Asia Pacific Journal of Advanced Business and Social Studies
ISBN (eBook): 978 0 9943656 7 5 | ISSN : 2205-6033
Year: 2023, Volume: 8, Issue: 1

# A REVIEW OF EXPERIMENTAL AND THEORETICAL STUDIES OF COAL DISCREPANCY

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## Abstract

This paper investigates the factors that contribute to the coal discrepancy phenomenon, not only in terms of quantity but also in quality or coal properties. A conceptual model of coal discrepancy was developed based on contextual contributing factors of discrepancy in the coal mining industry using a literature review, questionnaire and enriched by empirical data. The study was also completed by the field experiment to check the discrepancy in quality in each mining phase. The result is then processed using linear regression to obtain the coefficient correlation and equation that show the discrepancy trend. The study analyzed some significant contributing factors that impacted coal discrepancy in the mining industry, not only from internal companies, such as equipment parameters (physical availability, utilization, and productivity), geological model, and changes in design, but also changes in mining sequence due to concerns external to the company, such as environmental issues, land issues, and market demand. As the originality of this study, it enriches the existing body of knowledge by providing a novel framework of coal discrepancy and its contributing factors from internal and external sources. It also discusses the discrepancy issue in the quality or properties of coal by providing some equations based on empirical study to estimate the discrepancy level in each mining phase.

***Keywords:*** Coal Discrepancy, Mine Reconciliation, Coal Mined, Coal Quality, Change Sequence.

## 1. Introduction

Coal discrepancy 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 quite complex since it involves internal and external factors: equipment availability & utilization, weather, geological model, human behavior & etc. Based on the current literature, a study on coal discrepancy has developed but has not been thoroughly discussed, especially in aspects related to the achievement of overburden (OB) and the impact of changes related to the mining sequence. This research aims to explore several factors which affect the achievement of the production mine plan that will impact the coal discrepancy phenomenon. The changes that occurred in the mine had a direct impact on the implementation of the shipping schedule and resulted in a penalty or demurrage for the company. In some mines, this issue may be considered as an ordinary phenomenon. However, in mines that focus on cost optimization and operational efficiency, this issue must be carefully analyzed and followed up for the sake of business continuity. In some cases, a seemingly minor problem has resulted in significant costs as a result of disturbances in the company's product supply chain, including sales and penalties because the company is unable to fulfill the order as stated in the contract. The paper also will discuss the discrepancy in quality or properties of coal product that changed along the production value chain. Hence, by knowing the contributing factors of this phenomenon so mining companies could prepare the action plan to optimize the impact. This study was conducted at PT XYZ, one of Indonesia's largest coal mining companies, with a total coal production of around 60 million tonnes per year.

## 2. Literature review

To find out the factors that influence the coal discrepancy phenomenon, a literature study is carried out to develop a theoretical framework which then becomes a reference for the preparation of a conceptual framework, also known as a research framework. The literature review of this research began by searching for papers related to mine reconciliation and coal discrepancy in several databases such as Scopus, ScienceDirect, Web of Science, ResearchGate, and ProQuest, as well as several books as the supporting sources. On search engines at each journal, the exploration starts by using several keywords such as coal reconciliation, mine reconciliation, mine discrepancy, and coal discrepancy. Many studies had been done before in the field of mine reconciliation and discrepancy, such as Thomas & Snowden (1990), Schofield (2001), Morley (2003), Morley & Thompson (2006), Bester et al. (2016), Jang et al. (2016), and Otto & Musingwini (2019). Based on the summary of the literature review done in this study, most of the previous studies did not discuss in detail the aspects that have an impact on reconciliation or discrepancy, especially on mining operational aspects such as physical availability (PA) and utilization of equipment, weather impact, revision on design, productivity issues, and change in mining sequences, which have a significant impact on coal discrepancy phenomenon. Not only the impact of contributing factors from internal of company but also the contributing factors that come from the external of company such as the demand for specific product, the issue regarding land compensation for operational area, and the environmental issue. Other factors that are part of the variables in the previous studies but are not included (ignored) in the variables of this study are as follows.

- truck dispatch inaccuracies, because the official calculation of coal production in PT XYZ is based on survey measurements. The payload on the truck (dispatch system) is only for comparison data. The same reason also applied to other related variables from past studies, such as truck factors, truckload cells, and load bucket factors
- transporting and delivering coal to customers, because the coal sales process at PT XYZ is carried out on a free-on-board (FOB) basis, so losses that may occur after the ship departs from the port are not the responsibility of the seller
- coal processing, considering so many random variables that might contribute and the limited time in doing this research.

Meanwhile, several other variables used by previous studies have been included in the new variables used in this study, such as grade control, loss fines, and dilution, which are included in operational losses.

## 3. Research Methodology

The first step of this research process begins by conducting a literature study by looking for papers on coal discrepancy or mine reconciliation from various related journals or databases and identifying the factors that influence the phenomenon. As a result of this literature study process, 33 articles were obtained from several well-known databases such as Scopus, Web of Science, ScienceDirect, Research Gate, & etc. At the second step, several factors that impacted on this phenomenon, such as physical availability (PA) of equipment, utilization of equipment, geological model, revision of the design, and change sequence were determined.

The third step, after obtaining various factors that contribute to the phenomenon of coal discrepancy, the significant contributing factors are determine through a survey or questionnaire involving thirty-two experts on site from engineer level to manager level in the department that related to this phenomenon. As a result, the fourteen contributing factors or critical elements were generated. In the fourth step, a theoretical framework was developed that shows this phenomenon. In this case, coal discrepancy is modeled as a dependent variable whose amount is determined by the factors that contribute as independent variables. The coal discrepancy phenomenon occurs not only in terms of quantity, but also in quality or properties of coal as the results of coal proximate analysis. They are classified into four groups: (1) moisture, (2) volatile matter, which consists of gases and vapors released during pyrolysis, (3) fixed carbon, the non-volatile part of coal, and (4) ash, the inorganic residue left after burning. The proximate analysis of coal is offered as a set of test procedures that have been widely employed as the foundation for coal classification in the context of coal usage (Speight, 2015). In this research the quality that been analyzed are calorific value (CV), moisture content including inherent moisture, ash content, and sulphur content.

In the fifth step, to explore more about this phenomenon especially in a quality aspect, some field experiments were conducted. In this step, samples from some pits represent vary coal rank were monitored in quality during the coal value chain from pit to crusher. In the sixth step, it discusses the findings of experiment data, actual compare to quality of the initial model (ROM quality) and the measurement data was processed through linear regression to obtain the equation and trendline that represent the discrepancy in quality that change overtime. In the seventh step, based on the findings related to coal discrepancy, whether in terms of quantity or quality, a conceptual framework been developed to further explain the dynamic of the phenomenon. In the eighth step, the conceptual framework been discussed in detail especially to optimize this phenomenon in relation with human behavior and the agility of the organization in the dynamic circumstances. The last section concluded this study and discuss about the research implication and some potential future research as the enhancement.

## 4. Data Collection and Results

Based on the results of the literature study from various sources as mentioned before, some factors that impact the coal discrepancy phenomenon and the achievement of coal targets that have been planned are obtained. These factors are divided into factors that come from internal company and those from outside the company (external). The difference in OB removed production compared to plan will impact the achievement of coal exposed/uncovered which further impact the coal mined production. The contributing factors regarding the coal discrepancy phenomenon also obtain from conducting a survey or questionnaire which followed by PT XYZ's staff from the engineer/specialist level, senior engineer/specialist, superintendent, and manager level. Below are some factors that contribute to the difference in the production performance compare to the plan target.

1. Physical parameters of equipment
   This category includes parameters of equipment availability (Physical Availability or PA) as well as the percentage of equipment utilization or usage (US). These two parameters are usually combined in a new parameter, namely Overall Equipment Effectiveness - OEE) which is PA x US that expresses the total effectiveness of equipment utilization in operation. According to Mohammadi et al. (2015) OEE is one of the most widely used performance indicators in production industries to assess how effectively the manufacturing operations utilize the facilities, time, and material. It is a good indicator and compares the status of the performance with the designed capacity and the best practices in the industry. OEE analysis distinctly highlights the areas which need improvement, to optimize the production process. Included in this parameter is the

number of fleets or diggers compared to the plan. The variance compared to the plan will automatically impact the achievement of OB removal.

2. Productivity
   One of the well-known key parameters to optimize production in mining industry is productivity. Over the past one hundred and fifty years, the mining industry has been remarkably successful in growing its productivity (Humphreys, 2019). The achievement of OB removed and coal mined production is determined by various factors, including the productivity of digging equipment and hauling equipment. It refers to the output levels during a specific time period (e.g., tonnes of coal per year, bcm OB per hour). A strategy to increase productivity might look at the design of a pit or a mining method (Barden, 2022). The matching of truck and excavator is a significant element influencing loading efficiency and hence mining productivity (Manyele, 2017). The productivity of the excavator is influenced by the loading point conditions, the dimensions of the excavation profile which include the height and width of the excavation area, the condition of the excavated material (soft, hard, well fragmented broken material) and the skills of the excavator operator. As stated by Nasonov & Lykov (2018), mining technical circumstances, drilling and blasting operations technology, oversize yield, and coarseness of rock grading, all have a substantial influence on excavators' dependability and performance. Moreover, mining executives should encourage employees to be receptive to new approaches and technologies and collaborate more with equipment and technology vendors, allowing mining innovations to spread more broadly to promote productivity-improvement projects (Lala, Ajay et al. 2015).
3. Rehandle material (mud execution)
   The other element is the amount of rehandling material that has been used in pit execution, such as for mud handling in pits, especially at the ex-sump or pond that is inside the pit boundary that needs to be executed. Usually, rehandling material cannot be avoided in pit operations, but it can be optimized in total since it will increase the stripping ratio due to additional material and ultimately impact the unit cost of the operation.
4. The weather conditions
   Weather aspects in open-pit mines especially that located in tropical areas, greatly affect the total working time, especially in pit that cannot operate during the rain because the trucks cannot operate due to slippery roads. It caused a delay in operations, which is usually called a weather delay. The amount of delay will have an impact on the level of utilization of production equipment, especially diggers and trucks. The higher the weather delay, the lower the equipment utilization rate. This will have an impact on the achievement of OB removed, which will also have a direct impact on the achievement of coal mined. A simple model was developed using daily weather delay data from January 1st, 2021 to August 29th, 2022 (N = 606) and linked to the amount of OB removed and coal mined during the same period. On the chart of weather delay vs OB removed below, $R^2$ is 0.68, or R is 0.82 which has a strong correlation. Meanwhile, on the weather delay vs coal mined chart, a similar trend is obtained, namely $R^2$ of 0.59 or R of 0.76, which has a quite strong relationship.

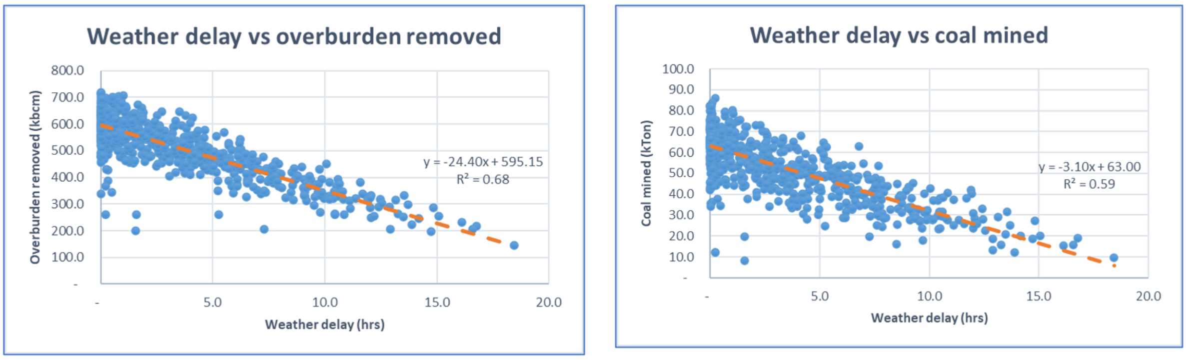


Figure 1: Impact of weather delay on overburden removed and coal mined

5. Geological model
The initial evaluation of a coal deposit often raises uncertainty with regard to the accuracy of the reported resources and reserves (Roux, 2021). The accuracy of the geological model of the deposit and geological structure below the surface greatly determines the clarity of the amount of deposit (coal or mineral) in it and directly impacts the feasibility of the project. On the other hand, the accuracy of the geological model of the deposit will be significantly influenced by the number and spacing of boreholes which are the basis for the correlation of the coal and mineral modeling. The tighter the drill holes, the greater the cost required to make a model. According to Ediweera & Wiewiora (2021) in their qualitative study, there is uncertainty in the ground about the deposits including the uncertainty in operation. This is in line with the study of Naworyta (2015) that concluded for the process of quality control at the stage of operational planning it is necessary to have sufficient exploration information about the deposits. One of the parameters that can indicate the difference between the model and the actual is the difference in the thickness of the coal seam. According to Kuncoro (2000), coal seam thickness is an important element that directly relates to resource calculation, exploration planning, production system, to the life of the mine. In understanding the varying coal seams thickness, then syn and post depositional processes need to be well understood. The coal seam has four thickness variations that can be separated into pinch out, washout, splitting and coal seam gradually turning into shally coal. The accuracy in resource and reserve calculations require clarity of coal seams thickness and errors in determining the coal seams thickness can lead to errors in resource until reserves estimation (Nalendra et al, 2017). The figure below is an actual case in PT XYZ, showing the importance of accuracy in geological model that will have an impact directly on the coal discrepancy phenomenon.

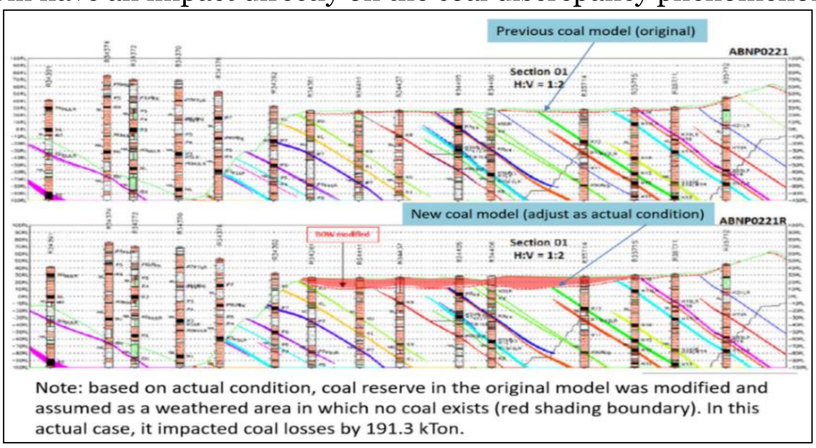


Figure 2: Actual case of coal loss due to adjustment on geological model

6. Changes on plan or change sequence (due to internal pit concern)
   This aspect, although sometimes not planned in advance, tends to play an important role in achieving short-term targets (the end of the week or month). Currently, in PT XYZ there is a daily checking on actual vs plan which is done regularly and followed by a regular discussion to review and ensure the achievement of the plan. However, sometimes this process has indirectly generated some changes to the plan that have been made before and finally create a gap to the original plan. Compare to the external factors which are largely uncontrollable in mining operations, the internal factors are the most dominant in terms of achieving the initial plan. Meanwhile according to Armstrong et al. (2021) in "Adaptive open-pit mining planning under geological uncertainty", geological uncertainty is endogenous to the production scheduling problem: it affects the decisions taken on which blocks to extract in a given time period and these decisions affect how the orebody is mined and make it possible to reduce the uncertainty locally as the extracted blocks provide knowledge of the true ore grades. Meanwhile, according to Ramazan & Dimitrakopoulos (2012), the problem of production scheduling in open pit mining is determining the parts of mineralized deposits to be mined annually in an optimum order of sequence to maximize the total discounted profit. Liu & Kozan (2012) stated to maximize the profit and the utilization of mine reserves while providing a better development program, a good mining plan/schedule must not only meet both the long-range and long-term mining requirements but also satisfy many practical details that are unique to day-to-day operations.
7. Revision of design (due to failure or optimisation)
   Usually, design changes are made to ensure that the design used as a reference in field implementation remains optimal and feasible both in technical and financial. Some of the contributing factors are changes in the geological model with the addition of new boreholes, following geotechnical recommendations in the failure area, &, etc. When landslide happen in a pit, the reserve was covered by failure material that need to be removed and automatically increase the mining cost. In some cases, the reserve was unable to be recovered since the landslide is huge or it's happened directly in the deposits itself.
8. Coal recovery (operational losses)
   The discrepancy issue might happen also during mining process. Sometimes in the pit development, especially in soft ground condition and narrow working condition it is difficult to expose and mined the coal properly and impacted to its recovery. The suitability of the digger to expose and mined the coal and its bucket dimension compare to the thickness of coal is critical to maximize the coal recovery. The other critical factor is the availability of pegs as the digging limit in the field to ensure the coal recovery during mining.
9. Changes from external factors
   Below are some examples of changes on mining sequence to accommodate external concerns.
   a. Changes in market demand, for example, an increasing in demand for high CV (calorific value) quality coal (bituminous) at a higher or premium price as an opportunity for sales
   b. The sequence change, due to the operation area is not ready yet as planned, and due to land compensation issue
   c. The sequence change, due to the permit for operation such as land clearing and redisturb permit or mining lease extention is not ready yet as plan
   d. Other external issues, such as disturbances from individual or group of people to mining activities due to environmental issues related to water quality, air and ground vibration, land claimer &, etc.

Various studies have shown that the continuity of mining operations will always be influenced by all stakeholders including the community around the operating area. According to Sucui Li et al. (2021), it is important to optimize ecological security patterns (ESP) in the coal resources-based city. Construction and optimization of an ESP can aid coordination of mineral resource development and ecological protection. Similarly to that study, Kamenopoulos et al. (2020) conclude about the importance of the social license to operate at the investment and operations stage of the coal mining projects. Meanwhile the absence of new coal plant development and environmental restrictions will hinder medium-term demand response (Oxford Analytica, 2015). There are many examples of the importance of managing environmental and socio-economic impacts around mines. One of them is mining in the Jiu Valley (Romania) which has a significant environmental and socioeconomic impact. The key issue these days is recognizing the proper and substantial consequences of mining operations, as well as creating methods to minimize and monitor the coal extraction process (Radulescu & Buia, 2002). As a result of this sequence change, there will be a difference or variation on the mine progress that can be seen in the map showing the final topography (face position) of the mine between the actual and the plan that is available in each pit. In the current practice, a routine monthly reconciliation process already developed to see the actual against the plans for each pit. One tool that is regularly made is called a rainbow contour map that shows the colors representing the scale of the variations. Changes in the pit sequence can also be tracked at the value of the stripping ratio (SR) between the planned and actual. The stripping ratio is the proportion of OB removed (in bcm) to coal extracted (in tonnes). The percentage of coal achieved compare to plan is also determined by the change in the stripping ratio. The chart below shows that from 2013 to 2022, PT XYZ frequently operates at a stripping ratio that different from the initial plan. Variations in the sequence, as well as changes in the stripping ratio, have an impact on the variance in the plan achievement. When operating at a low stripping ratio, the coal variance is positive, indicating that the actual coal mined exceeds the plan. However, while operating at a higher stripping ratio, the coal variance becomes negative, meaning the actual coal mined is less than planned. Operating at a higher stripping ratio than planned will result in the company's cash flow as a result of not achieving the planned coal. However, while running at a lower stripping ratio or below the plan, it appears profitable in the short term, unfortunately it has an impact on the company's cash flow in the long term because the remaining area is only a reasonably high-cost area. As a result, a balance between the projected stripping ratio and the actual achievement is essential.

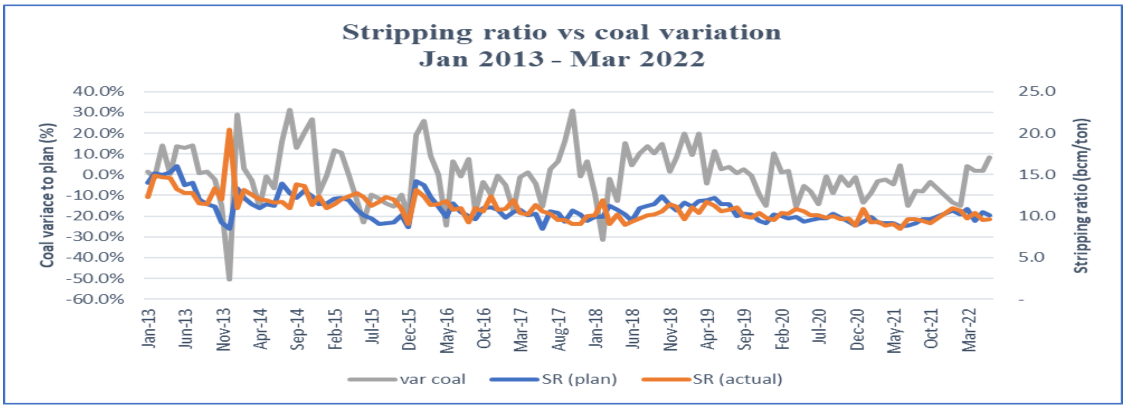


Figure 3: The comparison of stripping ratio and coal variance to plan

### 4.1. Result of Survey/Questionnaire

To obtain the views of experts, especially mining practitioners, regarding the coal discrepancy phenomenon, a survey or questionnaire has been carried out involving PT XYZ's staff from the engineer/specialist level, senior engineer/specialist level, superintendent level, and manager level. The purposes of this survey are to get a better understanding of the factors or elements that influence the coal discrepancy phenomenon (importance level) and to measure the impact caused by each element (low, medium, and high). This survey consists of two parts of a question. In the first part, questions focused on how important each factor has been in explaining the coal discrepancy phenomenon. There are five choices of answers, namely strongly agree (the score is 5), agree (the score is 4), neutral (the score is 3), disagree (the score is 2), and strongly disagree (the score is 1). This section also provides an opportunity for respondents to add other elements that fit this criterion. In the second part, each participant is asked to provide an assessment regarding the impact of each element on the coal discrepancy phenomenon, including the additional element that was input in the previous part. There are three choices of the answer, namely high impact (the score is 3), medium impact (the score is 2), and low impact (the score is 1). This survey was carried out at PT XYZ with the participation of 32 staff members involved in the phenomenon of coal discrepancy; 91% are male and 9% are female, and they are from various levels such as engineer/specialist (6%), senior engineer/specialist (44%), superintendent (38%), and managers (12%). In terms of age, most of the respondents were employees in the age range of 31–40 years (47%), 41–50 years (31%), 20–30 years (19%), and >50 years (3%). Most of the respondents came from the technical and operations departments of the pit, including coal mining (59%), mining services including drill and blast (25%), mine planning including mine optimization (10%), coal processing and handling (3%), and business improvement (3%). The respondent's length of work or service life was in the range of 15–20 years (41%), 10–15 years (34%), 0–5 years (19%), 20–25 years (3%), and >25 years (3%). According to the survey, there are twenty factors that have an impact on the phenomenon of coal discrepancy. The top five most significant elements were the geological model (total score 150), coal recovery or operational losses (total score 145), the revision on the design due to geotechnical failures, etc. (total score 141), the change sequence due to internal pit concerns (total score 131), and the change sequence due to demand (or marketing issues, total score 130). Meanwhile, as the result of the 2nd part, in terms of impact on the coal discrepancy phenomenon, the top five most significant elements in impact are almost similar to those in the 1st part (importance level): geological model (total score 89), coal recovery or operational losses (total score 82), revision on the design due to geotechnical failures, etc. (total score 81), rehandling material (or mud execution, total score 72), and changing sequence due to internal pit concerns (total score 71). Below is the system diagram of the coal discrepancy phenomenon as a function of some contributing factors as described above.

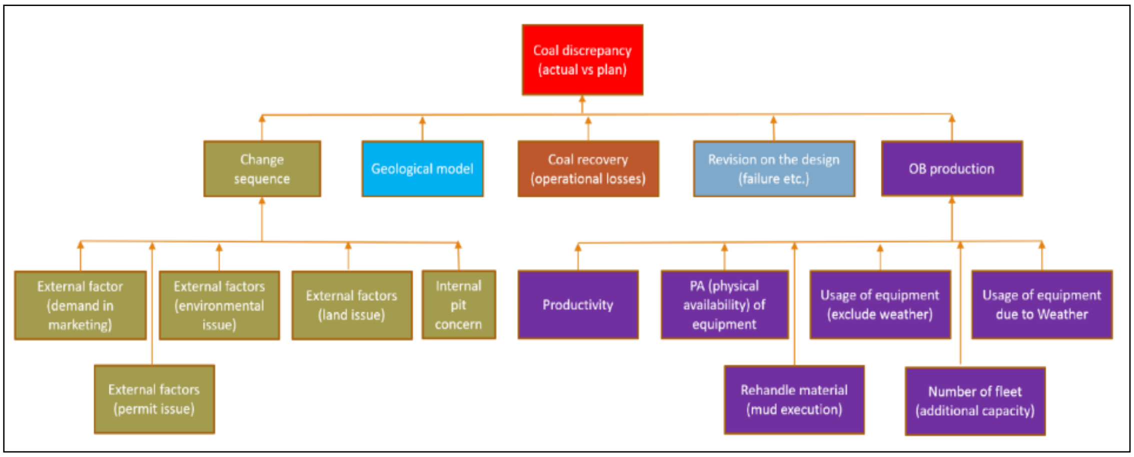


Figure 4: System diagram of coal discrepancy phenomenon

### 4.2. Discrepancy in quality

The discrepancy occurs not only in the volume of coal but also in the quality of coal as it is processed from the upstream to the downstream side of the mine. All production planning (forecasting) that is used for marketing purposes will use the Run of Mine (ROM) quality model that was created by the Mine Planning department. This quality is established by making certain basic assumptions and performing some unique computations. To understand the phenomenon of quality changes in coal from the beginning to the end of the process, samples of coal were collected at various stages of the value chain, from channel sampling in the pit to the crusher area. This is done to determine changes in the quality or chemical composition of coal. To further explore this issue, a field experiment was conducted to answer some main questions regarding the quality discrepancy, as follows.

1. At what point in the coal value chain does this discrepancy issue occur?
2. What is the amount of variance that occurs at each point of the value chain?
3. What are the factors that might influence the phenomenon?

Since the end of February 2022, three simple experiments have been carried out in pit A with a tonnage of 50,000 tonnes and a specific coal quality (CV > 6,322 kcal/kg), with the following stages. First, determine the boundary area of the coal seam to be mined in the pit. Geologists then conduct channel sampling in the pit, and the sample is sent to the laboratory to check the coal quality. Based on the geological model, specific qualities are generated according to the boundary that has been made, which includes the calorific value (CV), total moisture (TM), inherent moisture (IM), total sulfur (TS), and ash content (AC). This is necessary to ensure that the comparison process is appropriate (*apple-to-apple* comparison) for the same product (seam), from the same agreed-upon area, and compared after crushing in order to obtain an accurate comparison, which is a spatial reconciliation or three-dimensional (x, y, z of a reconciliation). During the mining process, it is ensured that it is carried out in accordance with procedures to minimize the dilution of coal, as well as in the transportation process. After mining, the product is then allocated to a special stockpile so that the sampling process (grab sampling) can be carried out and sent to the laboratory to be tested to determine the actual quality (properties). Hence, the product is sent to the dedicated crusher (considering the crusher schedule based on shipment needs) and the crushed product is sampled using a mechanical sampling process every 250 tonnes. With this sampling method, the accuracy obtained is categorized as high. The result of the experiment will then be analyzed and reviewed. This experiment then rolls out to pit B (with a tonnage of 15,000 tonnes) and pit C (with a tonnage of 18,000 tonnes) with different qualities to observe whether the other trend will happen at the lower quality product (CV < 5,000 kcal/kg).

Based on the results of data processing from the field experiment that has been carried out, several findings were obtained on some coal properties, as follows.

1. Calorific value (CV)
   In general, based on the experiment results, the calorific value decreases from the channel sampling in the pit to the sampling process after the coal has been ground (after being crushed). The rate of decrease per day from channel sampling to after crushing is -0.6% per day for product A, -1.9% for product B, and -0.3% for product C (a minus sign indicates a decreasing trend). By assuming the trend of quality discrepancy was linear, based on the regression approach to the existing measurement data, the following equation is obtained for product A and product B. At product A, $\mathbf{y = -31.9x + 7490.3}$, with a value of $R^2 = 0.54$ or $R = 0.73$, where y is the calorific value and x is time (in days). This R value indicates that there is a fairly strong relationship, and the nature of the relationship is inversely proportional. Meanwhile, $\mathbf{y = -86.7x + 4635.5}$, with $R^2 = 0.91$ or $R = 0.95$ for product B. This shows that the relationship between these two variables is very strong and inversely proportional. Since there is no grab sampling at the stockpile for product C, the data is not enough to be used to generate the regression trendline. The decreasing calorific value during the experiment is due to the contamination of the coal sample by other materials that increase the ash content of the coal product. Rehandling the product at the stockpile prior to sending it to the crusher may have loaded the based material, contributing to the increase in ash or dilution material. The after-crushed CV is compared with the ROM quality (model) from the Mine Planning Department, which is usually used for planning purposes in forecasting sales. In general, compared to the ROM model, the actual after-crushed quality is lower than planned: -5% at product A, -1.6% at product B, and -1.3% at product C.
2. Total moisture (TM)
   The total moisture increased from the time of channel sampling in the pit to the sampling process after the coal has passed through the grinding process (after being crushed). In general, the rate of increase in total moisture per day from channel sampling to after crushing is 1.4% per day in product A and 0.9% in product C. However, there is a different trend in product B, where there is a -0.7% decrease per day. By applying a linear regression approach to the existing measurement data, the following equation is obtained. At product A, $\mathbf{y = 0.09x + 7.52}$, with a value of $R^2 = 0.90$, where y is the total moisture as the dependent variable and x, or time (in days), as the independent variable. This value shows that there is a very strong relationship ($R = 0.94$) and that the nature of the relationship is directly proportional. At product B, $\mathbf{y = -0.23x+33.1}$, with $R^2 = 0.07$ or $R = 0.26$. It shows that the relationship between the two variables is very weak. Meanwhile, when compared to the model quality (ROM), it is shown that there is a significant difference when compared to the quality after crushing. The model quality of the product tends to be lower than the actual at product A and higher at product B and product C. At product A, the actual total moisture is 9.2% higher than the model but 3.4% lower than the model at product B, and 3.6% lower than the model at product C.
3. Inherent moisture (IM)
   There is an increase in inherent moisture from the time of channel sampling in the pit to the sampling process after the coal has passed through the grinding process (after being crushed). In general, the rate of increase in inherent moisture per day from channel sampling to after crushing is 4.4% per day for product A, 8.4% per day for product B, and only 0.6% per day for product C. By applying a linear regression approach to the existing measurement data, the following equation is obtained. At product A, $\mathbf{y = 0.16x + 4.12}$, with a value of $R^2 = 0.95$, where y is the inherent moisture as the dependent variable and x, or time (in days), as the independent variable. This value indicates that there is a very strong relationship ($R = 0.97$) and that the relationship is directly proportional. At product B, $\mathbf{y = 1.83x + 23.9}$, with $R^2 = 0.48$ or $R = 0.69$. When compared to the model

quality on ROM, it is shown that there is a trend toward a significant difference. Compared to the quality after being crushed, the model quality of the product tends to be smaller than the actual product. At product A, the inherent moisture in the model is 76.7% lower than after crushing, 14.9% lower in product B, and 12.6% lower in product C.

4. Total sulphur (TS)
   There is no general trend in this quality because total sulphur increased from channel sampling to after crushing in product A, whereas total sulphur decreased in products B and C. The rate of increment in total sulphur per day from channel sampling to after crushing is 2.9% per day for product A, a decrement of -3.6% per day for product B, and a decrement of -1.5% per day for product C. By applying a linear regression approach to the existing measurement data, the following equation is obtained. At product A, $\mathbf{y = 0.01x + 0.34}$, with a value of $R^2 = 0.69$, where y is the total sulphur as the dependent variable and x, or time (in days), as the independent variable. This value shows that there is a strong relationship (R = 0.83) and that the nature of the relationship is directly proportional. At product B, $\mathbf{y = -0.03x+0.68}$, with an $R^2$ of 0.75 or R = 0.86. It shows that the relationship between the two variables is strong and that the nature of the relationship is indirectly proportional. When compared to the model quality (ROM), it is shown that there is a significant difference when compared to the quality after crushing. The model quality of the product tends to be higher than the actual at products A and C but lower than the actual at product B. At product A, the total sulphur in the model is higher by 10.5%, 64.5% higher at product C, but less than after crushing at 66.7% at product B.
5. Ash content (AC)
   From channel sampling at the pit until after the crushed product, there are two distinct trends in this quality parameter. The ash of the product increased by 6.9% per day from channel sampling to after crushing for product A and significantly by 18.6% per day for product B. However, at product C, it was reduced by -0.6% per day. This significant increment in ash content, especially at products A and B, is mostly influenced by the increasing ash content, especially from segment grab sampling to after crushing, where the total increment is 190.2% at product A and 127.3% at product B, as seen in the figure below. This performance might happen since, during the rehandling process of the product at the stockpile, there is a possibility that the product is not as pure as before since it might be contaminated by other materials as a result of dilution. Meanwhile, by applying a linear regression approach to the existing measurement data, the following equation is obtained. At product A, $\mathbf{y = 0.1x + 2.59}$, with a value of $R^2 = 0.22$, where y is the total ash content as the dependent variable and x, or time (in days), as the independent variable. This value shows that there is a weak relationship (R = 0.46) and that the nature of the relationship is directly proportional. At product B, $\mathbf{y = 0.8x + 3.43}$, with an $R^2$ of 0.53 or R = 0.73. It shows that the relationship between the two variables is strong and that the nature of the relationship is directly proportional. When compared to the model quality (ROM), it is shown that there is a significant difference when compared to the quality after crushing. In general, the product's model quality is lower than the actual quality of all products. The actual total ash content of product A is 85.7% higher than the model, 31.6% higher at product B, and 102.1% higher at product C.

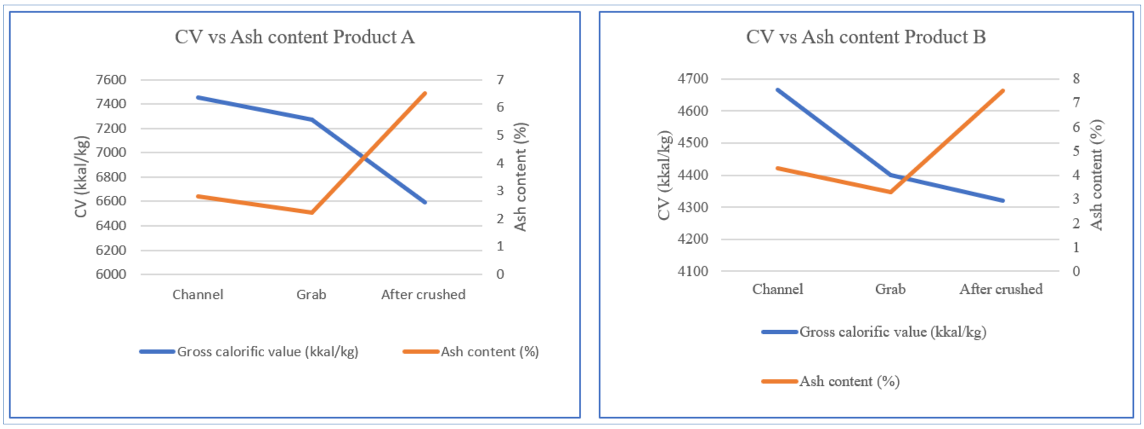


Figure 5: Comparison of Calorific value vs Ash content of Product A and B

## 5. Discussion

Coal discrepancy as a phenomenon is inseparable from the nature of the mining industry which is very dynamic and influenced by various internal and external factors. There are quite a lot of uncertainties in the mining world, such as uncertainty due to equipment availability (physical availability), equipment utilization, geological model, weather conditions, demand on the market, fluctuations in coal price, fuel price, and other elements related to production and so on. Other factors that also affect the achievement of coal discrepancy are changes in sequence due to incoming new information from other internal and external factors (Kumar & Dimitrakpoulos, 2021). With the various uncertainties that exist, the company as a learning organization should apply a proactive attitude to adapt (Armstrong et al, 2021) to existing changes and also immediately make the necessary adjustments, especially in the planning aspect to obtain the optimal sequence through the interactive planning process (Liu & Kozan, 2012). Planning and operating practices must aim to improve coal recovery, operational, and governance requirements in order to achieve consistency and integrity. In addition, production measurement and reporting outputs are essential requirements also for the successful reconciliation of coal recovery and mining performance against the plan (Tetteh & Cawood, 2017). A mining company should be able to respond optimally to any changes both internal and external to keep productive and efficient in operation. Thus, the decision-makers in determining the mining sequence will always be faced with various choices that must be made from one period to another and this is a form of dynamic inconsistency in the mining industry. It will be a challenge since each decision taken will create a coal discrepancy issue with a different result in magnitude. Meanwhile, when in the process of implementing the mine plan sequence and indications of significant variation in actual conditions with the geological model have been found, the company (management and planner) should take a proactive attitude (Chieregati et al, 2019) by reviewing the plan and make changes to the existing mine sequence to ensure the achievement of production targets and prevent loss occurs. In this case, it can be seen that a change in the decision to change the sequence will have a positive impact on the sequence since it enriches the existing strategy. However, in cases when there are changes in internal and external factors but the company does not make changes at all or is even slow to react, it shows that there is an issue related to the agility of the decision-makers in the company. In other examples of cases that may occur, it shows the negative impacts that may arise a dynamic inconsistency issue. When the initial plan is being executed in the field and everything is still running smoothly without any changes to internal or external factors, but the decision-makers regarding the mining sequence in the company make changes to the sequence and come up with a new plan. This of course will hurt the achievement of the initial plan and might be impacted product commitments both in quantity and quality that have been submitted to the marketing department of the company and further might impact the shipping schedule implementation. Mining companies should always consider the impact of decisions on changes in the sequence due to changes in internal and external factors. The company (management & planner) should always apply a proactive and adaptive attitude and perform periodic optimization of the existing sequence plan to ensure that the company, including its stakeholders, continues to get the optimum benefits in dynamic and challenging operating circumstances.

## 6. Conclusion

Coal discrepancy is a critical phenomenon that mining companies must address in order to maximize profits in volatile conditions. A continuing coal discrepancy will have a detrimental impact on the company's growth. To control this issue, each contributing factor must be monitored and optimized effectively. According to the findings of this study, which are stated in the conceptual framework, the causal factors come from various dynamic factors, both internal and external to the company, related to the availability of equipment and its utilization, the geological model, changes in sequence, revisions to the design, coal recovery (operational losses), and due to opportunities in coal prices, land acquisition issues, permit issues, and environmental issues. This phenomenon will undoubtedly occur in every mining operation, particularly in coal mining, but the most essential thing is to identify its source or causes and then eliminate or minimize it in order to maximize the achievement of the set target. Since the discrepancy arises not only in quantity but also in quality, initiatives to minimize the impact must be prepared and covered from planning to field execution. It begins with planning improvements to model quality (ROM), since it is essential in production forecasting and directly used for shipment scheduling and other marketing purposes. Efforts should also be made to minimize the issue of coal quality throughout the mining value chain, including extraction, processing, and transporting, in order to reduce the dilution of coal products. More research is needed to test the generalizability of the framework created in various situations, such as different mining production scales and other mining areas. In the context of coal quality discrepancies, additional research with more samples is also required to cover many types of coal properties, such as calorific value, ash, moisture, and sulphur content. Moreover, further research is required to learn about the possibility of an expansion model as a new framework, particularly to address the issue of coal discrepancy in the downstream coal chain, such as processing and transporting the coal to customers. This research can also be enhanced by statistically evaluating the structural relationship between all of the elements that lead to this phenomenon.

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