International Journal of Economics, Business and Management Research

Vol. 8, No.11; 2024

ISSN: 2456-7760

Real-time Monitoring System for Short-term Mine Plan Implementation to Optimize the Coal Discrepancy

Oktovianus Bakkula[1], Dermawan Wibisono[2], Mursyid Hasan Basri[3], Manahan Siallagan[4]
[1,2,3,4]Bandung Institute of Technology, School of Business and Management
Bandung, 40132, West Java, Indonesia

doi.org/10.51505/IJEBMR.2024.81113 URL: https://doi.org/10.51505/IJEBMR.2024.81113

Received: Oct 27, 2024 Accepted: Nov 05, 2024 Online Published: Nov 16, 2024

Abstract
This study aims to explore factors that contribute to mine plan achievement which further impact the coal discrepancy phenomenon or the variance between actual coal mined and planned. Secondly, the purpose is to develop a reliable monitoring tool for accurate implementation of mining activities at each stage, particularly for short-term periods such as daily and weekly plans. Data collection was carried out using empirical data collection of coal mined achievement from some pits, along with monthly data on the technical aspects contributing to this achievement. The coal discrepancy phenomenon is significantly influenced by four major factors, namely the accuracy of the geological model, change in mining sequence, operational loss and optimized mining. Implementing this new planning monitoring system has significantly increased compliance with planned mining sequences, facilitates the achievement of the final form of the mine in each period impacting short-term coal mined achievement. This research utilizes original digitalization in mine planning monitoring systems to optimize the mining sequence and improve the coal discrepancy phenomenon. It is critical since in coal mines, different stages of the mining process impact not only the amount of coal mined but also the aggregate properties of coal produced. It supports a resilient coal value chain, especially in the overburden removal phase, as an upstream area of coal mining.

Keywords: Coal discrepancy, geological model, mine monitoring, mine plan, mine sequence

1. Introduction

Coal has long been one of the most abundant fossil fuels on earth (Evans & Ramani, 2024) and has supported the energy systems of various countries around the world (Busch et al., 2023) as well as being a key energy source for industrial development (Lian et al., 2023). It is the most important energy source for electricity generation; 38.0% of global power generation (Zhang et al., 2022), half in the United States, was produced from coal, and in China, it was two-thirds of all electricity generated by coal (npr.org, 2024). It also forms an essential fuel for the production of steel and cement (Indonesia Investments, 2023). Currently, coal consumption accounts for a large proportion of world energy consumption because of its lower cost and will remain the major energy source of the global energy structure in the coming decades (Zhang et al., 2022). Meanwhile, coal companies have increasingly recognized the significance of coal discrepancies, which refer to the variance between the coal mined and the planned amount. Over the last two

Vol. 8, No.11; 2024

ISSN: 2456-7760

decades, scholars have become increasingly aware of the importance of coal discrepancies to the company's growth. It is a phenomenon that normally occurs in every coal mine and can arise in all mining value chains, from upstream to downstream, from mines to ships. This phenomenon is complex because it involves various internal and external factors, including the physical availability (PA) and utilization of equipment, changes in mining sequence due to internal concerns and environmental issues, mud handling, geological model, land acquisition issues, and fulfillment of demand on the marketing side (Bakkula et al., 2022). It is a critical phenomenon that mining companies must address in order to maximize profits in volatile conditions. A continuing significant coal discrepancy will have a detrimental impact on the company's growth. Achieving the mine plan is important considering that the production plan that has been developed is used in scheduling production, transportation, processing, shipping, and sales, which will then have an impact on the company's cash flow performance. In some cases, when shipments cannot be made according to the schedule agreed in the contract, the mining company, as the provider, will bear a penalty for the delay or demurrage.

Meanwhile, monitoring including evaluation is widely recognized as essential aspect of management aspect in many industries since it provides not only early and ongoing information to help shape implementation in advance of evaluations (ILO, 2011; Hall, 2022) but also constantly modifying and improving a project or program and the basis for evaluation and review (Gosling & Edwards, 2003) including policies in private and public sector organizations. It is the systematic and continuous collection and analysis of information about the progress of a piece of work over time (Gosling & Edwards, 2003). It also a comparison of a program, policy, or activity that is being implemented with the expected results to actively manage performance, maximize positive impacts, and minimize the risk of adverse impacts. Monitoring focuses not only on processes (activities and outputs) but also on outcomes and impacts as guided by an accompanying evaluation plan (Markiewicz, 2014).
The research questions for this research are as follows:

1) What are the contributing factors on the mine plan achievement which have a significant impact on the coal discrepancy phenomenon?
2) How does the role of digitalization and technology play in optimizing the significant contributing factors to this phenomenon?

The primary aim of this paper is to design a real-time monitoring system and tools to monitor the sequence of the pit and dump to ensure the optimal implementation of short-term mining phase plans. Implementing the latest technologies allows for the acquisition of real-time information from the monitoring tool. Based on the acquired information, the monitoring tool can display the real-time progress of the pit and dump, which enables the implementation of real-time performance analysis for pit and dump sequences, achieving efficient operation in a knowledge-based manner. This case study was conducted at PT XYZ, one of the largest coal mining companies in Indonesia, with a production capacity of around 50 million tons per year. The paper is organized as follows: Section 2 describes the previous monitoring system for the short-term mine plan implementation. Meanwhile, Section 3 briefly introduces the current literature on coal reconciliation and the mining industry's field monitoring aspects. In Section 4, we describe the research method. Section 5 illustrates the data collection and results of a new monitoring system design. Section 6 presents the findings and discusses them. Section 7 concludes the research, detailing its contribution, limitations, and future research opportunities.

2. Previous Monitoring System of the Short-Term Mine Plan Implementation

PT XYZ has implemented a fleet management system for managing trucks and shovels since 1995. This system regulates trucks from each digger (loading point) to each dumping point either automatically (unlocked system) or manually (locked system). It was also equipped with closed-circuit television (CCTV) at each pit to support pit monitoring. The existing fleet management system cannot directly control the implementation of mining plans in the field optimally. This system only focuses on the aspect of managing truck allocation to and from the digger in real-time to ensure that the usage of diggers and trucks can be optimized to support the achievement of the mining plan. In addition, the system generates report of various production KPIs, including overburden (OB) removed production, coal mined, productivity, loading time, spotting time, cycle time, etc., including forms a production database that can be accessed for reporting and evaluation purposes. To achieve consistency and integrity, planning and operating processes must aim to increase coal recovery as well as operational and governance needs. Furthermore, outputs from production measurement and reporting are required for the successful reconciliation of coal recovery and mining performance against the plan (Tetteh & Cawood, 2017). This research provides a novelty in mining monitoring, including fleet management systems since the mining sequence plan is not included and monitored in the most of existing fleet management system. The fleet management system is controlled by a group of people called dispatchers from the central control room who coordinate with the operation team in the field during the shift takes place.

For a long time, mining monitoring has been the main aspect of mining operations. In large-scale mining companies, real-time mining monitoring has become one of the main needs, considering that mining is a capital-intensive business. The monitoring process starts with the short-term engineer developing a weekly or daily plan regarding the shovel movement in the pit and also the dumping plan. The plan also includes detailed blasting boundaries, coal expose boundaries and other related boundaries. This plan will then be discussed with the pit management, such as the pit manager, superintendent pit technical, and superintendent pit production. After being reviewed and approved by the pit management, the short-term engineer inputs the detailed daily plan into the daily logbook manually as guidance for plan execution in the field, which will be updated daily. While the plan is executed in the field, there will be daily field coordination that involves the field supervisor, pit technical and pit geologist. Regularly, the field coordination is also attended by the pit management. However, the monitoring of plan implementation is still using the updated manual of pit progress by stake-out in the field run by the pit survey team. The result of the stake-out data is then downloaded manually and processed on a computer before it can be compared with the original plan. Usually, it takes time to process, at least a day before the data can be shown on the map. While waiting for the progress, the only way pit technical as a planner can check the implementation is by checking the progress directly in the field and supported by the pit survey team since the detail coordinate is critical in mines. During the execution in the field, the pit survey will install the pegs as the limit of digging for the digger, dump limit, progress elevation, coal plan boundary, broken boundary, & etc., as shown in Figure 1 below.

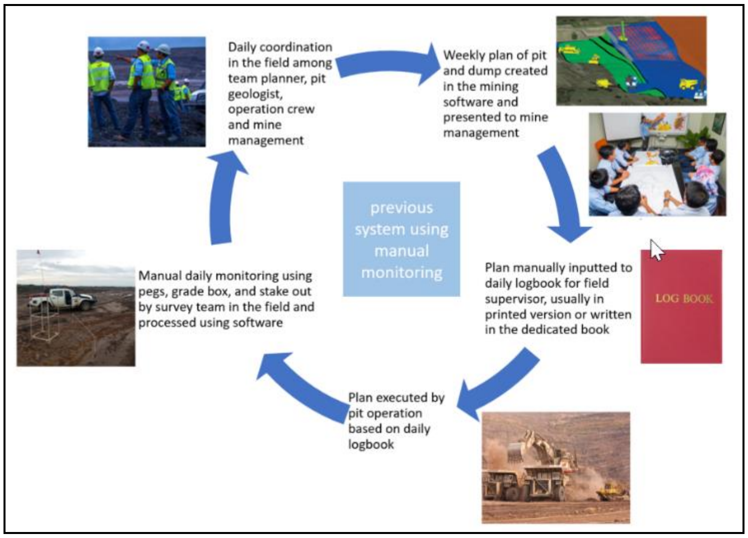

Figure 1. Flowchart of the previous planning, execution, and monitoring process

3. Literature Review

Previous studies in the field of mine reconciliation and discrepancy include Thomas & Snowden (1990), Schofield (2001), Morley (2003), Morley & Thompson (2006), Bester et al. (2016), Jang et al. (2016), and Otto & Musingwini (2019). According to Holtham et al. (2011), reconciliation enables the continuous refinement and improvement of both planning and production processes by comparing achieved results with expected outcomes. Similarly, according to Musmualim et al. (2015), mining reconciliation is the comparison between the mine plan and the actual realization in the field. So, it is critical to ensure the monitoring of mine progress to ensure the targeted pit's face position or pit development will be achieved to ensure the coal flow from pit to port.

Monitoring is a fundamental and universal management technique for identifying program strengths and weaknesses (Gosling & Edwards, 2003), as well as a vital communication tool between the project and its stakeholders (USAID, 2014). It is critical to determine whether the intervention is required to attain the overall objectives. The theory of change explains how an intervention will produce the desired outcomes. A causal-result chain (or logical framework) describes how a program's sequence of inputs, activities, and outputs will produce certain results (ILO, 2011). This is also a key principle in performance management systems, or results-based management (RBM), which emphasizes continual monitoring rather than merely at the end of a project. RBM is a management strategy or approach in which all actors, whether directly or indirectly, ensure that their processes, products, and services contribute to achieving desired outcomes (United Nations Development Group, Results-Based Management Handbook, 2011). RBM also provides broad principles for what should be addressed when planning, managing, and evaluating projects and activities. It is more of a "mind-set," in the sense that it specifies what, but not how, each stage of the project and operations cycle must be handled in order to accomplish good planning, follow-up, and control. However, individuals in charge of executing change processes through projects and programs require clear guidance on how to establish a strategy and monitor results (Ortengren, 2016). Given the importance of monitoring, a systemic thinking approach is essential, which includes three key principles: interrelationships, multiple perspectives, and boundaries. It underlines the importance of adopting systems concepts when monitoring, regardless of whether the monitoring approach is based on systems or is more traditional. Complexity-aware monitoring aids adaptive management by helping us understand interrelationships, engage with multiple perspectives, and reflect on boundary judgments (USAID, 2014).

On the other side, mining technology continues to develop to support operations today. However, studies of monitoring in mining still focus on aspects of monitoring environmental impacts (Radulescu & Buia, 2002; Juciano & Katia, 2021; Sucui et al., 2021; Liu, Yuntao et al., 2022; Liu, Yajing et al., 2023; Bae et al., 2023; He et al., 2023), dust and atmospheric particulate matter (Sondergaaard, 2021; Xiang-ying, 2022; Zafra-Perez et al., 2023); water quality (Loredo, 2010; Wang et al., 2023; Kazapoe et al., 2023), monitoring the stability of mine slopes (Ulusay et al., 2014; Obregon & Mitri, 2019; Bastola et al., 2020; Yi et al., 2021; Su et al., 2022; Nguyen et al., 2024), and monitoring the impact of vibrations from blasting (Xu et al., 2023; Rao et al., 2023; Mohanty et al., 2023). However, studies related to digitalization in monitoring mining stages in the field are still not well developed. Meanwhile, the accurate monitoring and timely maintenance of mining equipment have become the prerequisites for constructing the smart mine and the efficient management of coal mining operations (Zhang et al., 2022). In small to medium-scale mines, the mining sequence monitoring process in the field is still carried out in a conventional way, namely by carrying out manual pick-ups or stake out using survey equipment such as theodolites, lasers, etc., which are then inputted into mining software and then processed until analysis can be done. The development of the industrial 4.0 era is expected to support the mine monitoring process. Due to the potential advantages of promoting the automation of coal mining, smart mining has attracted wide attention from industry and academia (Zhang et al., 2022). Thus, considering the dynamic and capital-intensive nature of the mining industry, a reliable monitoring system for the implementation of each mining stage is needed to ensure the achievement of short-term mining plan targets and to support a resilient coal value chain.

4. Research Method

To obtain a complete picture of the factors that have an impact on the coal discrepancy phenomenon, data collection was carried out using empirical data related to coal discrepancy. We conducted empirical data collection of coal mined achievement from seven pits, along with monthly data on the technical aspects contributing to this achievement. The planner team or engineering team, namely the mine engineer and pit geologist, jointly validate this reason, which is then approved by the mine manager as the person in charge of the mine. The team collected data from the beginning of January 2023 to the end of May 2023. Then, we grouped the reasons for the emergence of discrepancies or differences in coal achievement and resulted into four

ISSN: 2456-7760

main sections: geological model, operational loss, change in sequence and optimized mining. The optimized mining is carried out optimally in an effort to conserve reserves, especially at the end of the finishing pit with a vertical mining process or in seams near the fault area. Included in this effort is the optimisation of thin-seam mining recovery with a thickness of less than 50cm. Prior to the optimisation effort of coal deeper than design, a feasibility study on the safety, economic, and technical side, including a geotechnical assessment, must be conducted first.

5. Results

5.1 The result of empirical data

The reasons related to the emergence of discrepancies or differences in coal achievement were then analysed and resulted in four main groups, namely those related to geological model, operational loss, change in sequence and optimized mining as shown in Table 1 below.

Table 1. The Actual Cumulative Discrepancy Based on Causes

Cause of Discrepancy	**Variance (Tonnes)**	
	Original	Absolute
Geological model	-318,165.4**	819,992.10
Operational loss	-222,031.80	222,031.80
Change in sequence	300,980.0***	603,560.00
Optimized mining	403,095.80	403,095.80
Total	**163,878.60**	**2,048,679.70**

*Note.** The negative sign (-) indicates it has impacted the negative coal discrepancy (less than the initial plan). ** Cumulative of model impact, both negative and positive. *** Include 151,290 tons of negative coal discrepancy.

The data shows that there was a significant variance between the actual coal achievement and the plan. The biggest negative contributing factor is the geological model, followed by operational loss and changes in sequence. So, it is critical for mining company to optimize those contributing factors through reliable real-time monitoring system especially to address loss due to operational mishandling and change in sequence. Therefore, monitoring the mining progress is crucial because any variations, particularly those that result in a reduction in quantity of coal (negative discrepancy), can have a significant impact on the coal value chain. One of mining's most important features is the geological model. This is quite reasonable because it is the basis for making pit designs related to deposit distribution, deposit characteristics, detailed stratigraphy, the geological structure around the deposit, and subsurface properties (Wang, 2020). However, uncovering the structure of different subsurface features with rarely measured data is difficult (Zhao et al., 2023), and it greatly affects the clarity of the amount of deposit projections (Jessel et al., 2018), which has a direct impact on project feasibility (Roux, 2021). Furthermore, the geological model is also an important basis or guide during the mining process (Jessel et al., 2018). Meanwhile mining production is very much determined by the accuracy of plans that have been made spatially and have been outlined in projections map of the final shape of the mine at the end of each period, such as weekly, monthly, and yearly. This projection map is known as a face position map. Differences in the final shape will have an impact on changes in coal flow achievement, not only in terms of quantity but also in terms of quality. This, of course, will have a significant impact considering that these two aspects also influence the sales aspect especially in mines that already have contracts with customers regarding sales, including product quality. Changes in aspects of the mining stages can be caused by changes in the plan made by the pit technical planner with the approval of the mining decision maker or by deviations that occur when the plan is executed by the operations team. A regularly used control tool for this purpose is the rainbow contour map, which visually represents the scale of variations through different colors. The colors also indicate the amount of variation in the plan, with a base interval of 10 meters per elevation of excavation or digging progress. In the context of monitoring the implementation of medium to long-term plans to evaluate the implementation of plans over a monthly, quarterly, or annual duration, the use of the rainbow contour can be implemented. However, in the context of short-term monitoring plans that are daily to weekly in nature, the use of the method will be difficult to apply considering that the process of providing daily data takes a longer time. It will not applicable considering when the daily data is ready, the period to be evaluated changes. Thus, a real-time planning monitoring system needed is not only precise but also can be accessed more quickly to facilitate monitoring of plan implementation in the field to support decision-making and follow-up on the achievement of short-term plans that have been made.

5.2 Design of improved monitoring system of the short-term mine plan implementation

In the new improved planning process, a weekly plan will be presented through a digital presentation. Meanwhile daily plan, and all critical boundaries, including the log book, will be uploaded to the server and can be accessed through the real-time monitoring application using a tab by the field supervisor or a PC desktop by pit technical as a planner. All of the stages of digger movement in the pit as well as dumping progress can be accessed through the application as inputted by the planner. So, the plan implementation will be precise and will prevent mis-execution in the field since the stage can be accessed directly. This new application is tailor-made by the planner team and supported by the Information Technology (IT) consultant in the development process. It utilizes the global positioning system (GPS) data of each digger and truck position in the field that is already available in the fleet management system, as shown in Figure 2 below. For the progress of the pit, the GPS position is combined with the targeted face position and critical boundaries that have already been input in the application by pit technical as planner. In the dumping or disposal area, the GPS of the truck assigned to the dump area is utilized to check the progress of the dumping area.

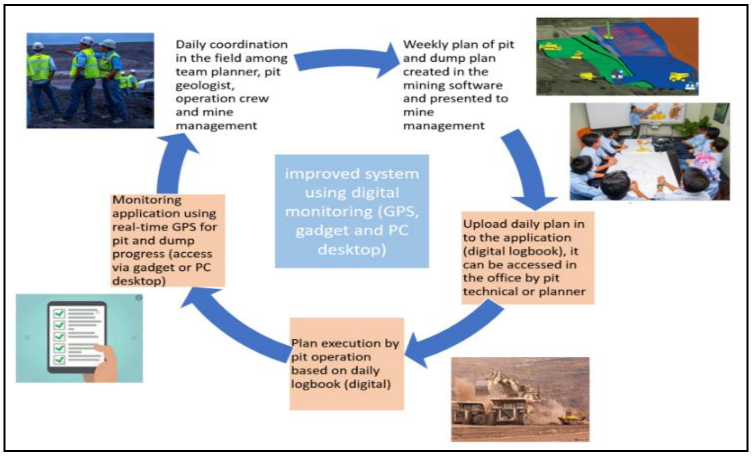

Figure 2. Flowchart of the improved plan implementation monitoring process

The GPS service in the application is in real-time, so both planner and supervisor in the field can optimize the action plan faster. As the monitoring tool, this application is already equipped with early warning system. In some cases, the digger in the pit will operate out of boundary, so a potentially hard digging event will happen, which will impact productivity. In the new monitoring system, the alarm will be triggered by a specific radius, which can be setup. It can also be setup for specific purposes, such as safety, to prevent the digger from getting bogged down while operated in a known potential soft area, at the limit between hard and soft material, or near the potential failure area to keep the safe distance. The operator at the cabin will get the notification or reminder, as well as the field supervisor or planner, to prevent the incident. In the dumping area, the benefits are to prevent the dumping being out of design or to prevent material type misallocation, as shown in Figure 3 below.

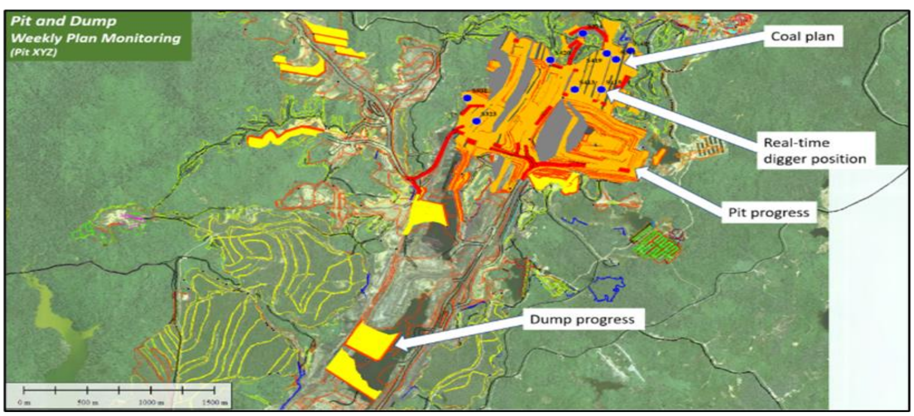

Figure 3. Pit and dump real-time plan implementation monitoring

The spatial compliance is critical for the pit and dumping area since a little mishap will impact the high cost. In the dumping area, it will assist in material allocation since there is a specification of rehabilitation that must be complied with, such as the limits of potential acid-forming (PAF) and non-acid-forming (NAF) material. The breaches in this specification will impact environmental issues, especially water quality issues, due to acid mine drainage. In the specific case of coal discrepancy, this real-time system will ensure the operational loss event will be minimized since the limit of coal is already in the system, and there will be an early warning system for the operator as well as the field supervisor and planner. Regarding the compliance of the sequence by the operation crew, this system will ensure all of the stages and movement sequence can be seen in the application, so it will minimize mis-sequence events. In the aspect of the geological model, this system can support awareness for the operation crew regarding the coal limit since the existing coal boundary can be uploaded by the planner and geologist team, so the operation team will be more aware of the coal position and the digger will not operate in the unplanned area with high stripping ratio (SR) or area where no coal exists.

Through this latest monitoring system, the progress of the execution of the plan stages in the field can be monitored at any time compared to the plans that have been made. So that when there is a deviation from the sequence that has been created, each party, in terms of the technical team or planner, operations crew, and mine management, can provide feedback to the operations crew for immediate improvements before the deviation from the plan gets bigger and has an impact on achieving the mining targets that have been made. This monitoring system was created to complement the existing fleet management system and is focused on monitoring the suitability of the implementation of mining stages in the field to the plans that have been made for both the pit and dump areas.

Below are the summary benefits of this real-time monitoring system.

a. Real-time monitoring of planning implementation on field operations
b. Improve accuracy in planning and implementation
c. Quick coordination and follow-up action related to short-term planning on field operations
d. Real-time safety control and monitoring
e. Fast and real-time stage plan update
f. Mitigate low productivity of diggers by preventing them from digging outside the boundary of the blasted material
g. Environmental compliance by mitigating material misallocation, & etc.

6. Research finding and Discussion

6.1 Finding

Once the new real-time planning monitoring system is completed, we carry out a socialization process and field trial to assess its impact on the planning process and production achievements in the field. In the initial stage of the trial, the planning display was used for the monitoring process by installing a big screen to be placed in the office so that the mine monitoring process could be carried out by pit technical as a planner and mine management. Apart from that, screens to monitor mining progress are also installed in the muster area where the operation crew carries out the over-shift process. It is hoped that with a screen to monitor mine conditions in real-time basis, crew members who will work, both supervisors and all operators, will aware about the real-time progress in the field so that they are more aware of their duties on the next shift. This will also support the continuation of information about hazard conditions in the field, which will ultimately support safety aspect. Since this monitoring tool was installed in the office for planners and management so they could easily monitor the real-time field conditions and provide appropriate feedback.

To measure the effectiveness of implementing the real-time planning monitoring system, the level of compliance with the sequence was measured in pit A, in a specific time range randomly during February 2024. The level of compliance is obtained by dividing the number of diggers working within the boundary plan by the total number of diggers operating in pit. After implementing this initiative for the planning and operation crew to monitor the achievement of the mining sequence, it was seen that there was a significant increase in the percentage of compliance with the plan in daily basis. Before implementing the new monitoring system in pit A, the percentage of daily compliance with the plan only 82.2% in average. At several events, there was still excavation outside the planned work area. Since the use of the new monitoring system, average compliance with planned sequences has increased by 14.1% to 96.3%, and to date, daily compliance has reached 100%, as shown in Figure 4.

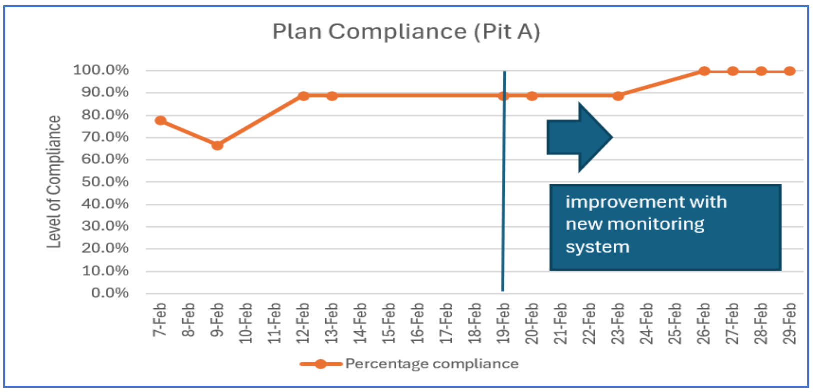

Figure 4. Pit sequence compliance monitoring in pit A

The same monitoring system can be used also for each dumping location compared to the weekly plan face position for dumping area. The increasing of compliance levels is expected to minimize variations between the actual face position and the planned one, ultimately optimizing the planned coal achievement performance. Since the utilization of this new monitoring system in week 8th, February 2024, the increase in plan compliance has significantly contributed to the increase in average daily coal exposed achievement in pit A, as shown in Table 2 below.

Table 2. Average daily coal exposed achievement in Pit A

Week	Coal exposed (in ktonne)		Plan Achievement
	Actual	Plan	
6	9.3	8.7	106.9%
7	9.2	8.7	105.0%
8*	**11.4**	**8.7**	**130.6%**

Note: * The implementation of new planning monitoring system

Furthermore, the effectiveness of this new planning monitoring system can be assessed also by observing the decrease in hard digging events caused by diggers operating outside the boundary of the blasted material (free dig). With the early warning system, as one of the features of this system, it is hoped that supervisors and digger operators will be aware of the condition of the material being excavated. By reducing excavation events outside the blasted boundary, digger productivity will be maintained as planned, mine productivity will be optimized, and this will then have an impact on achieving the planned coal targets.

6.2 Discussion

Coal discrepancies is directly related to the attributes of the mining industry, which is dynamic and impacted by a range of internal and external factors. There are a lot of uncertainties in the mining world, such as uncertainty due to equipment availability (physical availability or PA), equipment utilization, geological model, weather conditions, market demand, fluctuations in coal price, fuel price, and other elements related to production, and so on (Ramazan & Dimitrakopoulos, 2012; Liu & Kozan, 2012; Naworyta et al., 2015; Chieregati et al., 2019; Gong et al., 2020; Kumar & Dimitrakpoulos, 2021; Ediiriweera & Wiewiora, 2021; Armstrong et al., 2021). At present, productive and cost-effective mining operations have become a necessity. To accomplish this, the phenomenon of coal discrepancies, including deposit reconciliation, must be closely monitored. Integrated coal mine planning, which requires the integration of mine planning technical inputs such as survey, geology, planning, mining, processing, and finance, is one of the key to support this effort. Hence, a thorough approach for tracking, measuring, and reconciling coal from the mine plan to the customer is required.

Our research aims to fill the knowledge gap on the causes of coal discrepancies as a phenomenon. We employed an approach that utilizes empirical data on discrepancies from January to May 2023, we also collected information on the actual cause of the coal discrepancy over the same period. The data demonstrates that the geological model's accuracy, change in sequence, operational loss, and optimized mining are the primary determinants. This provides us with a clear understanding of the crucial variables that require careful consideration and close monitoring to address the coal discrepancy issue. Given that the phenomenon of coal discrepancy will always occur in mining operations, the company can develop initiatives to monitor these contributing factors and prepare the necessary controls to minimize their impact by identifying the factors that have a significant impact (Chieregati et al., 2019).

This study has practical implication since it identifies the key factors that significantly impact the coal discrepancy issue. Mine management, as decision-makers at the mine, can create measures to monitor and optimize these key effects by being aware of them. We can put in place a number of programs to deal with those main contributing factors: first, we may improve the accuracy of geological models by continuously evaluating how well the current models match the real field conditions. In order to support the operations, the pit geologist (grade control) must constantly improve the current model as mining advances. In order to meet production targets and avoid losses, the company (pit technical, planner, and decision maker) should take a proactive approach by reviewing the current plan, including the mining sequence, as soon as they implement the mine plan sequence and find significant differences between actual conditions and the geological model. When field conditions allow, it is necessary to either prepare an efficient drill pad to minimize material rehandling and optimize costs or add additional drill holes in areas characterized by high uncertainty, such as the location of soft material, swamps, areas near faults, and potential washout areas. Secondly, the mining plan's field implementation calls for a tremendous deal of cooperation and support. It is essential that the operations crew, pit technical, and pit geologist (grade control) work together. It is important that the planner and geologist team work in collaboration with the operation crew to minimize operational losses that may arise during mining. The pit geologist and pit technical or planner must provide the operations crew with reliable information regarding the mining plan. To optimize this contributing aspect, they must then set coal boundaries—designated by pegs in the field—and maintain daily coordination. Thirdly, we require daily collaboration regarding the sequence change, especially between the operations crew, pit geologist, and pit technical (planner). Through this coordination, mine management is directly involved in the field, ensuring alignment between the stages of the mining plan and the field's actual progress. Additionally, to maintain continual implementation of the developed plans, we must execute the specific stages of the mining plan during each shift, provide them in writing, and implement an appropriate over-shift procedure among the operation crews to guarantee the continuous implementation of each mining plan in the field.

The digital real-time planning monitoring system will provide speedy feedback and enabling operational strategies to be enriched without delay. It will support efforts to achieve coal targets and minimize the emergence of coal discrepancy phenomenon. This new planning monitoring system will also transform the delivery of planning process from a manual system outlined in a manual plan via a daily log book to a digital system that can be directly accessed via an application in the field. The existence of a real-time monitoring system for the actual implementation of the mine plan in the field is beneficial for the operations team to ensure that the plan execution is in accordance with each work stage made by the planner team. On the technical team's side, as planners, this monitoring system helps the planning team oversee and participate in controlling the plan execution process by the operations team, as well as provide evaluation material for the progress of achieving the mine plan. This planning monitoring system also makes it easier for planners team to carry out the delivery plan process for operations, as well as for the operations team to immediately access any changes. The initiative also has a positive impact on mine management to monitor the performance of the team, both planning and operations teams, on the plans that have been made. The existence of real-time planning monitoring also facilitates the evaluation and decision-making process by mine management. In this way, the accuracy of planning achievements can be increased to support the achievement of mine plan targets. With this monitoring system, it is hoped that events related to key performance indicator (KPI) production, such as hard-digging events related to productivity, can be minimized. Through a real-time planning monitoring system and direct alerts and notifications, this can mitigate the occurrence of hard digging events and the occurrence of coal losses in operational. In addition, the system will enhance safety in operations by eliminating digger events in areas with safety concerns, such as potential collapse areas, swampy, high cliffs, and buried old pit boundaries. Thus, with this digital monitoring, it is hoped that mine productivity will increase, including accuracy in implementing planning in the field, and ultimately will have an impact on achieving the mine plan while optimizing the coal discrepancy phenomenon.

This real-time planning monitoring system has made a positive contribution to the level of compliance with the planned sequence. It is also has a positive impact on achieving planned coal targets and has been proven to have a positive impact on optimizing the coal discrepancy phenomenon. It is beneficial to support ensuring the continuous optimization mainly two of the four significant contributing factors in optimizing the coal discrepancy phenomenon as the finding of this research, which are operational losses and change in sequences due to internal pit concerns to support the resilience of the coal value chain, especially in the upstream area of coal mining.

7. Conclusion

Coal discrepancy as a phenomenon is inseparably linked to the characteristic of the mining sector, which is dynamic and influenced by a variety of internal and external causes. The analysis used empirical data related to reason of actual discrepancy from some pits during January to May 2023. Finally, the following conclusions are drawn:

1. The coal discrepancy phenomenon is significantly influenced by four major factors, namely the accuracy of the geological model, change in sequence, operational loss and optimized mining. The research results can provide theoretical guidance for the development of an application of technology to monitor these contributing factors.
2. During that period, there was a total discrepancy of 2,048,679.7 tonnes. The causes of this discrepancy consist of a geological model accuracy of 819,992.1 tonnes (40%), a change in sequence of 603,560 tonnes (29.5%), operational loss of 222,031.8 tonnes (10.8%), and optimized mining of 403,095.8 tonnes (19,7%).
3. The new real-time mining sequence monitoring has proven beneficially to address the phenomenon by supporting the achievement of plan target. Since the use of the new planning monitoring system, average compliance with planned sequences in pit A has increased by 14.1% to 96.3%, and to date, daily compliance has reached 100%.
4. Since the utilization of this new planning monitoring system in week 8th, February 2024, the increase in plan compliance has significantly contributed to the increase in average daily coal exposed achievement in pit A from 106,9% up to 130,6%.

As theoretical contributions, we contribute to the literature on the coal discrepancy phenomenon, including how to improve it through a real-time planning monitoring system. This will enrich existing science and practice. As a novelty of this research, the digitalized real-time planning monitoring system using GPS, from the planning of pit and dump to execution, has not been developed before. This study is not without limitations, which represent opportunities for future research. Firstly, the tools to measure the overall level of compliance with the plan. Quantitative demonstration of the other benefits of the monitoring tool, from many pit samples is also required. Secondly, this study has focused on the coal discrepancy issue in the operational aspect of the mine. Since the contributing factor of discrepancy has a wide scope, not only internal but also external to the company, and based on the findings of the study, it is also critical to monitor the discrepancy related to geological model in real-time basis. The early monitoring system regarding indications of discrepancies should be developed to prevent losses in mine operations.

References

A. Kumar, and R. Dimitrakopoulos, "Production scheduling in industrial mining complexes with incoming new information using tree search and deep reinforcement learning", *Applied Soft Computing*, vol. 110, Oct. , 2021, 107644. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1568494621005652?via%3Dihub

Armstrong, Margaret et al. (2021). Adaptive open-pit mining planning under geological uncertainty. Resources Policy Volume 72, August 2021, 102086. https://www.sciencedirect.com/science/article/pii/S030142072100101X?via%3Dihub

Bae, Mi-Jung et al. (2023). Community recovery of benthic macroinvertebrates in a stream influenced by mining activity: Importance of microhabitat monitoring, Environmental Research, Volume 234, 2023, 116499, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2023.116499.

Bakkula, Oktovianus et al. (2022). A Review of Experimental and Theoretical Studies of Coal Discrepancy. 6th Asia Pacific Conference on Contemporary Research (APCCR, Indonesia) ISBN: 978-0-6482404-6-4; www.apiar.org.au https://apiar.org.au/conference-paper/a-review-of-experimental-and-theoretical-studies-of-coal-discrepancy/

Bastola et al. (2020). Slope stability assessment of an open pit using lattice-spring-based synthetic rock mass (LS-SRM) modeling approach, Journal of Rock Mechanics and Geotechnical Engineering, Volume 12, Issue 5, 2020, Pages 927-942, ISSN 1674-7755, https://doi.org/10.1016/j.jrmge.2019.12.019.

Busch, Henner et al. (2023). Mining coal while digging for justice: Investigating justice claims against a coal-phase out in five countries., The Extractive Industries and Society Volume 15, September 2023, https://www.sciencedirect.com/science/article/pii/S2214790X23000655

Chieregati, Ana et al. (2019). Proactive reconciliation as a tool for integrating mining and milling operations. International Journal of Mining Science and Technology Volume 29, Issue 2, March 2019, Pages 239-244. https://www.sciencedirect.com/science/article/pii/S2095268617304895

Ediriweera, A. and Wiewiora, Anna. (2021). Barriers and enablers of technology adoption in the mining industry. Resources Policy. https://www.sciencedirect.com/science/article/abs/pii/S0301420721002026

Evans, M. Albert and Ramani, Raja Venkat. "coal mining". Encyclopedia Britannica, (2024). https://www.britannica.com/technology/coal-mining. Accessed 29 January 2024. https://www.npr.org/2010/04/08/125694190/why-we-still-mine-coal

Gasparotto, Juciano and Martinello, Kátia Da Boit, (2021). Coal as an energy source and its impacts on human health, Energy Geoscience, Volume 2, Issue 2, 2021, Pages 113-120, ISSN 2666-7592, https://doi.org/10.1016/j.engeos.2020.07.003

Gong, Wenping et al. (2020). Stratigraphic uncertainty modelling with random field approach. Computers and Geotechnics Volume 125, September 2020, 103681. https://www.sciencedirect.com/science/article/abs/pii/S0266352X20302445

Gosling, L and Edwards, M. (2003). Toolkits: A practical guide to assessment, monitoring, review and evaluation. Second edition. Save the Children, UK. https://resourcecentre.savethechildren.net/pdf/toolkits-a-practical-guide-to-planning-monitoring-evaluation-and-impact-assessment2003.pdf/

He, Tingting et al. (2023). A novel index combining temperature and vegetation conditions for monitoring surface mining disturbance using Landsat time series, CATENA, Volume 229, 2023, 107235, ISSN 0341-8162, https://doi.org/10.1016/j.catena.2023.107235.

International Labour Organization (2011). Basic Principles of Monitoring and evaluationhttps://www.ilo.org/wcmsp5/groups/public/ed_emp/documents/publication/wcms_546505.pdf

Jang et al. (2016). Illumination of parameter contribution on uneven break phenomenon in underground stoping mines. www.elsevier.com/locate/ijmst http: //dx.doi.org/10.1016/j.ijmst.2016.09.019

Jessell, Mark et al. (2018). Assessing and Mitigating Uncertainty in Three-Dimensional Geologic Models in Contrasting Geologic Scenarios https://www.researchgate.net/publication/329801069_Assessing_and_Mitigating_Uncertainty_in_Three-Dimensional_Geologic_Models_in_Contrasting_Geologic_Scenarios

Kazapoe, Raymond et al. (2023). Relationship between small-scale gold mining activities and water use in Ghana: A review of policy documents aimed at protecting water bodies in mining communities, Environmental Challenges, Volume 12, 2023, 100727, ISSN 2667-0100, https://doi.org/10.1016/j.envc.2023.100727.

Kumar, A. and Dimitrakopoulos, R. (2021). Production scheduling in industrial mining complexes with incoming new information using tree search and deep reinforcement learning. Applied Soft Computing Volume 110, October 2021, 107644. https://www.sciencedirect.com/science/article/pii/S1568494621005652?via%3Dihub

Lian X, Wang and W, Zhang J. (2023). How to optimize dust pollution control in opencast coal mines: Analysis of a joint social regulation model based on evolutionary game theory. PLoS ONE 18(7): e0289164. https://doi.org/10.1371/journal.pone.0289164

Liu, Yajing et al. (2023). Evaluation and dynamic monitoring of ecological environment quality in mining area based on improved CRSEI index model. Heliyon, Volume 9, Issue 10, 2023, e20787, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2023.e20787.

Liu, Yuntao et al. (2022). Identification of the disturbed range of coal mining activities: A new land surface phenology perspective. Ecological Indicators Volume 143, October 2022, 109375. https://www.sciencedirect.com/science/article/pii/S1470160X22008482

Loredo, Jorge et al., (2010). Surface water monitoring in the mercury mining district of Asturias (Spain), Journal of Hazardous Materials, Volume 176, Issues 1–3, 2010, Pages 323-332, ISSN 0304-3894, https://doi.org/10.1016/j.jhazmat.2009.11.031.

M, Bester et al. (2016). Reconciliation of the mine to design as a critical enabler for optimal and safe extraction of the mineral reserve. http://www.scielo.org.za/pdf/jsaimm/v116n5/08.pdf

Markiewicz, A. (2014). Core Concepts in Developing Monitoring and Evaluation Frameworks. Anne Markiewicz and Associates. https://www.betterevaluation.org/sites/default/files/ME_Framework_Resource_Guide_Jan_2014doc.pdf

Mohanty, Madhumita et al. (2023). Effect of blast induced vibration on coal mine overburden dump slope through discrete element method, Structures, Volume 56, 2023, 105013, ISSN 2352-0124, https://doi.org/10.1016/j.istruc.2023.105013.

Morley C. (2008). Guide to creating a mine site reconciliation code of practice. https://www.researchgate.net/publication/263770315_Guide_to_creating_a_mine_site_reconciliation_code_of_practice

Morley, C. (2003). Beyond reconciliation — A proactive approach to using mining data. https://www.researchgate.net/publication/228799954_Beyond_reconciliation_a_proactive_approach_to_using_mining_data

Morley, C. and Thompson, K. (2006). Extreme reconciliation — a Case study from Diavik Diamond. https://www.researchgate.net/publication/228669000_Extreme_Reconciliation A_Case_Study_from_Diavik_Diamond_Mine_Canada

Musmualim, Musmualim, et al. (2015). Rekonsiliasi Penambangan Antara Rencana Penambangan Bulanan Dengan Realisasi Di Tambang Swakelola B2 PT. Bukit Asam (Persero), Tbk. Jurnal Ilmu Teknik Sriwijaya, vol. 3, no. 1, 2015. https://media.neliti.com/media/publications/102947-ID-none.pdf

Naworyta, Wojciech (2015). Planning for reliable coal quality delivery considering geological variability: A case study in polish lignite mining. Journal of Quality and Reliability Engineering. https://www.researchgate.net/publication/272020714_Planning_for_Reliable_Coal_Quality_Delivery_Considering_Geological_Variability_A_Case_Study_in_Polish_Lignite_Mining

Nguyen, Hoang et al. (2024). Chapter 6 - Application of artificial intelligence in predicting slope stability in open-pit mines: A case study with a novel imperialist competitive algorithm-based radial basis function neural network, Applications of Artificial Intelligence in Mining and Geotechnical Engineering, Elsevier, 2024, Pages 97-111, ISBN 9780443187643, https://doi.org/10.1016/B978-0-443-18764-3.00001-1.

Obregon Christian and Mitri, Hani (2019). Probabilistic approach for open pit bench slope stability analysis – A mine case study, International Journal of Mining Science and Technology, Volume 29, Issue 4, 2019, Pages 629-640, ISSN 2095-2686, https://doi.org/10.1016/j.ijmst.2019.06.017.

Otto, T.J. & Musingwini, C. (2019). A spatial mine-to-plan compliance approach to improve alignment of short-term and long-term mine planning at open pit mines. Journal of the Southern African Institute of Mining and Metallurgy https://www.researchgate.net/publication/332996933_A_spatial_mine-to plan_compliance_approach_to_improve_alignment_of_short-and_long term_mine_planning_at_open_pit_mines

Ortengren, Kari (2016). A guide to Results-Based Management (RBM), efficient project planning with the aid of the Logical Framework Approach (LFA) https://cdn.sida.se/publications/files/sida61994en-a-guide-to-results-based-management-rbm-efficient-project-planning-with-the-aid-of-the-logical-framework-approach-lfa.pdf

Radulescu, M. and Buia, G. (2002). Significant impacts and environmental risks generated by coal extraction in Romania, Environmental Management and Health, Vol. 13 No. 3, pp. 235-241. https://doi.org/10.1108/09566160210431033

Ramazan, Sahih. and Dimitrakopoulos, Roussos. (2012). Production scheduling with uncertain supply: a new solution to the open pit mining problem. https://www.semanticscholar.org/paper/Production-scheduling-with-uncertain-supply%3A-a-new-Ramazan Dimitrakopoulos/0bca7aff0c27aefeae509221e7cd438eb21bc8c2

Rao, Xiaokang and Huang, Shengxiang (2023). GNSS blasting vibration monitoring and feature recognition method Journal of Applied Geophysics, Volume 218, 2023, 105212, ISSN 0926-9851, https://doi.org/10.1016/j.jappgeo.2023.105212.

Roux, L. (2001). Density – A contentious issue in the evaluation and determination of Resources and Reserves in coal deposits. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S2225-62532021000500010

Schofield, N.A. (2001). The myth of mine reconciliation https://www.researchgate.net/publication/294220953_The_myth_of_mine_reconciliation

Sondergaard, Jens and Mosbech, Anders (2021). Mining pollution in Greenland - the lesson learned: A review of 50 years of environmental studies and monitoring, Science of The Total Environment, Volume 812, 2022, 152373, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.152373.

Su, Peidong et al. (2022). Stability prediction and optimal angle of high slope in open-pit mine based on two-dimension limit equilibrium method and three-dimension numerical simulation, Physics and Chemistry of the Earth, Parts A/B/C, Volume 127, 2022, 103151, ISSN 1474-7065, https://doi.org/10.1016/j.pce.2022.103151.

Sucui, Li et al. (2021). Optimizing ecological security pattern in the coal resource-based city: A case study in Shuozhou City, China. Optim Eng (2013) 14:361–380 DOI 10.1007/s11081-012-9186-2. https://www.sciencedirect.com/science/article/pii/S1470160X21006919

Tetteh, M.N.M. and Cawood.F.T. (2014). Variable components of the mine call factor from a surface mine perspective using AngloGold Ashanti Iduapriem Mine as a case study. https://www.researchgate.net/publication/320107928_Variable_components_of_the_Mine_Call_Factor_from_a_surface_mine_perspective_using_AngloGold_Ashanti_Iduapriem_Mine_as_a_case_study

Thomas, M. and Snowden, V. (1990). Improving Reconciliation and Grade Control by Statistical and Geostatistical Analysis: Strategies for Grade Control, AIG Bulletin, Volume 10, pp. 49-59. http://www.sciepub.com/reference/129639

Ulusay, Reset et al. (2014). Improvement of slope stability based on integrated geotechnical evaluations and hydrogeological conceptualisation at a lignite open pit, Engineering Geology, Volume 181, 2014, Pages 261-280, ISSN 0013-7952, https://doi.org/10.1016/j.enggeo.2014.08.005.

United States Agency for International Development - USAID. (2014). Systemic Thinking for Monitoring: Attending to Interrelationships, Perspectives, and Boundaries https://usaidlearninglab.org/system/files/resource/files/systemic_monitoring_ipb_2014-09-25_final-ak_1.pdf

United Nations Development Group, Results-Based Management Handbook, 2011. https://www.unicef.org/rosa/media/10356/file

Wang, Hongyu et al. (2023). Monitoring the ecological restoration effect of land reclamation in open-pit coal mining areas: An exploration of a fusion method based on ZhuHai-1 and Landsat 8 data, Science of The Total Environment, Volume 904, 2023, 166324,- ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.166324.

Wellmann, Florian et al. (2010). Towards incorporating uncertainty of structural data in 3D geological inversion. Tectonophysics Volume 490, Issues 3–4, 30 July 2010, Pages 141-151. https://www.sciencedirect.com/science/article/abs/pii/S0040195110001691

Wellmann, Florian and Regenauer-Lieb, Klaus (2012). Uncertainties have a meaning: Information entropy as a quality measure for 3-D geological models. Tectonophysics Volumes 526–529, 10 March 2012, Pages 207-216 https://www.sciencedirect.com/science/article/abs/pii/S0040195111001788

Wellmann, Florian and Caumon, Guillaume (2018). 3D Structural geological models: Concepts, methods, and uncertainties., Advances in Geophysics Volume 59, 2018, Pages 1-121. https://www.sciencedirect.com/science/article/abs/pii/S0065268718300013 https://doi.org/10.1016/bs.agph.2018.09.001

Xiang-ying, Hao et al. (2022). Intelligent Dust Removal in Coal Mine Using Extension Data Mining Procedia Computer Science, Volume 214, 2022, Pages 779-785, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2022.11.241.

Xu, Guoquan and Wang, Xinyu, et al. (2023). Support vector regression optimized by black widow optimization algorithm combining with feature selection by MARS for mining blast vibration prediction, Measurement, Volume 218, 2023, 113106, ISSN 0263-2241, https://doi.org/10.1016/j.measurement.2023.113106.

Yi, Zhiyu et al. (2021). Long-term Landsat monitoring of mining subsidence based on spatiotemporal variations in soil moisture: A case study of Shanxi Province, China, International Journal of Applied Earth Observation and Geoinformation, Volume 102, 2021, 102447, ISSN 1569-8432, https://doi.org/10.1016/j.jag.2021.102447.

Zafra-Perez, Adrian et al. (2023). Aerial monitoring of atmospheric particulate matter produced by open-pit mining using low-cost airborne sensors, Science of The Total Environment, Volume 904, 2023, 166743, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.166743.

Zhang, Geng et al. (2022), Industrial Internet of Things-enabled monitoring and maintenance mechanism for fully mechanized mining equipment, Advanced Engineering Informatics, Volume 54, 2022, 101782, ISSN 1474-0346, https://doi.org/10.1016/j.aei.2022.101782.

Zhao, Lin-Shuang et al. (2023). An efficient model to estimate the soil profile and stratigraphic uncertainty quantification. Engineering Geology Volume 315, 20 March 2023, 107025. https://www.sciencedirect.com/science/article/abs/pii/S001379522300042X.