scopes for the repurposing of assets and liquidation of the hypothetical mines M1, M2 and M3 as well as mines M4 and M5, which have their real liquidated counterparts.

### Table 7. A comparison of the actual costs with the liquidation costs of mine M5 calculated by the single-criterial and multi-criterial approaches.

<table>
<thead>
<tr>
<th>Assessment parameter</th>
<th>Calculated liquidation cost</th>
<th>Share of the actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mining excavations length, m</td>
<td>163.2 million EURO</td>
<td>214.87%</td>
</tr>
<tr>
<td>Cubature of all mine shafts, m³</td>
<td>297.4 million EURO</td>
<td>391.60%</td>
</tr>
<tr>
<td>Number of facilities to be liquidated, units</td>
<td>524.9 million EURO</td>
<td>691.19%</td>
</tr>
<tr>
<td>Average single-criterial</td>
<td>328.5 million EURO</td>
<td>432.55%</td>
</tr>
<tr>
<td>Multi-criterial</td>
<td>236.6 million EURO</td>
<td>311.50%</td>
</tr>
</tbody>
</table>

**Fig. 9.** Preliminary liquidation cost and time estimation results for mine M5. Source: own study.
Fig. 10. Comparison of the liquidation costs of mine M5 calculated based on single and multiple criteria with actual costs. Source: own study.
actually liquidated mine M5 belonged to the medium-large mine (MLM) group and was undergoing liquidation for 4 years [50,55]. The most likely liquidation cost estimated by the method was as great as 311.55% of the actual value. The original mine M5 was a merging of multiple old smaller mines with numerous small surface facilities, many short shafts and a simple network of long mining excavations. All these elements generated relatively low liquidation costs, which was why the obtained estimated costs were so unexpectedly high. In the experts’ view, if this mine were a typical example, then the assessment by the method would have been correct. This confirmed one of the assumptions that the method yields correct results only for typical mine conditions [27,52].

Mining enterprises lack comprehensive and coherent solutions pertaining to the estimation of planned liquidation process costs for mines undergoing closure, though many partial elements of such a concept do exist [15,44]. The proposed procedure can be a form of supplementing this gap.

Based on the conducted analysis it was concluded that the preliminary liquidation time and cost estimation should factor in the total mining excavations length, shaft size and number of surface facilities in combination. The parameters adopted for the assessment represent constituent elements of the liquidation process (Processes 1, 2 and 4). These are the physical liquidation processes of shafts, mining excavations and surface facilities, for which a statistical liquidated mine spends about 11% of the budget allotted for the closure. The remaining part of the mine liquidation cost ensures the correct course of Processes 1, 2 and 4. The full liquidation of redundant mining plant facilities or their reclamations requires additional spending of the budget remaining at a level of about 89%. The simplest way of estimating the remaining required costs could be to link the liquidation process costs with the liquidation time, though only a part of the costs depends on the passage of time [15,54].

5. Conclusions

- The presented modified method for the preliminary assessment of mine liquidation costs and time can be a useful comparative tool when estimating the time and costs related to the potential liquidation of different mining plants or their parts during the planning of the entire process. As per a social agreement, the closure of successive mining plants proceeds according to a schedule, and it should be expected that such a situation may occur in the near future.
- The method utilises the 20 and more years of experience of Spółka Restrukturyzacji Kopalni S.A., but it can also be applied by any company that conducts mine liquidation processes.
- The method algorithm is based on obtaining but a few of the most basic parameters specific to a liquidated mining plant, which are unrelated to the liquidation process structure as developed by SRK S.A.
- The presented tool can facilitate the rationalisation and minimisation of costs incurred by a company, and may also serve as one of the elements for increasing the efficiency of mining plant liquidation.
- The method can provide optimisation independent from the “scale” of the liquidation task. Designing a more accurate method for analysing the potential costs, with a division into the individual, constituent liquidation processes, will require additional research. The tool may require further refinement, but even in its current form, it may be a very useful support instrument in the engineering design of mine asset liquidation and repurposing.
- Unresolved problems include the estimation of liquidation time and costs, also in the case of atypical courses of the primary liquidation processes, as well as the differentiation of process costs and time depending on the model of the mining plant to be closed. This area only offers the standardised knowledge of professionals.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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