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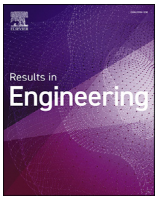

The development of a mining method selection model through a detailed assessment of multi-criteria decision methods

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ABSTRACT

In the past decades, attempts were made to build a systematic approach to mining method selection (MMS) Ooriad et al., [1]. This is because MMS is a complex and irreversible process. Since it can affect the economic potential of a project, the approach must be as thorough, precise, and accurate as possible. The key challenges of the previously established techniques such as the Nicholas and Laubscher method are that, there was a lack of engineering judgement in the process of selecting a mining method. In other instances, not all the parameters required in the mining method selection process were considered; i.e. economics would be the basis of the final decision of a mining method without taking into consideration other factors such as geology [2]. While other techniques just considered a few parameters and a limited number of mining methods as alternatives (Namin, 2008). Some techniques were customised procedures for a specific orebody [3]. Each orebody is unique; therefore, the approach of just adopting the same mining method for similar commodities was not always an effective or realistic approach Therefore, the existing procedures were found to be inadequate and not applicable for consideration in all MMS processes.

To solve the challenges stated above, an up-to-date approach to MMS is the use of multi-criteria decision-making (MCDM) tools to aid in the process. The MCDM are effective in facilitating a decision-making process; however, the use of MCDM has not gained enough popularity across countries and in the mining industry especially in MMS [4]. Their successful implementation in other industries such as in manufacturing companies, water management, quality control, transportation, and product design [5] present an opportunity for further exploration in MMS. In this research, these MCDMs were further explored as starting point to solving the challenge faced in MMS.

With the aim of developing a systematic and an unbiased approach that caters for subjective and objective analysis in MMS, this study investigated 10 MCDMs- TOPSIS, TODIM, VIKOR, GRA, PROMETHEE, OCRA, ARAS, COPRAS, SAW, and CP with potential to solve the MMS challenge. The study focused on deriving a model where the MCDMs can be integrated and be successfully used for MMS. Included in the research are factors and mining methods that are necessary in MMS. The aim was to use the factors and mining methods as inputs to the developed MMSM.

In the result section, case studies were used to analyse the MCDMs following a descriptive and a statistical analysis (sensitivity analysis, spearman correlation, and Kendall's coefficient.). PROMETHEE, TOPSIS, and TODIM stood out as methods for use in the selection of mining method in the coal mining industry. From the research findings, it was generally concluded that OCRA, ARAS, CP, SAW, and COPRAS are simplified approaches of the afore-mentioned methods. VIKOR's rankings were outlying and the conclusion was that it was not a suitable method for MMS. GRA's conclusion based on the literature view was that there remain many unanswered questions about its mathematical foundations.

The MMSM was developed using the results obtained. In the MMSM, first, the user defines the problem. The approach is of case-based reasoning (CBR); where the user can retrieve, re-use, revise and then retain the information (in the database) for future use. The user can always search within the database for a similar problem to select a MCDM, factors and methods; and this may be one of the future areas of improvement on the developed MMSM because there are a number of factors, MCDMs, and mining methods that the user may need to go through before getting to the relevant MCDM. One of the recommendations made by the author was that the user must understand the theoretical background of the MCDM before using it in the MMSM. In future studies, algorithms

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for selection of a suitable MCDM in the MMSM can be developed so that once the problem has been defined and structured; the user may not struggle with knowing which method to use amongst the suggested. Also, an application-based approach may be investigated further.

1. Introduction

There have been extensive studies conducted to find a suitable process of Mining Method Selection (MMS). This is a process of selecting an extraction method for a defined deposit. It involves proper planning, research and informed decisions carried out by experts in the mining industry. Ooriad et al., stated that MMS is a complex and challenging activity because of the many factors that form part of the decision process. Also, because the nature of an orebody is unique, it would not be a realistic approach to just adopt a specific mining method without catering for the needs of a specific orebody. Kant (2016) emphasised that the MMS is a critical process because it is irreversible once implemented. So, all decisions throughout the life of mine will be dictated by the chosen mining method; and the economic potential of a project can be affected by this decision.

It is of paramount importance that a suitable mining method is selected to maximise profit, recovery of the deposit and provision of a safe working area for the employees.

There are previously established approaches that have been used across all the commodities. Some were successful at implementation. While others still needed to be developed further to be effective. Techno-economic models were developed in the 60s. The method was inadequate because it was only based on the financial estimations of the financial effects that would results if a specific mining method was chosen [2].

In the early 70s, Boshkov and Wright proposed a qualitative classification for underground mining methods. It only considered the geological and geotechnical factors applied in similar geological conditions. The selected mining methods as alternatives were those which have been applied in similar geological conditions [3]. Like the techno-economic model, it was inadequate because of its nature of exclusivity. Morrison classification method was developed thereafter in 1976. It divided methods under 3 groups: caving methods, controlled subsidence, rigid pillar supports. There was limited number of MM as alternatives. The first quantitative tool was developed by Nicholas in 1981. The tool considered rock mechanics characteristics as the most important factor for both underground and surface methods. Criteria such as orebody characteristics are used. Points are assigned, and a numerical ranking is used. It only works with 10 predefined methods (Guray, 2003). In the same year, Laubscher developed a classification method, based on mass mining methods [6]. Hartman followed in 1987 with his method that looks at the geometry of the deposit as well as the ground conditions of the ore zone. A method is chosen based on how well it suits the ground conditions. University of British Columbia (UBC) method was then developed in 1995 as a modification of Nicholas approach. It was designed to represent the Canadian practice. Overall, the techniques and methods were found to be inadequate, and incomplete to perform a fair and reliable mining method selection process. The reasons are: adopting the same mining method within the same region was not always effective and was not a realistic approach due to the uniqueness of each orebody. In other instances, there was lack of engineering judgement. The fact that no formula exist for MMS makes it a difficult process. Some techniques offer a limited number of alternatives (mining methods) and factors (e.g geology) in decision-making. Lastly, it was identified that one predominant factor led to the exclusion of the other factors in other techniques.

An up-to-date approach in the early 2000s was to use multi-criteria decision models (MCDMs) because of their proven record of effectiveness in facilitating a decision-making process. Amongst the existing decision-making techniques AHP, PROMETHEE, TOPSIS, TODIM, VIKOR, ELECTRE, and GRA have been used in the MMS process. However, they are not widely applied in the mining industry, and the current research expands on the existing knowledge of the MCDMs as they present an opportunity for further exploration in MMS. Additionally, OCRA, ARAS, COPRAS, CP and SAW were investigated as additional decision-making methods even though no existing proof could be found of their previous application in the mining industry.

To address the need of MMS, the aim of the research was to develop a mining method selection model/methodology through a critical analysis and assessment of the application of MCDMs. This is done to address the shortcomings of the existing traditional approaches of MMS. The overall aim of the methodology/model is that it must serve as a checklist in conducting a retrospective critique on existing coal mining methods operations. Again, the decision-making approach must be able to offer a guideline for new coal mining projects on how an optimum mining method can be selected while considering factors that affect MMS.

It is the aim of the study to aid in strategic decisions that ought to be made for the future of coal mining for coal mines that would find this study useful. Generally, the author acknowledges the fact that a one-size fits all model cannot be developed in the mining industry due to variations of deposits; however, a general guideline is still a possible solution; especially the MCDM approach to solving MMS because there has been limited mining application. Also, the country that contributed the most to information on MCDMs was Iran. Even though the U.S.A, China, and Australia are some of the largest coal producers in the world, there has not been much from them concerning the MCDMs. It must also be noted that the study will follow a decision-making approach instead of a problem-solving approach. This means that the focus is aimed at the future of coal mining. A list of the possible benefits from the study are shown below:

- Improving the MMS decision-making process for the coal mining companies.
- Provision of a systematic and unbiased approach that caters for subjective and objective analysis in MMS.
- Better insight and understanding of factors that affect coal MMS.
- Review of the potential yet fully unexplored mining methods such as coal gasification and coal bed methane in South Africa.
- Increased level of confidence of the MCDM will help South African Mining companies to utilise these models, as application has been limited in the country's coal mining.
- Improvement in the long-term planning of mines
- MMSM can be stepping stones to novel methods of mining

2. Literature review

The literature review was obtained from different sources; journal databases to library catalogues. The information gathered is presented to form part of the building blocks of the development of an MMSM. It consists of the previously established techniques, factors as well as mining methods.

2.1. Existing approaches to MMS

This section introduces MCDM which may have been used in the mining industry for methods selection. For each method, the functionality, application in mining and other industries, shortcomings and strength are presented.

2.1.1. AHP

The development of AHP by Thomas Saaty dates to the 1980s. The main purpose of its development was to assist decision makers to make decisions in an organised manner. This is a method that can handle an ill-structured and complicated problem; and still be effective in facilitating the decision-making process [7]. AHP's ability to represent the elements of a problem in a hierarchy form allows the problem to be broken down into smaller constituents' part; with the objective/goal of the decision-making process on top [8].

According to Velasquez and Hester [9]; the advantages of AHP are that it is easy to use and flexible in that its' size can be adjusted to accommodate different decision-making problems. AHP is also not data-intensive like other MCDM methods. Its ability to handle both qualitative and quantitative criteria has led to its popularity (Ataei et al., 2008). Data can be normalised when measured in different scales, and can later be aggregated (Musungwini & Minnitt, 2008). Moreover. Cheng and Li (2001) believes that AHP is accurate in making business decisions because of its ability to check the consistency of the expert's judgement.

Although it has gained power and use across different industries, it has also been criticised because of how its standard consistency test function [7]. In their research, Maletic et al. [7] proposed that a quality control approach could be used to conduct the consistency test.

Musungwini and Minnitt (2008) also identified three limitations of this method. Firstly, calculations can be rendered complex if the number of criteria to be compared increases. The recommended maximum number of criteria is nine; so, its total comparisons will be 36. If criteria are greater than nine, the matrix may be complex and difficult to solve. Secondly, the final decision (ranking of alternatives) can be affected if the scale of relative importance was to be increased. Lastly, AHP only works with a positive reciprocal matrix as explained earlier in the section.

Additionally, Hester and Velasquez (2013) indicated that AHP is susceptible to rank reversal in that, if alternatives are added at the end of the process, the final rankings could flip or reverse.

2.1.2. TOPSIS

Hwang and Yoon proposed technique for Order preferences by Similarity to Ideal Solution widely known as TOPSIS in 1981. Amongst the MCDM, TOPSIS is the most straightforward technique [5]. There is limited subjective input that is needed in TOPSIS expect for weights. The main aim of the method is to ensure that the distance between the best alternative and positive ideal alternative is minimized, while maximizing the distance to the negative ideal solution [10].

Unlike AHP, TOPSIS does not have a component to check for the inconsistency of the judgement and expressed preferences. In addition, TOPSIS must rely on other weighting methods such as AHP since it cannot elicit weights. Therefore, this means that if the weights are not accurate weights, using TOPSIS method may not be viable [10]. Like AHP, TOPSIS can also cause rank reversal where the preferences of alternative can change if more criteria are added/removed. However, among many methods, it has the fewest rank reversals [5].

On a positive note, TOPSIS can identify the best alternative quicker than many MCDM [10]. Its logic is rational and understandable. In addition, the importance of weights can be incorporated into the comparison procedure [11]. The performance of alternatives and criteria can be visualised on a polyhedron; and the computation process can easily be done using a spreadsheet [5].

Over 100 papers have been published where TOPSIS was applied [12]. Because of its ability to accommodate many alternatives and criteria, it has been applied in various areas such as in manufacturing companies, water management, quality control transportation, and product design [5]. TOPSIS has also been used to compare financial performances of companies [10]. Additionally, Hester and Vasquez (2013) confirm its use in the supply chain management, logistics, engineering, marketing and environmental management.

Tajvidi et al. [13] used TOPSIS in selecting an optimum tunnel support system, combining it with methods like SAW. Aghajani and Osanloo [14] applied the method in combination with AHP when selecting a loading and transportation system for an open pit mine. Ooriad et al., has used the TOPSIS method to select a suitable mining method for Tazareh Coal Mine (Iran).

2.1.3. TODIM

TODIM (Tomada de Decisao Interative Multicriterio in Portuguese) means "Interactive and Multi-Criteria Decision Making" method. It is a distinct method that has its basis on the prospect theory [15]. It was founded by Gomes and Lima in the early 90s to assist in ranking of alternatives where the decision maker has to effectively formulate a decision in the face of risk [16].

The advantage of TODIM is that it is effective in behavioural decision-making. This is because the decision maker's psychological character is taken into account and can capture loss and again under uncertainty [17]. The attenuation factor, which can be adjusted, can reflect the risk preference of the decision maker [18].

Even professionals without a concrete background of MCDM define the method as a tool that is easy to implement [19]. It can work with both qualitative and quantitative criteria. Other than TODIM the existing MCDM methods look for a solution corresponding to a global measure of a value, while in TODIM, the concept of global measurement is calculated while applying the prospect theory [16]. TODIM's application has been limited. However, has been applied in the mining industry [20].

2.1.4. VIKOR

According to Hayati et al. (2015), VIKOR is a Serbian phrase that means 'Vlse Kriterijumsk Optimizacija Kompromisno Resenje', which means "Multi-Criteria Optimization and Compromise Solution". The method was developed in 1894 to select an alternative as a compromised solution from a list of alternatives in order to make a final decision. According to the method, the closest valid solution to the ideal solution is the compromise solution (Hayati et al., 2015). The VIKOR method ranks alternative according to three scalar quantities$(S_i,\ R_i\ and\ Q_i)$ which are independently evaluated against the criteria [21].

Unlike AHP, there is no pairwise comparison of the criteria in the VIKOR because criterion can be evaluated independently. In addition, the computations can be less in the face of several criterion. (Hayati et al., 2015). Apart from weight determination, VIKOR only requires the decision maker's intervention where the coefficient 'v' value must be chosen. The TOPSIS and VIKOR have the same approach except that VIKOR allows for weight change through the coefficient 'v' [21].

Another added advantage to VIKOR method is that it allows the decision maker to check how far the second-best alternative is from the first. If the method finds that the best alternative in terms of Q_i is the best in terms of the global criteria performance only (S_i) or in terms of the performance measurement of single criterion (R_i) only, then the first best alternative cannot be considered as the best in isolation, but with other alternatives in a subgroup. Therefore, VIKOR gives satisfaction to acceptability of the final rankings [21]. The method is a useful tool especially where the decision maker is unable to express his/her preferences at the beginning of the process [22].

VIKOR has been used in many applications as recorded by Moghassem and Fallahpour (2012). It was used in 2016 by Wang et al. for renewable energy resources selection in China. Kuo et al. (2011) to evaluate the quality of airports service used VIKOR again. The successful application of VIKOR has extended too many fields such as manufacturing, material selection, marketing, construction, risk and financial management, supply chain, health-care, performance evaluation and many other areas (Mardani et al., 2015). In the mining industry, there has been limited application of VIKOR. Mahase et al. [23] identified two areas dealing with mine planning and related studies to have applied this method. Azimi *et a*l used VIKOR in evaluating the strategies of the Iranian mining sector in 2013. To derive the preference order of open pit mines equipment, Bazzazi et al. [24] applied a modified version of VIKOR. There are over 176 papers published between 2004 and 2015 where VIKOR was applied; either alone or through an integrated approach (Mardani et al., 2015).

2.1.5. GRA

Grey Theory is a mathematical theory that was proposed in 1982 by Deng to solve problems with uncertainty and incomplete information. The grey theory consists of five parts; Grey prediction model, Grey relational analysis (GRA), Grey decision, Grey programming, and Grey control. The area of interest for decision makers is the GRA. This technique treats each alternative as a sequence of data. It then analyses the relational degree between each alternative and the reference sequence [25].

The main idea of the GRA is to compare the geometrical similarity between the reference sequence and the data sequences of several alternatives. A higher relational degree means that the sequences (data and reference) are close to each other [26].

GRA application has been significant; from agriculture to environment and engineering (in decision-making). Wu [27] used it for decision making in credit risk analysis. Hasani et al. [28] determined the optimum process parameters for open-end spinning yarns by applying GRA. To find the most suitable watermarking scheme, Lin et al. [29] used GRA. Kandasamy and Vinodh [30] applied GRA in material and end of life strategy selection. GRA has also been used in combination with other MCDA methods such as in evaluating the customer perceptions on in-flight service quality using a fuzzy-grey method by Chen et al. [31]. To optimize multi-response simulation problems, Kuo et al. [32] used a grey-based Taguchi method. Although it has been successfully applied, GRA has also been criticized for its lack of mathematical foundation (root) to explain its origin, laws and constraints [33].

In the mining industry, Dehghani et al. (2017) used GRA to select a mining method. To assess mine safety, Xu Q and Xi K [34] used GRA in combination with bow tie. GRA was used to study the coal mines accidents by Shuai and Jin-Long [35]. In 2018, Bao et al. applied GRA in combination to DEA model to evaluating the safety benefits of the mining industry occupational health and safety management systems.

2.1.6. PROMETHEE

PROMETHEE which stands for Preference Ranking Organisation Method of Enrichment Evaluation was been developed in 1982 by Brans. Since then, PROMETHEE I to VI have been developed to function as outranking methods. Alternatives are compared in pairs with respect to each criterion (Tomic, 2011). A preference function approach is followed in PROMETHEE. A preference function $P_j(a, b)$ for alternatives ‘a’ and ‘b’ depends on the determined difference $[d_j(a,b)]$ of the alternatives for a chosen criterion, j. Additionally, it depends on the preference functions.

Giurca et al. [36] used PROMETHEE in selection of Photovoltaic Panels. PROMETHEE has been successfully applied in strategic planning of natural resources [37]. Energy technologies have been previously assessed using PROMETHEE [38]. PROMETHEE has also been implemented in the Robotics field [39].

Zooming into application in the mining industry, PROMETHEE was used for a Chromite mine in Turkey to select the most suitable underground ore transport system [40]. Bogdanovic et al. [2] integrated AHP with PROMETHEE for mining method selection. Elevli and Dermici [40] applied PROMETHEE to select the most suitable underground ore transport. For selecting an underground mining method, Balusa et al., (2018) integrated WPM and PROMETHEE.

A clear advantage the PROMETHEE method has over AHP and other MCDMs is that there is no need to perform a pair-wise comparison when alternatives are removed or added in the evaluation process [41]. Hyde et al. [42] highlighted some of the limitations of PROMETHEE to include the following: Decision makers finds it difficult to define the preference and indifference thresholds because of limited availability of selection guidelines. The uncertainty of the chosen thresholds is also not fully accounted even though a sensitivity analysis is later performed. The subjective input of the preferences introduces yet uncertainty. Additionally, Hyde et al. [42] further advises the user to note the fact that the six criterion functions introduced do not address the imprecision of the decision matrix constructed from expert judgement. So, difficulties may still be encountered in the process of using PROMETHEE because of these limitations and a considerable amount of uncertainty remains in the ranking process [42].

2.1.7. ELECTRE

ELECTRE (Elimination Et Choix Traduisant la REalite) translated to mean: Elimination and Choice Expressing Reality was developed in 1968 by Bernard Roy. Since then, different ELECTRE methods have been developed. ELECTRE I & ELECTRE IS were developed for selection problems. ELECTRE TRI is for sorting problems, and ELECTRE II, III, and IV are for ranking problems [37]. The method is used for analysing data in a decision matrix to rank a set of alternatives. Like PROMETHEE, the are indexes (concordance and discordance) that are used in the pairwise comparison between alternatives [43]. The following are steps involved in ELECTRE I:

One common advantage for many decision-making methods is the ability to handle both qualitative and quantitative criteria. ELECTRE possess such ability. Sometimes ELECTRE fails to sort the alternatives in different ranks, in those cases a hybrid approach may be necessary [44, 45]. A hybrid approach is a process of integrating MCDMs methods to reach a final ranking.

Hobbs and Meier [46] have used ELECTRE in the civil and environmental engineering. Ashfari et al. [44,45] used it for personnel selection. Over 540 papers where ELECTRE was applied have been published. The papers represent fields such as energy management, natural resources, environmental management, health, safety, medicine, design, and mechanical engineering. To select optimal technology for surface mining, Stojanovic et al. [47] applied an integrated AHP-ELECTRE. Bodziony et al. [48] used ELECTRE to select surface mining haul trucks.

2.1.8. OCRA

Like the other MCDM, OCRA was developed in 1991 by Parkan to calculate the performance of alternatives. It uses an intuitive approach to incorporate the preferences of the decision maker about the relative importance of the criteria [49]. The decision maker’s preferences for the criteria is reflected by the preference ratings of the alternatives [50].

The advantage of OCRA over some MCDM is that, one can deal with both beneficial and non-beneficial criteria separately without having to lose some information in the process. The method is not a parametric approach and that implies that it is not affected by additional parameters in the process and less steps are required for the whole procedure [49]. Also, Chakraborty and Chatterjee [50] add that OCRA can deal with situations where there is a dependency between the relative weights of the criteria and the alternatives.

In application, Madic et al. [49] used the method to select non-conventional machining processes using the OCRA method. Parkan used it in 2002 to measure the operational performance of a public transit company. Chakraborty et al. [51] applied OCRA with other MCDM to selection location of distribution centres. For Biomass selection, Martinez et al. [52] used OCRA method with TOPSIS. There has been limited application of the method in the engineering field, especially in the mining industry.

2.1.9. ARAS

According to Adali and Isik [53]; ARAS is a method that determines the performance as well as compare alternatives with a chosen ideal alternative. Zavadskas and Turksis developed it in 2010 with an emphasis that a degree of optimality is obtained by determining the ratio of the sum of the weighted normalised values of an alternative to the sum of the values of the weighted normalised of the optimal alternative with respect to criteria [53]. The method is simple and can be performed in excel. Therefore, the fact that it does not have a complex theoretical background like AHP and the rest makes it favourable to those who wants a simplistic answer [54].

The application of ARAS method has been evident over the years.

Zavadskas and Turskis [55] used the method for the first time to evaluate the microclimate in office rooms. Kocak et al. [54] used the method to select a subcontractor in the construction industry. It was used to rank Serbian banks in 2013 by Stanujkic et al. Dahooie et al. [56] applied ARAS in evaluating oil and gas well drilling projects. Adali and Isik [53] applied ARAS in an air conditioner selection problem. Nguyen et al. [57] carried a conveyor equipment evaluation out using ARAS and AHP. Like OCRA, there is few or no application in the engineering field, especially mining field.

2.1.10. COPRAS

The development of COPRAS by Zavadskas and other researchers dates to 1996. It is a fast-developed method to deal with real problems. The method can be performed without difficulty even when the attribute and alternatives are large; and it can handle both qualitative and quantitative criteria [58]. However, COPRAS is less stable when a sensitivity analysis is performed and gives different rankings when there are changes in the weights [59].

It has been applied in a supplier selection problem because of its simplicity and advantage of plugging values onto EXCEL for a faster implementation [60]. Chatterjee and Charaborty [61] used it to for a manufacturing firm to select the most appropriate flexible manufacturing system. Assessment of road design has been done by COPRAS [62]. In combination with the fuzzy AHP, Das et al. [63] used COPRAS to measure the relative performance of Indian technical institution. It has also successfully been applied in the construction as well as property management [64].

2.1.11. SAW

Hwang and Yoon suggested the SAW method in 1981. It is also called the weighted linear combination method [13]. It is described as one of the most straight-forward MCDM methods. Its application is usually for benchmarking; to evaluate results from other techniques [58].

The advantages of the method is that it is intuitive to decision makers, and there is no need for any complex compute program as the computations are easy. However, the drawbacks are that the criteria should be a maximizing criterion before any calculation; this means that minimizing criteria must be turned to maximizing, and that leads to the method not reflecting real situation problems. As a result, the results obtained may not be logical. Despite the drawbacks, the application of SAW ranges from water management, to business and financial management [9]. Afshari et al. [44,45] applied the method in personnel selection problems. Setyani and Saputra to determine flood-prone area at Semarang City used the SAW method in 2016. There has been limited use of SAW in the mining industry.

2.1.12. CP

According to Park et al. [65]; Zeleny proposed CP in the 70s for identification of an alternative that is closest to the ideal solution based on the distance measure L_p. Poff et al. [66] applied CP to evaluate forest management approaches. Park et al. [65] emphasised that CP is effective in solving environmental problems. It has also been used in the field of water resource management. However, when compared with other methods, it is significantly less used [67]. The method has proven to be robust and sensitive to the weight and the 'p' value chosen by the decision maker. It is therefore advisable to perform a sensitivity analysis to check for stability in the answers obtained [66].

3. Results

Section 3 will summarise the findings from studying the method selection techniques, factors, and mining methods. It is the aim of this chapter to class approaches and techniques to methods selection, to test the techniques against each other in different case studies, to check for consistency in decision making, and stability of the final rankings of alternatives. Two analysis approaches were carried out; statistical and descriptive.

The results from this section were used to develop the proposed MMSM in section 4. Its capability and applicability are detailed in the following section. The results section is divided into two section; a descriptive and statistical approach to comparing the MCDM. It must be noted that individual MCDAs have been used.

3.1. Case study evaluation

Two case studies from different publications will be used to evaluate the MCDM methods that were introduced in the previous section. Saaty & Ergu introduced a set of criteria that will be used to evaluate the MCDMs. The Saaty & Ergu list of criteria was used because it highlights major criteria that can be used for comparison. The set is listed below. In addition to the criteria, the MCDMs' extent of application will be evaluated as well:

- Simplicity of execution
- Logical Mathematical procedure
- Input Parameters
- Synthesis of judgmenet with merging function
- Rank of tangibles
- Generalizability to ranking intangibles
- Rank perseveration and reversal
- Sensitivity analysis
- Conflict resolution
- Trustworthiness and validity of the approach.

Case Study 1:

This case study illustrates the process of selecting a mining method through an integrated approach. A fuzzy AHP to calculate the criteria weights and individual TOPSIS (to select the mining method) are applied to facilitate the decision-making process.

The case study uses information from: Shariat S, Yazdani-chamzini A, Bashari B·P, [68]; Mining method selection using an integrated model, International research journal of applied and Basic Sciences, 6(2): 199–214. The mine that was investigated is located in the Wester Zanjn province in Iran. It forms part of the major producers of zinc. The orebody is located within a metamorphic basement plunging east ward at 10–20. It is 600 m long in the N–S line and 200–400 m across.

In this case, a fuzzy AHP determined the weights of the criteria, and the criteria were used to rate and rank the importance of the mining method alternatives in the TOPSIS model. Amongst the alternatives, cut and fill method ranked the highest and was confirmed through a sensitivity analysis. The selection process was performed for an Angouran Zn–Pb mine in Iran. The final ranking of the methods was: A4>A2>A3>A1>A6>A5.

The significance of the case study was that it illustrated the decision process of MMS by using TOPSIS as one of the investigated MCDM in the literature of this current study. Even though it is not a coal mining example, it better illustrated the use of MCDMs in decision making.

The mine started as an open pit. However, as depth increased (2880 m), it was required that a mining method be suggested for continued operations. The criteria used for this specific case study problem and the alternatives are summarised in Table 1.

In the case study it is mentioned that fifteen decision makers were involved in evaluating alternative mining methods based on the given criteria for the selected case study mine. All the criteria are benefit criteria and the higher the score, the better the performance of the mining method [68].

To compare the performances of the MCDM, the author took the existing case study above and applied the other MCDMs on it (PROMETHEE, CP, ARAS, OCRA, CORPAS, VIKOR, TODIM, GRA and SAW) with the following aim: to check for consistency in the above results obtained from the case study. Also, how further apart are the results/rankings if they are not similar. Below are the results from the 10 different methods.

Table 1
Criteria and Alternatives for the case study mine.

Criteria	Alternatives
• C1: Orebody thickness	• A1: Block Caving
• C2: Orebody dip	• A2: Sublevel Stoping
• C3: Orebody shape	• A3: Sublevel Caving
• C4: Grade distribution	• A4: Cut & Fill
• C5: Orebody depth	• A5: Top Slicing
• C6: Orebody RSS	• A6: Square Set Stoping
• C7: Footwall RSS	
• C8: Hanging wall RSS	
• C9: Orebody RMR	
• C10: Footwall RMR	
• C11: Hanging wall RMR	

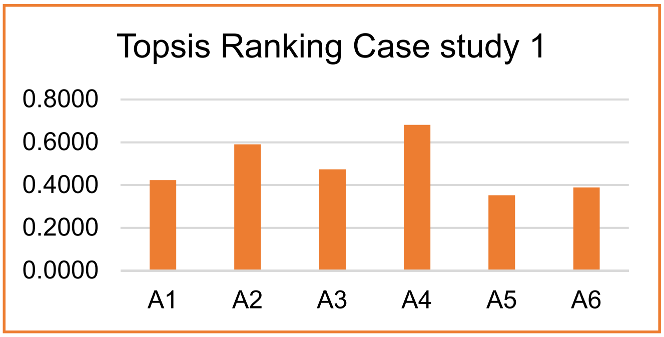


Fig. 1. Topsis final rankings case study 1.

The results based on the TOPSIS methods are as shown in Fig. 1. The alternative with the highest relative closeness is rated as the preferred alternative based on the calculations conducted. A4 (Cut and Fill Method) was chosen as the most suitable to exploit the given deposit. While the least preferred option is A5.

According to the result obtained from using TODIM, A2, which is Sub-level Stoping, dominates the rest of the alternatives. A4, which was proven as the best in TOPSIS (original data) and after the sensitivity analysis, is dominated by two more methods in TODIM. Even though the ranking of the above two methods differ, a sensitivity analysis had to be carried out to validate the results from the TODIM method (See Fig. 2).

In the GRA method, The grey relational coefficients are averaged to obtain the grey relational degree (GRD). This degree shows the similarity of the comparability and reference sequence. The higher the value of the GRD, the better the ranking. A2 (sub-level stoping) is the highly ranked; then A4 comes second. A5 is the least preferred alternative (See Fig. 3). The results were further validated by a sensitivity analysis.

Using Promethee II, net out-ranking flows were calculated using a Promethee software and A2 was found as the alternative that outranks the others. A4 in this case came second (See Fig. 4).

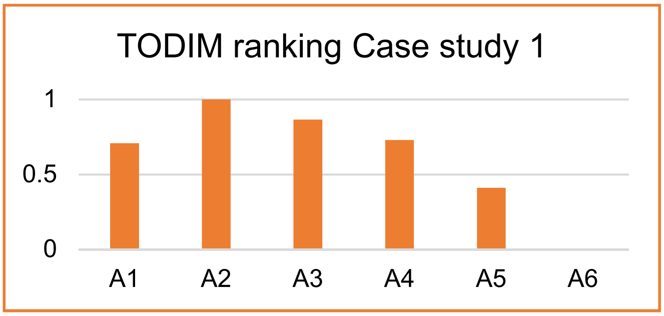


Fig. 2. TODIM Final ranking case study 1.

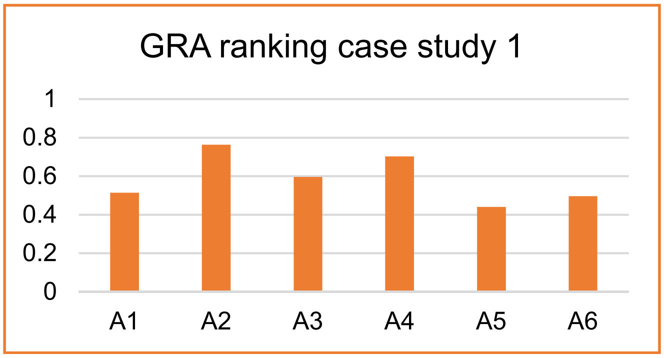


Fig. 3. GRA final ranking case study 1.

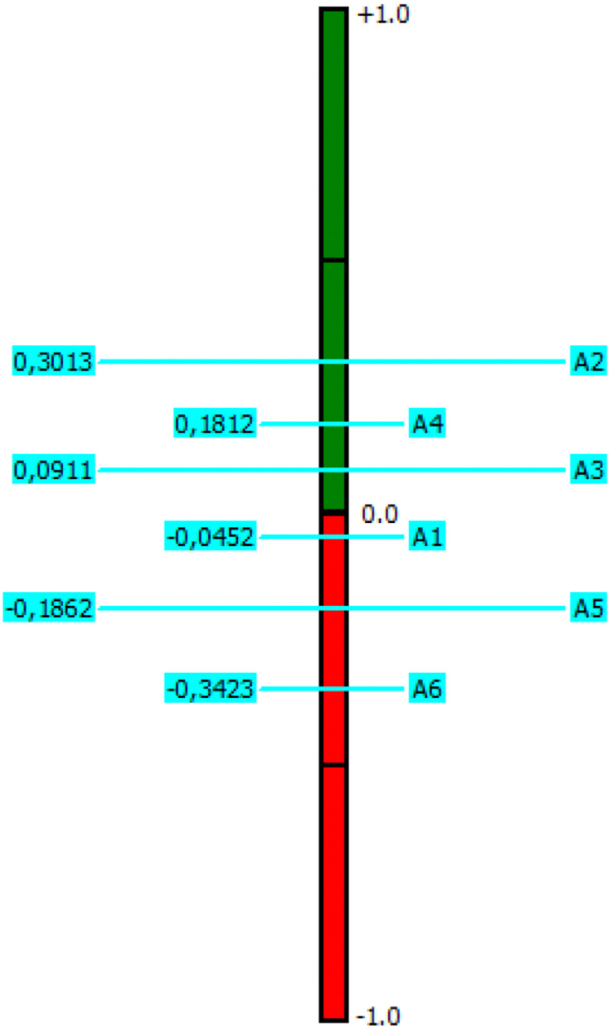


Fig. 4. PROMETHEE II final ranking of alternatives for case study 1.

For OCRA, the overall ratings of the alternatives were determined using the relevant equation and are shown in Fig. 5. A2 is the alternative with the highest overall performance; followed by A3. The worst performing alternative is A6.

Using ARAS, the alternatives were then ranked through the utility function value. This value determined the relative efficiency of an alternative over the optimal alternative. The results are shown in Fig. 6. A2 is rated as the best choice, followed by A4. The worst choice is A6.

On CORPAS method, once the beneficial criteria are summed up, a relative significance value of the alternative that shows the priority of the alternatives can then be calculated. From the calculations, a quantitative utility value was then be calculated. A higher value implies a higher

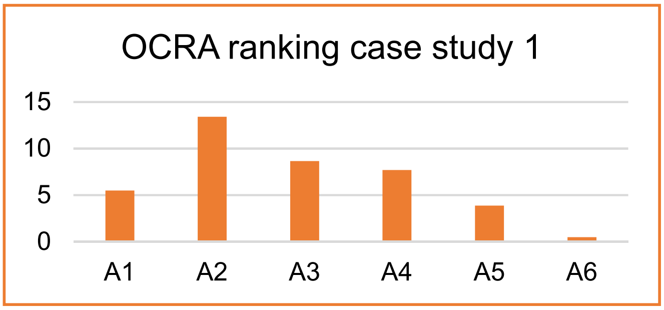


Fig. 5. OCRA final rankings case study 1.

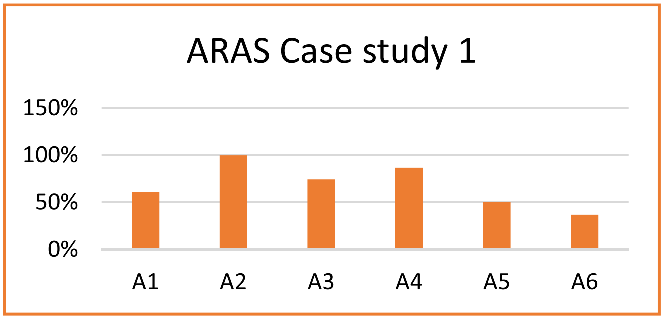


Fig. 6. ARAS final rankings case study 1.

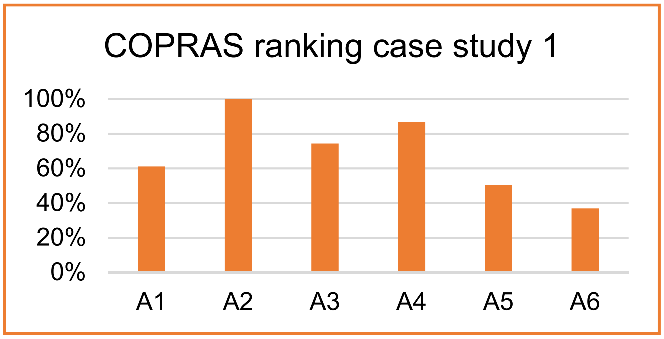


Fig. 7. CORPAS final rankings case study 1.

ranking. In the rankings shown in Fig. 7, A2 emerged as the winning option. While A6 was ranked the worst amongst the alternatives.

When using the CP method, the best alternative will have the lowest distance metric, and that implies that it is closest to the ideal solution. A4 appears slightly lower than A2, but they are both closest to the ideal solution compared to the rest of the alternatives, with A6 being the furthest as shown in Fig. 8.

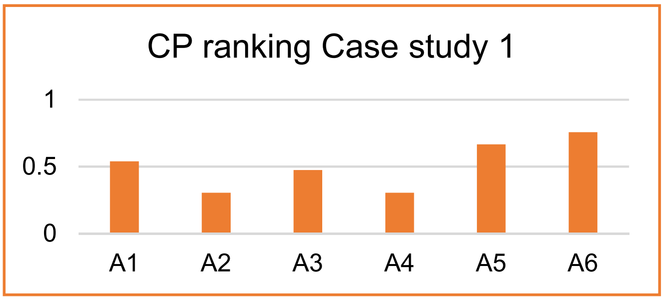
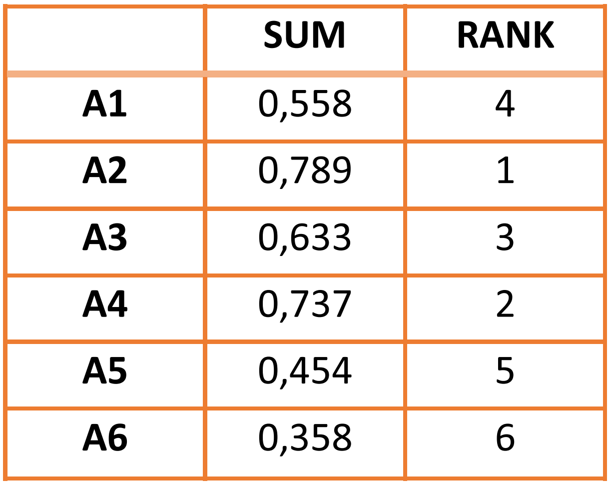


Fig. 8. CP final rankings Case study 1.



	SUM	RANK
A1	0,558	4
A2	0,789	1
A3	0,633	3
A4	0,737	2
A5	0,454	5
A6	0,358	6

Fig. 9. SAW final rankings case study 1.

When using the SAW method, the alternative with the highest score is the most suitable. In this case, A2 appears to be the highest followed by A4. A6 with a score of 0,358 is the least preferred option (See Fig. 9). A4 has the lowest index, and therefore it is the best option according to the VIKOR method. Also, A4 was able to meet the set conditions as required by the VIKOR method. The robustness of the results were checked through a sensitivity analysis.

The combined results of all the 10 MCDM yielded the frequency of ratings shown in Table 2 The table shows how many times each alternative appeared in a rank, that is, A1 was ranked at number 4 by 9 out of 10 methods. A2 from the combined MCDM results was rated as the best option because it emerged as the most suitable method in 7 out of the 10 rating methods; while A6 emerged as the worst option in 8 out 10 rating methods.

The ranking of alternatives for the combined MCDMs was: A2 > A4 > A3 > A1 > A5 > A6. There was a slight difference from the original results where the TOPSIS method was used in the case study. In the case of the combined ratings on Table 2, Sublevel caving ranked the highest.

Table 3 sorts the MCDM's according to the results of their ratings. Group 1 shows the MCDM with the same rankings of alternatives from the results shown and explained. This information will help the author in checking for consistency in ratings. A measure of similarity has also been calculated using the Spearman Correlation.

Table 2
Ranking frequencies of MCDM in the case study.

	Ranks→	1	2	3	4	5	6
Alternatives	A1	0	1	0	9	0	0
	A2	7	2	1	0	0	0
	A3	0	2	7	0	1	0
	A4	3	5	2	0	0	0
	A5	0	0	0	1	7	2
	A6	0	0	0	0	2	8

Table 3
Groups of similar rankings of MCDMs.

Group 1 • PROMETHEE • CORPAS • ARAS • SAW	Group 2 • TODIM • OCRA
Group 3 • TOPSIS	Group 4 • CP
Group 5 • GRA	Group 6 • VIKOR

3.2. Descriptive analysis of the MCDMs

Saaty and Ergu described a set of criteria that can be used to evaluate different MCDMs in order to answer the question: “When is a Decision-Making method trustworthy?” The following set of criteria are evaluated against the MCDMs described in the literature review.

3.2.1. Simplicity of execution

In simplicity of execution, Saaty and Ergu [69] suggested that the user of the MCDM must be able to perform the decision-making process without the need of an expert to supervise the process. The mathematics and underlying logic of the procedure must not hinder a successful decision-making process. A scale to rate the ease of use for the methods is given as, low: if the method’s logic is complicated and not suitable to be used by non-expert; medium if there is much effort that goes into learning it; high if it can be implemented in almost all studies and can be easily understood by layman.

Based on the Author’s experience backed up by research, the author has assessed the methods as follows:

From the current research experience with the application of TOPSIS, the method is user friendly and one experiences a high simplicity of use. This claim is backed up by the extent of application of the TOPSIS. It was been previously mentioned in this current research that over 100 papers have been published where TOPSIS is applied. The following are some of the comments from the previous users of TOPSIS.

Pavic and Novoselac [70] attest to the simplicity of TOPSIS in their publication; that the method has a simple mathematical model and is a practical method since the user can rely on computer support for computations. Yavuz [71] confirmed the ease of use of TOPSIS compared to the other MCDM methods when he used it for wheel loader selection in a coalmine. The computational process of TOPSIS is said to be straightforward by Garcia-Cascales & Lamata (2012).

From the current research experience, the author found that TODIM method is simple to use once the user understands the procedure. However, there can be computational mistakes in the process because of the effort that goes onto its implementation. In terms of the pre-defined ratings of simplicity of execution, TODIM is rated medium. It was previously mentioned in the literature review that Rangel et al. [19] said the method is easy to be implemented even by users who are not professionals.

According to the current research, VIKOR is simple to use and is rated highly. However, the need for user input of some other parameters such as the ‘v’ parameter may make the process tedious.

Wu (2002) mentioned some of the advantages of GRA. Amongst them was the simplicity in computations and the straight forwardness of the method. In this current research. GRA was used, and the author found the method easy to implement. The rating GRA is given in this study is a high rating.

The simplicity of PROMETHEE in application and conception has led to its widespread use and a fast-growth (Balali et al., 2014). However, the difficulty of PROMETHEE shows up when the preference function has to be chosen; and may be difficult when the decision maker has no experience of using this MCDM. Therefore, the simplicity is given a medium rating.

ELECTRE is a complex method and difficult for non-experts. Balali et al. (2014) attest that ELECTRE does suffer from sophisticated mathematical formulation. A low rating is given to ELECTRE.

OCRA, ARAS, COPRAS, SAW, and CP methods are simple to execute in decision-making and will therefore be given a high rating of simplicity.

3.2.2. Logical, mathematical procedure

This criterion simply means that a method must have a mathematical representation, logical reasoning behind the theory and justification. A low rating is given to a method with just a simple mathematical logical procedure; a medium rating is given to a method that uses reference sequences or relative difference to rank alternatives; and high rating for methods using pairwise comparison technique to determine the dominance of one criterion over another.

The mathematical approach of TOPSIS is well structured and uses relative difference of the distances for ranking. Therefore, it is given a medium rating.

TODIM uses pairwise comparison to determine the dominance of one criterion over another. In addition, from tits equations, it can eliminate inconsistencies that do arise from the pairwise comparison technique. Therefore, it is given a high rating.

There are no pairwise comparisons in the VIKOR method and criterion can be evaluated independently. A relative difference is thus used at the final ranking of the alternatives; and VIKOR is rated medium in this case.

According to Lu [33]; the theory behind GRA does not have any solid foundation in mathematics. The assumption made in GRA is that the data is exponential; however, there are no further explanations on why such a claim is made. This makes it difficult to know the interpretations if the data is not exponential. Some other challenges faced and could be the reason for limited application of GRA are the quality of English as well as the writing style and the limitation in the theory application. A low rating is given.

It does not consider discordance but does use the pairwise comparison to determine the dominance degree of one alternative over the other. PROMETHEE therefore receives a high rating.

It does consider discordance and does use the pairwise comparison to determine the dominance degree of one alternative over the other. A high rating is therefore given to ELECTRE.

OCRA, COPRAS, SAW, ARAS: These methods are given a low rating because they just use a simple mathematical equation to show and justify their procedure.

CP’s procedure uses a relative difference and is therefore given a medium rating.

3.2.3. Input parameters

A method must be justified in at least three ways; in its procedures, consequence of the procedures and approaches. If there are input parameters, there must be justifiable theory behind. A low rating is given to methods without any justifications of the parameters; Medium rating if it involves parameters in some part, and high if it involves complete and logical reasoning to input parameters.

The only input on the TOPSIS method are the weights given by the decision maker to each criterion. This means that subjectivity is further reduced on this method and therefore it is given a high rating.

In TODIM, the input parameters are the weights of the criterion and the attenuation factor. This factor can be adjusted between 1 and 10.1 is usually used because it signifies that the losses would contribute with their real values. The reasoning for both the parameters is logical; therefore, a high rating is given to TODIM.

A decision maker intervenes in the VIKOR process to determine the weights of the criteria and to choose the value of the coefficient ‘v’, which should be between 0 and 1. This parameter gives the importance of weight of the measures. A v equal 0.5 is usually chosen so that both the utility and regret measures are given equal weight. A value less than 0.5 gives more weight to the regret measure; while a value greater than 0.5 places more importance to the utility measure. The parameter is logical and therefore VIKOR is given a high rating.

There is a lack of axiomatic foundation for GRA. In addition, it was noted that there is missing proof of reliability of the method by theoretical research. Clarification needs to be done or it may hinder adoption in many industries for application. Thus, a low rating is given.

There are thresholds as input of the decision maker’s preference. It was suggested that the use of the thresholds must be based on previous studies for guidance. That justifies the use of preferences in PROMETHEE. In addition, one of the studies that formed part of the research suggested two ways of setting the thresholds; one is to set the indifference to zero and preference threshold as the maximum evaluation between the alternatives. The other approach suggested by the author was to set the indifference as the minimum and preference as the maximum alternative. PROMETHEE is given a medium rating.

In the procedure of ELECTRE, there are threshold (c and d) that the decision process depends on. The values of these thresholds depend on the Decision maker. It is believed that these values have an influence on the final ranking, and the fact that it is not ensured that using a higher *c* and a lower *d* will lead to small number of non-dominated solutions [21], it is not suggested that ELECTRE be used for decision making process for MMS.

OCRA, ARAS, COPRAS and SAW: The above listed methods do not have any other input parameter except the weights. Medium ratings are given to these methods.

The weights of the criteria and the p-parameters are the input of the decision maker in the CP process. The p-parameter shows how the decision maker compensate for the deviations in the process of decision-making. Medium rating is given to CP.

3.2.4. *Synthesis of judgements with merging functions*

In this criterion, the judgements from different experts are synthesised. To obtain an overall rank, the evaluations must be synthesised. If a method synthesizes the evaluations by averaging weights, it is rated low. A method will be rated medium if a simple weighted method is used. A high rating is given if there is a rigorous merging function with reasonable weights used.

In the aggregation process, TOPSIS uses an equation that considers the distance from the positive ideal and from the negative ideal. TOPSIS does not consider the relative importance of this distance between the alternatives. A high rating is given to TOPSIS.

TODIM measures the dominance degree of each alternative by calculating the partial and overall dominance of each alternative. From the dominance degree, rankings can be made. It follows a rigorous procedure and can be highly rated.

In the aggregation process of VIKOR, a L_p -metric, which is a distance function, is calculated. It represents group regret that an idea cannot be chosen. L_1 is represented by S-group as the sum of all the individual regrets. While L_∞ represent the R-group. That is the maximum regret that an alternative could have (Tseng & Opricovic, 2007). Q aggregates the S- and R-group with the ‘v’ parameter. The method is therefore rated highly because of the rigorous merging process.

In GRA the magnitude of correlation between alternatives and the reference sequence is calculated using the grey relational degree. A high rating is given to GRA.

A net preference flow is introduced as an aggregating utility function, and the equations used are shown the previous mentioned steps for PROMETHEE. Research found that the foundation of net flow if PROMETHEE and the S-Group of VIKOR have the same foundation (Tseng & Opricovic, 2007); and their results are similar if PROMETHEE uses its Linear (Type 5) function. A high rating is given. A high rating is given.

The output of the ELECTRE process is a set of concordance of alternatives, which indicates how one alternative dominates the other. The ranking is partial in ELECTRE because some alternatives remains incomparable. Medium rating is given.

OCRA, ARAS, COPRAS, CP, SAW: Medium ratings are given to the methods above because while others average weights in their process, simple weighted methods are used.

3.2.5. *Ranking of tangibles*

Alternatives are ranked either higher, lower or equal to the other alternatives they are competing with on the evaluation of the tangible criteria. If a method does not involve ranking, it is ranked low. If it uses ordinal scale, it uses medium and high if cardinal scale is used to rank alternatives.

All the methods can deal with both quantitate and qualitative data and uses cardinal scale; therefore, they are rated highly in this criterion.

3.2.6. *Generalization to ranking of intangibles*

Intangible criteria are often part of a decision problem; and they need to be quantified. If a method is applicable to both tangibles and intangibles, and asses the intangibles by using pairwise comparison technique, it is then rated high. If it transforms intangibles into cardinal numbers by using interval. Ratio/absolute scale, it is rated medium; and if it just assigns arbitrary ordinary numbers to quantify the intangibles, it is rated low.

In PROMETHEE and ELECTRE, alternatives are evaluated on a pairwise comparison technique. The deviations between two evaluations of alternatives are considered. They are therefore given a high rating.

In TOPSIS, TODIM, VIKOR, GRA, CORPAS, ARAS, CP, SAW and OCRA, Medium rating since they use a cardinal absolute scale, but not a pairwise comparison technique.

3.2.7. *Rank preservation and reversal*

MCDMs’ one of the significant drawbacks is due to the phenomenon called: rank reversal. This phenomenon explains the change of alternatives ranking if one or more alternatives are added or removed from a decision problem. Sometimes the best alternative can become the worst alternative, especially where the rank reversal totally inverts the ordering. A method which does not deal with rank reversal at all is rated low; one which basically deals with it is rated medium, and one which implements ways in its procedure for interpreting reasons for rank preservation and reversal is rated highly.

The above-mentioned phenomenon has made the validity of TOPSIS debatable. Because rank reversal would clearly mean that a better decision/alternative depends on the number of alternatives. Fortunately, Garcia-cascales & Lamata (2012) identified two points that causes rank reversal in TOPSIS. Namely; the ideal solutions and the normalisation process. In their research, they modified the above-mentioned points and rank reversal was dealt with. Because there have been previous attempts to deal with rank reservation and preservation, TOPSIS would therefore be rated medium because the solution has not yet been widely accepted and when applied, it gives different rankings compared to the original TOPSIS.

TODIM is also mentioned as one of the methods that do suffer from rank reversal, however, a solution for it is its normalisation procedure. Therefore, it is rated medium.

There has been limited studies concerning rank reversal for PROMETHEE. The first people to address it were De Keyser & Peeters in 1996. It was only in 2013 that Veryl and De Smet investigated the probability of rank reversal in PROMETHEE I and II. It was shown that these two classes of PROMETHEE do suffer from rank reversal. However, in 2016, Brans & De Smet showed that the removal or additions of alternatives does not lead to rank reversal in PROMETHEE. Therefore, it was tested in the current studies and found that it is stable. So, a high rating is given to PROMETHEE concerning rank reversal.

In ELECTRE, the rank reversal is caused by the pairwise comparison. It is also noted that rank reversal probability of occurrences increases as the number of alternatives are increased. Also, under equal weights for criteria, there is more rank reversal. Therefore, the method is rated low because there is no proven method to deal with rank reversal in ELECTRE.

In SAW and OCRA, because of their normalisation procedure, SAW and OCRA suffers less from rank reversal. A medium rating is given.

CP suffers from rank reversals and has been proven in this study as sensitivity analysis was carried out. Therefore, a low rating is given.

3.2.8. *Sensitivity analysis*

A method is rated low if it only asses a single parameter; medium if it works on two to three parameters; and high if it can assess more parameters.

A medium rating is given to TOPSIS because it can assess the weights of the criterion and the evaluations of each criterion against the alternatives.

A high rating for TODIM is given because it can assess the following parameters for sensitivity: attenuation factor, criteria weights, the choice of the reference criterion, and the performance evaluations of the alternatives.

The v-parameter and weights can be changed in VIKOR. Therefore, a medium rating is given to the method.

Only two parameters can be varied in GRA method; weights of the criterion and the identification coefficient. Therefore, a medium rating is given to GRA.

In PROMETHEE, preference, indifference, preference functions, and the weights of the criterion can be changed to see asses the influences of each. Therefore, a high rating is given to PROMETHEE.

ELECTRE assesses 3 parameters; concordance and discordance index, as well as the weights. It is therefore given a high rating.

OCRA, ARAS, COPRAS and SAW: These methods do not have special input parameters except the weights of the criterion. Since they only asses one parameter, they are given a low rating.

In CP, only two parameters can be varied; the ‘p’ value and the weights. Therefore, CP is given a medium rating.

3.2.9. Applicability to conflict resolution

A method must be able to resolve the conflict that exist within the criteria of making a decision. There must be fair trade offs in the process; such as normalisation to find the best solution where conflict is concerned. A low rating is given to methods which use a simple mathematical compensation technique; medium rating for methods using analytical methods, and high rating for methods providing an understandable, acceptable, practical and flexible way of resolving the conflicts in criteria.

TOPSIS process of normalising uses a vector normalisation. It must be noted that the normalised value could be different for different evaluation unit of a criterion (Tseng & Opricovic, 2004). For example, if a problem with two alternatives is evaluated against 3 criteria and the evaluations are 3, 4, and 5 for A1 and 2, 3, 9 for A2: the normalised values of 3 will be different. Therefore, TOPSIS is given a medium rating.

A high rating is given to the normalisation procedure of TODIM.

In the normalisation procedure of VIKOR, a linear transformation is used; and it does not depend on the unit of the criterion, or whether it is a minimum or maximum criterion. The normalisation procedure is aggregated in calculation the utility and regret measures.

In PROMETHEE, conflict resolution is resolved in the aggregation process. A high rating is given.

In GRA, ELECTRE, OCRA, ARAS, COPRAS, CP and SAW, they all can resolve conflict that exist in the criteria and they are all given a high rating in this case.

3.2.10. Trustworthiness and validity of the approach

The quality of a method and what makes it trustworthy must be considered. Questions to be asked are: can the method yield the choices that accurately reflect the values of the user? If a method has been widely applied, it provides a platform to be trusted and can be rated high. Medium ranking is for methods which have limited application, and low rating is for methods which have not been applied in the field of question.

TOPSIS has proven itself and has provided it’s on platform for future applications in almost all industries. The number of papers that have been published where TOPSIS was applied are over 100. In different journals such as expert systems with applications, applied soft computing, knowledge-based systems, information sciences, and many more. Therefore, in terms of trustworthiness and validity of the approach, TOPSIS is highly rated.

Limited application of TODIM in mining method selection. Medium rating is given.

There is limited application of VIKOR in mining method selection. Medium rating is given.

GRA has enjoyed wide application in agriculture, environment, and marketing industry. However, there is limited application in the mining method selection industry. Medium rating is given.

The disadvantages of ELECTRE makes it unsuitable for use in the mining industry because in the ranking process, it often does not lead to one solution. It is therefore suitable for decision problems that have few alternatives and less criteria. Low rating is given.

A high rating is given to PROMETHEE like TOPSIS because there have been numerous applications in the mining method selection industry.

OCRA, ARAS, COPRAS, CP and SAW: The methods have not been applied in mining method selection before and therefore, they are given low rating since there is no proof of application and the level of confidence is low.

As rated H-represent High, M-Medium and L-Low. From the results presented, the author has low confidence in ELECTRE, SAW, COPRAS, ARAS, OCRA, and CP. The methods that stand out as a result of the descriptive analysis are TOPSIS, and PROMETHEE. VIKOR, GRA, and TODIM’s confidence is neither low nor high; and was therefore assessed based on the final decision of the author considering the statistical analysis performed.

It must be noted that ELECTREE was eliminated in the first stages because of its inability to rank results and therefore could not be analysed with the other methods except in descriptive analysis since it is based on literature and the author’s experience in application of the methods.

3.3. Statistical analysis of the Mcdms

3.3.1. Sensitivity analysis

Sensitivity analysis is of paramount importance for the MCDMs because of their nature of input parameters that are subjective. The ability to test for the robustness, and uncertainty is relevant where group decision making is concerned. The results from the sensitivity analysis help in increasing confidence, and credibility of the results. Also, the overall risk associated with the decision-making process is thus reduced. It was found by Triantaphyllou (2000) that the most sensitive criterion in decision problem is the one with the highest weight if weight changes are measured in relative terms (%). To relate the rest of the criteria to match the changes of the critical criterion weight, the equation taken from Leoneti [72] was used. However, the author modified the critical criterion percentage from just considering 10% to considering any percentage for a good stability check and to ensure that the sum of the final weights would still equal 1.

$$w_n^* = \frac{w_n\left(1 - w_i^*\right)}{\left(1 - w_i\right)}$$

where.

w_i represent the original weighting of the critical criterion.

w_i^* represent the original weighting of the critical criterion plus the % change.

w_n represent the original weight of criterion n.

w_n^* recalculated weighting for criterion.

The Case study was used for performing a sensitivity analysis. The first method to be evaluated was TOPSIS. Only the weights of the method were modified between −50% and 50% changes. The results obtained are depicted in Fig. 10 F.

The radar graph in Fig. 10 shows the changes in rankings when weights are adjusted. It is observed that A1’s ranking did not change throughout the adjustments; while A5 changed between rank 5 and 6. A6 recorded the most changes by moving around all the ranks except for rank 1.

The changes became stable as the weights were being reduced. At +10% and −10%, there were no changes in rankings; however, as the weights were further reduced by 20%–50%, a stable ranking was observed and has been taken as the final rank for TOPSIS. The original ranking for TOPSIS was A4>A2>A3>A1>A6>A5 and after the sensitivity analysis was performed, the ranking became: A4>A1>A3>A2>A5>A6.

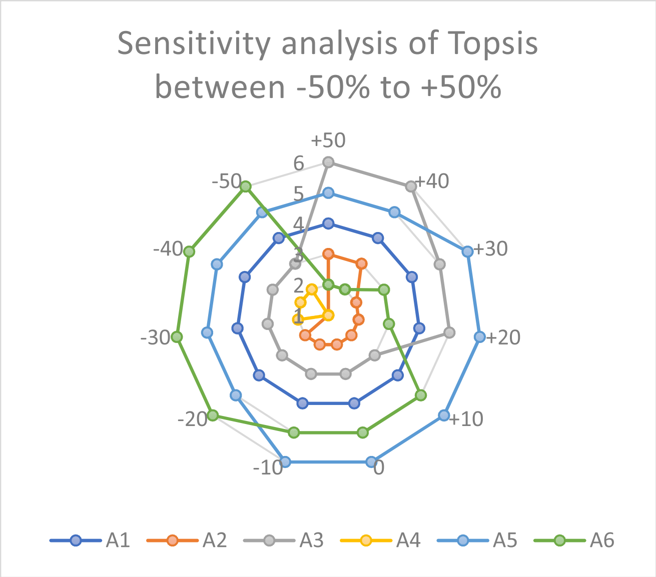


Fig. 10. TOPSIS′ weights sensitivity analysis.

TODIM allows for changes in weights of the criterion, the attenuation factor which ranges between 1 and 10, reference criterion, and the performance evaluation. The weights of the criteria were changed as per the formula presented above. Adjustments of the weights were made from −50% to +50% and there were no changes in the rankings of the alternatives. The reference criterion was also changed. Initially, the highest weighted criterion was chosen as the reference criterion. In sensitivity analysis, the lowest criterion was checked, and it did not lead to changes in the rankings. Since for this study, the performance evaluations of the alternatives against the criteria will not be analysed because the author wants to maintain the original evaluations, the last parameter to be checked was the attenuation factor. The factor was ranged between 1 and 10, and even though there were changes in the final values, they were too minimal to cause changes in the rankings. The initial rankings were and the rankings after performing the sensitivity analysis were similar.

VIKOR's input parameters were also check for stability in their rankings. The v-parameter ranges from 0 to 1. For the initial rankings, a value of 0,5 was used. The values were varied between 0 and 1 and a stable ranking could not be obtained. The rankings were similar between 0,0 and 0,3. At 0,4 and 0,5 the rankings were different. Between 0,6 and 0,8 the rankings were similar again and changed at 0,9 but remained constant to 1. The results indicated that the rank depends on the ‘v’ that is used, and one cannot depend on the rankings of VIKOR to base the final decision.

The weight variations were the input parameters that were checked as well. Initially, the ‘v’ parameter was kept constant as the weights were varied. However, a stable ranking could not be obtained. The ‘v’ parameter was changed to 1 since the ranks using v = 1 showed similarity with the ranks of other MCDM. The results from v = 1, were found to be stable. The instability was considered negligible and the final rankings of VIKOR were determined from v = 1 with weight variations. (See Figs. 11 and 12)

The initial and after sensitivity analysis was performed results for VIKOR are A2>A3>A5>A1>A4>A6 and A4>A1>A3>A5>A6 respectively.

GRA's rankings were then checked against weight variations as well the grey coefficients. Firstly, the weights were varied between −50% and +50%. A6 was found to be the most unstable as the weights were changed. It moved from rank 6 at −50% change to rank 3 at +50% change. Variation of weights resulted in a lot of instability, but only outside the −10%–10% change. The results are shown in Figs. 13 and 14.

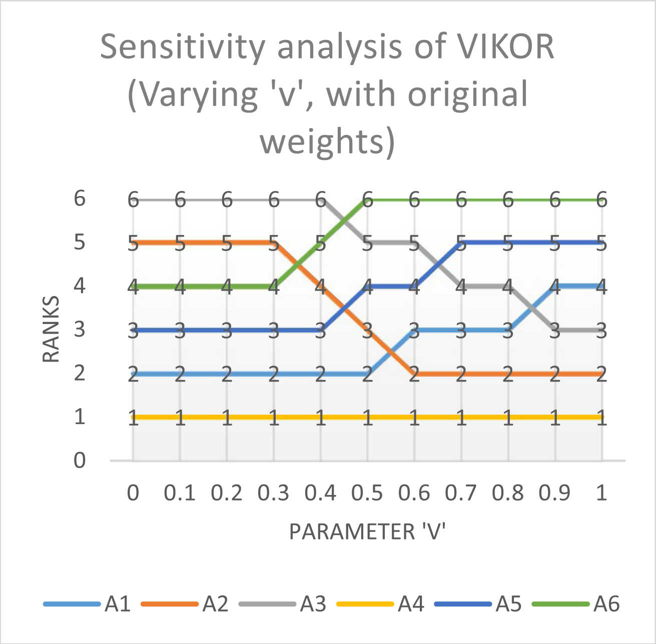


Fig. 11. VIKOR sensitivity analysis_1.

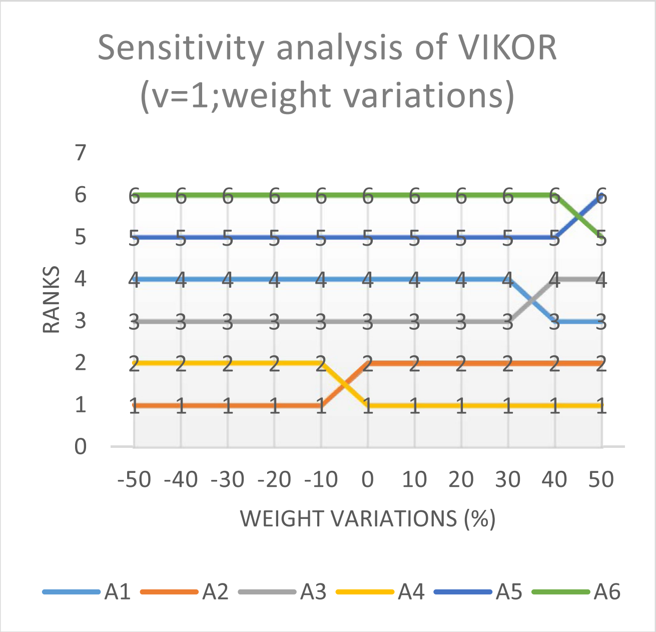


Fig. 12. VIKOR sensitivity analysis_2.

The Grey coefficient was varied between 0,1 and 1. The changes were minimal and were only between A4 an A6 as shown below. The overall changes when the grey coefficients and weights were varied were negligible. Therefore, the results of GRA are stable and were not changed. The ranking remained as A4>A1>A3>A2>A6>A5.

The Stability of OCRA's ranking was assessed and there were no changes even when the weights were varied from −50% to 50%. The rankings remained the same (A4>A1>a2>A3>A5>A6). In the case of OCRA, a stability check was done on equal weights of the criterion since no other input parameter could be varied.

ARAS stability check was also on the variation of weights. The rankings remained stable; and the equal weight criterion rating were checked. The only change observed was a swap between A3 and A4. The rest of the rankings remained stable. So, the initial and final rankings

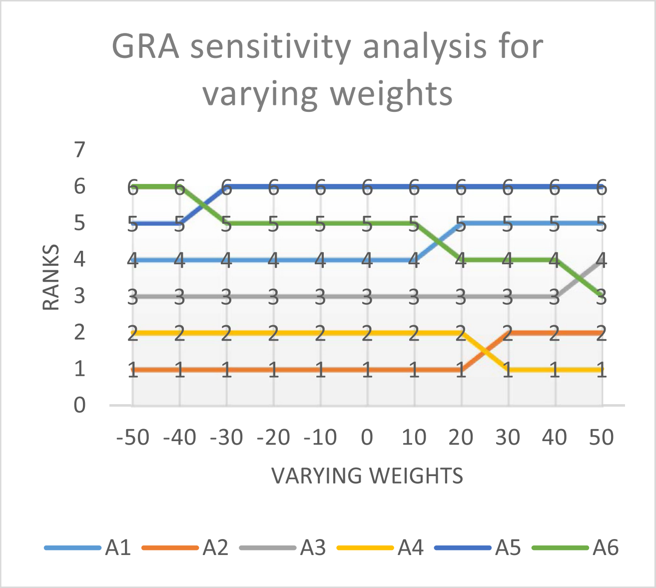


Fig. 13. GRA sensitivity analysis_1.

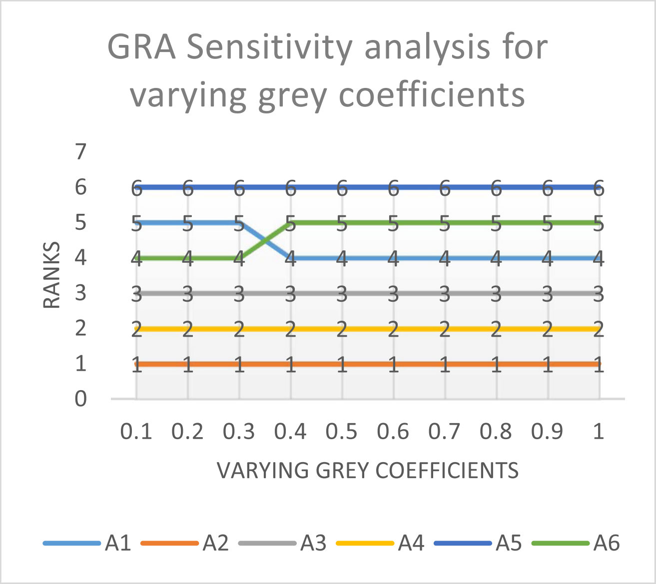


Fig. 14. GRA sensitivity analysis_2.

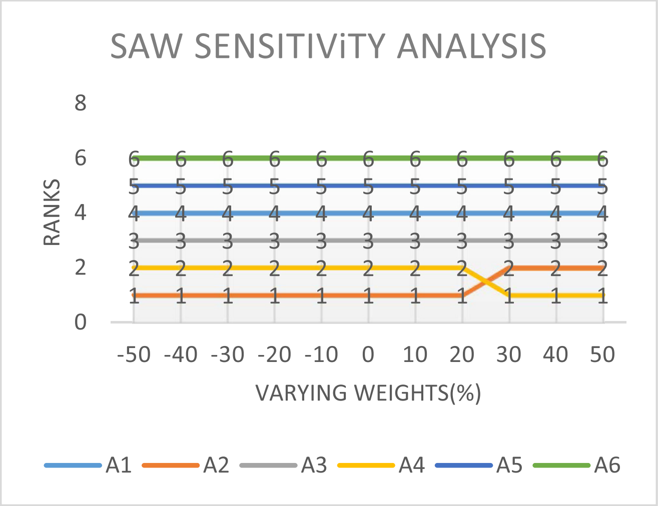


Fig. 15. SAW sensitivity analysis.

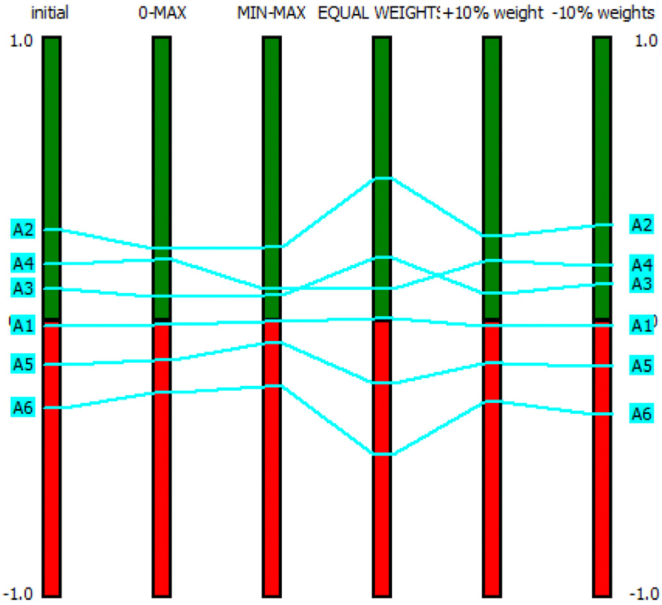


Fig. 16. PROMETHEE sensitivity analysis.

were: A4>A1>A3>A2>A5>A6 as well as A3>A1>A2>A4>A5>A6 respectively.

In CORPAS stability check, the input parameter were the weights variations. The sensitivity results of weight variation between −50% and 50% were all the same but different from the initial rankings (A4>A1>A2>A3>A5>A6) because of a swap of A3 and A4.

CP method was checked. The input parameter 'v' was checked at p = 1, p = 2, and p = 10, 20, 100 (which represent infinity). The rankings only became stable at p = 10. Varying weights were checked at the different p's (1, 2, and 10). P = 2 and p = 10 did not provide stable rankings. The final ratings were A4>A2>A3>A1>A5>A6.

SAW method's stability was checked based on weight variations between −50% and 50%. The changes were minimal such that the initial rankings were accepted as the final ranking of alternatives (See Fig. 15).

PROMETHEE was the last method to be checked for its stability. The VISUAL PROMETHEE was used and the results are shown in Fig. 16. The input parameters that were varied were the preference and indifference thresholds as explained in the descriptive analysis of PROMETHEE. On weights, the equal weights, −10%, and +10% weight scenarios were checked. The overall ratings indicate that PROMETHEE is stable even after parameter changes. Though the values changed and there was a swap between A4 and A3, the changes were not enough to effect changes of the ranks.

Sensitivity analysis was performed for all the MCDMs, and the new rankings from the sensitivity analysis of all the 10 MCDMs are shown on Table 4. The initial ratings of the following methods have changed: TOPSIS and VIKOR. TODIM, GRA, PROMETHE, OCRA, ARAS, SAW and CP's overall rankings were stable and therefore did not change. However, out of the 10 methods, 6 methods have the same rankings unlike before sensitivity. It can therefore be concluded that the ratings for case study should have been **A2** > **A4** > **A3** > **A1** > **A5** > **A6.** This confirms the frequency of ratings of case study.

3.3.2. Spearman correlation

The 10 MCDMs that have been investigated and detailed in the previous pages were compared based on their final performances that led to

Table 4
Aggregated Final sensitivity analysis.

	TOPSIS	TODIM	VIKOR	GRA	PROMETH	OCRA	ARAS	CORPAS	SAW	CP
A1	4	4	4	4	4	4	4	4	4	4
A2	1	1	1	1	1	1	1	1	1	2
A3	3	2	3	3	3	2	3	3	3	3
A4	2	3	2	2	2	3	2	2	2	1
A5	5	5	5	6	5	5	5	5	5	5
A6	6	6	6	5	6	6	6	6	6	6

the rankings. The spearman correlation coefficient (rho) was used. The coefficient helps to determine the strength of the relationships between the MCDMs. In other words, it is used to measure the similarities between two sets of rankings. The value obtained from the correlation ranges between −1 and +1. If the value is large and closer to +1, it then indicates a good agreement between the MCDMs. The formula below was used to calculate this coefficient:

$$r_s = 1 - \frac{6\sum_i^n d_i^2}{n^3 - n}$$

where:

d_i represent the difference between MCDM ranks
n represent the sample size (in this case; the alternatives)

For the case study, the spearman correlation coefficients were calculated for the 10 MCDMs. According to the observations, the coefficients ranged between 0,371 and 1000. TODIM is similar to OCRA. PROMETHEE is similar to ARAS, CORPAS, and SAW. And according to the characteristics of co-efficient R, the methods have a very strong relationship. The results of TOPSIS compared to GRA, and CP are satisfactory. However, VIKOR showed to be an outlier and its similarity to the rest of the methods was found to be low (See Fig. 17).

3.3.3. KENDALL'S coefficient

To check for the overall similarity of the rankings, the Kendall's coefficient was calculated for the overall rankings using the formula below. This value ranges between 0 and 1; with 0 indicating that there is no agreement and 1 shows the agreement between the MCDMs. The coefficient was calculated as 0,866 which suggested that there was almost a perfect agreement between all the considered MCDMs. According to the Kendall's coefficient of concordance interpretation, a coefficient great than 0.7 shows a strong agreement (See Table 5). The following formula was used:

$$W = \frac{12\sum_i^n d_i^2}{m^2 \times n(n^2 - 1)}$$

where:

m is the number of judges/rate(rs); in this case, the MCDMs.
n id the number of alternatives.
d shows the differences of the ranks

A Null Hypothesis: H_0 meant that there was no statistically significant degree of agreement amongst the MCDM; while H_1 meant that there was a statistically significant degree of agreement between the MCDM. The P-value that indicates the level of significance was calculated to be 0,00. The hypothesis says if $p < 0{,}05$, the null hypothesis is rejected, and the alternative hypothesis is accepted.

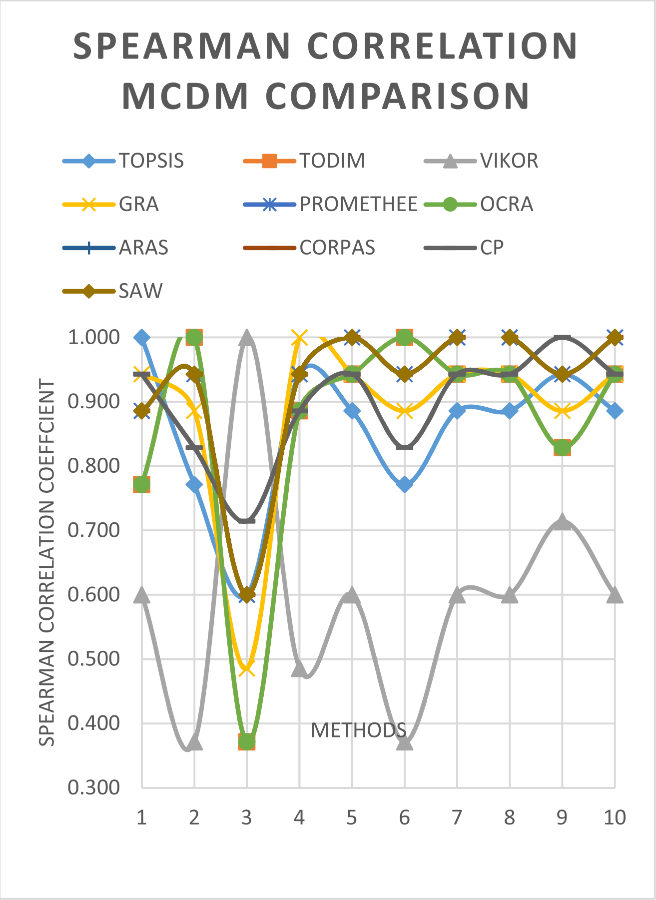


Fig. 17. Spearman correlation coefficient.

Table 5
Kendall's coefficient for the 10 MCDMs.

W	0,866
chi-square	43,31
Degrees of freedom	5
p-value	0,00

Using the weighted rank measure of correlation, $r_{w,}$ Table 6, has been produced. It is evident that when there is a change in the ranking position, a change in the value of the r_w is observed. PROMETHEE, ARAS, CORPAS and SAW's measure of similarity is close to TOPSIS.

Based on the Spearman and $r_{w,}$ the comparison shows the below Table 8. The similarity decreases as the ranking move from the best solution. VIKOR is further from TOPSIS and the measure of similarity is 0,6734 compared to methods like Promethee whose measure is 0.9142 that are close to TOPSIS.

3.3.4. Agreement on the top 3 ranks

In this section, the test based on the agreement of the top 3 ranked alternatives is performed. (1, 2, 3) means the first three ranks match. (1, 2, #) means the first two ranks match, and (#, #, #) means that there is no match. In the rankings of MCDMs for the case study, the following sets matched in their first 3 ranks: TOPSIS and CP; TODIM and OCRA; GRA, PROMETHEE, ARAS, COPRAS and SAW.VIKOR resulted in the maximum number of mismatches because its first three ranked alternatives did not match with any of the other MCDMs.

3.3.5. Ranks matching percentage

The test in this section referred to the number of ranks matched (1–6) expressed as the percentage of the number of alternatives. The only

Table 6
Weighted rank measure of correlation, r_w results.

	TOPSIS	TODIM	VIKOR	GRA	PROMETH	OCRA	ARAS	CORPAS	SAW	CP
A1	4	4	2	4	4	4	4	4	4	4
A2	1	1	3	1	1	1	1	1	1	2
A3	3	2	5	3	3	2	3	3	3	3
A4	2	3	1	2	2	3	2	2	2	1
A5	5	5	4	6	5	5	5	5	5	5
A6	6	6	6	5	6	6	6	6	6	6
r_w		0,8775	0,6734	0,9020	0,9142	0,8775	0,9142	0,9142	0,9142	0,8693

methods with 100% matches were between TODIM and OCRA; PROMETHEE, ARAS, COPRAS, and SAW. Even though TOPSIS and CP match in the first three ranks, overall, the match is only 67%. VIKOR and GRA's rankings do not have 100% matches with any of the MCDMs. The highest match percentage for VIKOR was 33% with CP.

3.3.6. Resolving conflicting MCDMs

Different MCDMs resulted in different rankings of alternatives. This was because the decision-process of each method was different. Therefore, the author saw it fit to find a solution where the ranking conflicts can be resolved. One way of resolving conflicting results from the MCDMs was to use group decision making (GDM). In GDM, individual interests are reduced and integrated to form a group preference (Banarjee & Ghosh, 2013). In this case, two rules were used; additive ranking rule and multiplicative ranking rule. In additive ranking rule, the rankings were summed up and an average of the rankings was obtained as the final rank. In multiplicative rankings, a product of the rankings from the MCDMs was raised to the power of 1/MCDMs. The following were the results of the group decision making for case study.

The results obtained from either additive or multiplicative confirms the results of the sensitivity analysis. The results agree with 6 out of the 10 studied MCDMs (Table 7).

4. Proposed model

Using the results obtained, and the literature reviewed, the author developed the MMSM. The testing of the MCDM was not necessary since each MCDM was tested in the result section and the functionality of each have been explained. The result section analysed the MCDMs using different analysis methods, and the MCDM methods that emerged as the best were then used to develop the MMSM.

The case study was used to test the functionality of the MCDMs. Initially, there were variations in the rankings. A sensitivity analysis was performed. The results from the sensitivity analysis helped in increasing confidence, and credibility of the results. Also, the overall risk associated with the decision-making process was thus reduced. It was found by Triantaphyllou (2000) that the most sensitive criterion in decision problem is the one with the highest weight if weight changes are measured in relative terms (%). To relate the rest of the criteria to match the changes of the critical criterion weight, the equation taken from Leoneti [72] was used. However, the author modified the critical criterion percentage from just considering 10% to considering any percentage for a good stability check and to ensure that the sum of the final weights would still equal 1.

Table 7
Group decision making rankings.

Alternatives	Additive ranking		Multiplicative ranking	
A1	3800	4	3732	4
A2	1400	1	1282	1
A3	3000	3	2911	3
A4	1900	2	1761	2
A5	5100	5	5071	5
A6	5800	6	5785	6

Table 8
A comparison between the Spearman correlation and weighted rank measure of correlation, r_w.

	R_w	R_s
TODIM	0,8775	0,7710
VIKOR	0,6734	0,6000
GRA	0,9020	0,9430
PROMETHEE	0,9142	0,8860
OCRA	0,8775	0,7710
ARAS	0,9142	0,8860
CORPAS	0,9142	0,8860
SAW	0,9142	0,8860
CP	0,8693	0,9430

From the sensitivity analysis all 6 methods except TODIM, GRA, CP, and OCRA agreed on the rankings. Initially, the groupings of the MCDMs in the case study results also showed that VIKOR and TOPSIS' ratings were different, and they were grouped differently. However, after the sensitivity analysis, their ratings changed and agreed with the 4 methods to make up 6 agreeing methods. It was then concluded that 6 out of 10 methods are fit to be used in the MCDM.

From the Spearman correlation test, 1 (VIKOR) of the six methods did not correlate with the rest of the methods; and ranked between low and moderate in terms of its agreement with the rest of the methods. TOPSIS did not have a 100% correlation with the remaining 4 (PROMETHEE, ARAS, COPRAS, and SAW) methods but showed a very high correlation which represented a strong relationship and was therefore not be eliminated. In the first three ranks test and the ranks percentage match test, the four remaining method were still in agreement. However, CP and TOPSIS had similar first three ranks. GRA agreed with the four methods. VIKOR still remained an outlier. According to the ranking % match, the 4 methods agreed and had 100% match. GRA, TODIM, OCRA and CP had a 67% agreement. TOPSIS and VIKOR's percentage agreement with the 4 were low at 33% and 17% respectively.

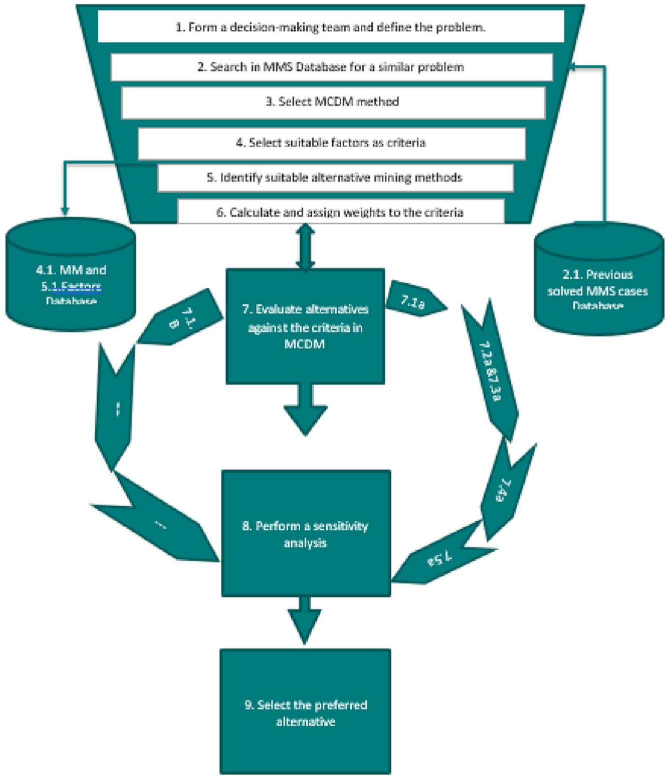
From the descriptive analysis, the author recommended PROMETHEE, TOPSIS, and TODIM as the best and most applicable in the mining industry. The following conclusions were made. CP is a simplified approach of VIKOR and TOPSIS. OCRA is a simplified version of TODIM. COPRAS, ARAS, and SAW are simplified versions of PROMETHEE. GRA's lack of a mathematical foundation, explanation, and the proven fact that it does not match with any MCDM's rankings makes it impossible to be included in the model.

Therefore, the methods to be included in the model are TOPSIS, PROMETHEE, and TODIM. This does not mean these methods do not have shortcomings, however, they are less risky to use. It must be noted that their shortcomings will form part of future studies. For example, in

PROMETHEE, there are thresholds that must be used as inputs, and they form part of the user's preferences/choice. That makes the method subjective and difficult in that an inexperienced user may not know what or how to choose the thresholds. With TODIM, the author's experience in using the method was that the method was prone to errors because of the complexity in computations. On the other side, TOPSIS had rank reversal problems. So, all these methods still have shortcomings even though they were suggested for use.

4.1. Development process of the MMSM

The model has been developed and is shown below:



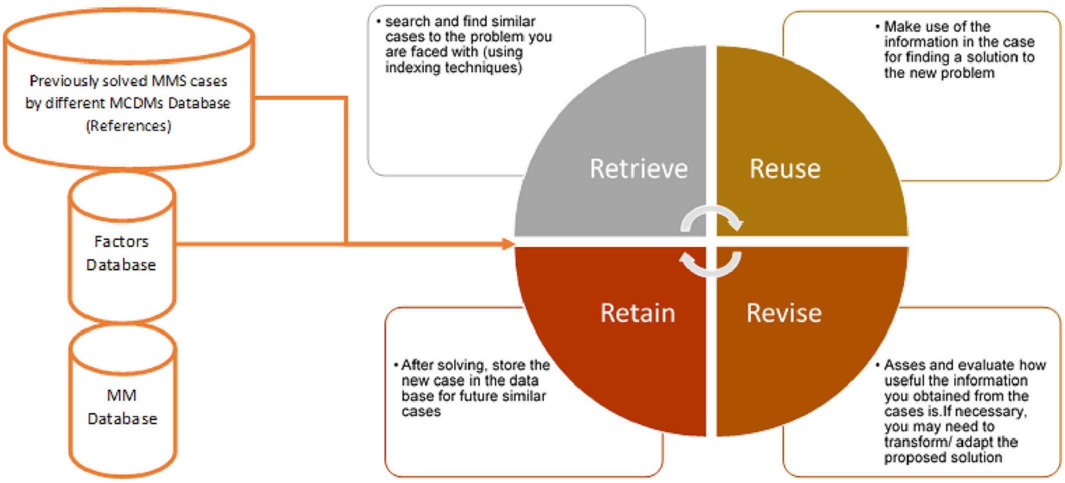
Each step of the model is broken down below:

1 Form a decision-making team and define the problem.

The first thing the users of the model must do is to define the problem at hand. The users must define the mine under investigation, its geological and any other information that will be critical when selecting a mining method. An ill-structured problem may prove difficult to solve. When the problem has been sufficiently defined, the users must identify the decision goal. It was recommended that a neutral third party facilitates the decision-process. Key players such as geologists, mine planners, engineers, and other relevant parties must be brought together for the decision to be made.

2 Search in MMS Database for a similar problem.

The approach is of case-based reasoning (CBR); where the user can retrieve, re-use, revise and then retain the information for future use. The user can always search within the database for a similar problem before selecting a MCDM. The author recommends PROMETHEE, TOPSIS, and TODIM to be used. However, depending on the nature of the problem, any other MCDM can be used.



The reason the author suggested the CBR approach on the developed MMSM was because CBR offers a platform for continuous learning as each solved problem is added to the data base. Its solution-finding capabilities are high because the user can always find a similar problem within the database and that saves time.

Problems that are difficult to solve can always be compared to similar ones in the database to reach a solution.

3 Select MCDM method

After the problems in the data base have been searched and compared to the defined problem, a MCDM must be selected. It was recommended that TODIM, PROMETHHE, or TOPSIS be used for the MMS problems. The background principles of selecting an alternative when using MCDMs are similar. A Matrix is constructed based on the preferences of the decision makers. Weights are determined, and the normalised matrix is calculated. The user must take note of the type of criteria when selecting the criterion in step 4 of the developed model. The correct formulas must be used for the type (benefit or cost criteria) of criteria. The higher the value, the more an alternative is preferred.

4 Select suitable factors as criteria

From the factors and mining method database, the user can then select suitable criteria and alternatives respectively. The CBR approach is still utilised for both mining method and factors data bases. Even though factors are many and different, the discussed factors can be grouped under these categories:

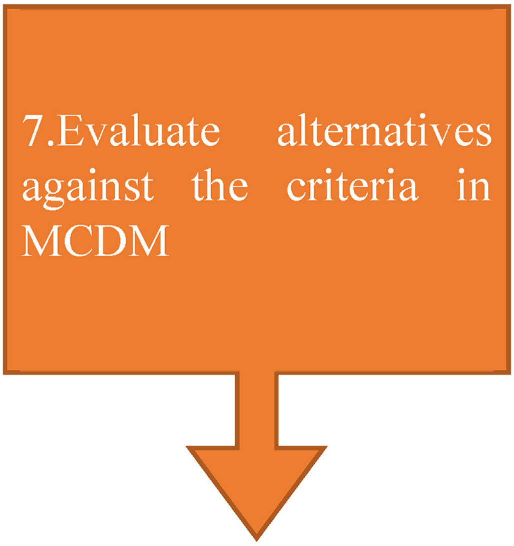
- Geological and hydrological factors
- Geotechnical factors
- Environmental factors
- Economic factors
- Technological factors
- Spatial characteristics of the investigated deposit.

So, as more factors are added into the decision-process, they can be stored under the aforementioned categories for ease of searching in the future. More categories can be added should the need arise. The same applies for the mining methods. This MMSM does not limit the user to the described mining methods only, and that was an added advantage compared to the traditional techniques of MMS.

5 Identify suitable alternative mining methods

6 Calculate and assign weights to the criteria

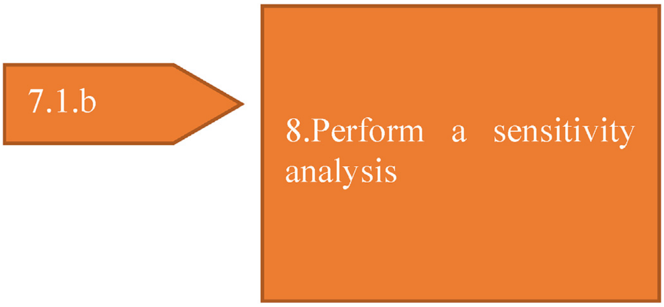
To perform the evaluation process, weights must be assigned to the criteria. In the literature review, AHP was introduced as one of the MCDMs. However, AHP was used for weight assigning in this study. In AHP, the decision makers construct a pairwise comparison matrix, and find the relative priorities of the criteria. The calculation of weights was a subjective process; fortunately, AHP allows for a consistency ratio to be calculated for accuracy. Should the weight-assigning process be found to be inconsistent, the decision-makers need to evaluate their priority ratings and make necessary changes.



7 Evaluate alternatives against the criteria in MCDM

In step 7, the alternatives are then evaluated against the criteria. Rankings will be derived from the evaluations. The are two routes after obtaining the rankings; the user can perform a statistical analysis or take the rankings as the final decision. In the statistical analysis, three tests are performed; Spearman correlation (7.1.a), agreement of the first 3 ranks (7.2.a), and rank match percentages (7.3.a).

The spearman correlation determines the strength of the relationships of the MCDMs by calculating the similarity between two set of rankings. The second test is based on the agreement of the top 3 ranked alternatives. (1, 2, 3) means the first three ranks match; (1, 2, #) means the first two ranks match, and (#, #, #) means that there is no match. The last test refers to the number of ranks matched expressed as % of the no. Of alternatives. This route is applicable if more than 1 MCDM were used to obtain the rankings.



A Kendall coefficient is then calculated in 7.5a to check for the agreement in the MCDMs. If the coefficient equal 1, then the process is ended, and the final rankings will then be derived based on all the tests. If the coefficient is less than 1, then a conflict resolution can be applied. In conflict resolution, additive and multiplicative rankings are determined, and the rankings are obtained. A sensitivity analysis is then performed, then the final decision is taken.

9.Select the preferred alternative

8 Perform a sensitivity analysis

Alternatively, after the evaluations of the alternative against the criteria in step 7, a sensitivity analysis can be performed (8) directly without doing a statistical analysis. In sensitivity analysis, weights are reassigned based on the agreement of the decision-makers. Other scenarios based on the controllable variables within each MCDM can be created in the process to confirm the results. For example; in TODIM, other than the weights, the attenuation factor and the choice of the reference criterion can be adjusted.

9 Select the preferred alternative

After observing the effects of the changes on the final rankings through a sensitivity analysis, the process comes to an end. In step 9, a decision is reached. A preferred alternative will be taken as the mining method to be used in the specific mine. The users can always confirm the final rankings with experiential knowledge. Some of the advantages of the developed MMSM.

- The MMSM allows the user freedom to choose MCDM; so, the user is not limited to a single method with its shortcomings.
- The user can easily compare the results after using multiple MCDMs.
- The information used can be stored into the database for future use.
- There is no limitation on the number of criteria and alternatives that can be used as inputs in the system.
- The procedure provides a good platform for future developments into an app-based format or software
- The MMSM can be used even for other commodities outside coal mining.

The disadvantage of the MMSM:

- Users need to understand the theoretical background of the MCDMs before making a choice on which one to use for the decision process. However, in future studies the author intends to develop an application-based procedure so that the functionality of each MCDM may be built in and the user will just insert the evaluation performance of alternatives against criteria to obtain the final rankings.

5. Conclusions

The aim of project was to develop a mining method selection model through a detailed assessment of MCDMs. This was because attempts to build a systematic approach to mining method selection have been made in the past. However, there has been limitation from the traditional approaches presented. Therefore, objectives were set to achieve the aim of the project. The main aim was to study in detail the MCDMs that were previously used in decision-making in and outside the mining industry.

Ten MCDMs- TOPSIS, TODIM, VIKOR, GRA, PROMETHEE, OCRA, ARAS, COPRAS, SAW, and CP were studied in detail; their application, functionality, advantages and disadvantages. ELECTRE and HPV were also introduced. However, they could not be studied in detail and are not recommended. ELECTRE fails to sort the alternatives ratings in ranks. While HPV cannot be implemented in the absence of voters. AHP was introduced as well. However, in this study, it was only used for weight elicitation since the introduced MCDM cannot assign weights.

In the results section, the MCDMs were analysed following a descriptive and a statistical analysis. In the descriptive analysis, a set of criteria was introduced and used to evaluate the MCDMs. In the statistical analysis, tools such as sensitivity analysis, spearman correlation, and Kendall's coefficient were used. Two ways (additive, and multiplicative) of resolving conflict in the ranks were introduced and the final ranking of the combined MCDM was obtained. After such a comprehensive analysis, it was found that PROMETHEE, TOPSIS, and TODIM stand out and can be successfully used in the selection of mining method in the coal mining industry. The other methods (OCRA, ARAS, CP, SAW, and COPRAS) have been found to be simplified approaches of the aforementioned methods. VIKOR's rankings were outlying and it was concluded that it was not a suitable method for MMS. GRA's conclusion based on the literature view is that there is no founded mathematical explanation behind its existence because there remain may unanswered questions about its foundations.

The last section of the project presented a MMSM procedure of choosing a mining method. The approach has been simplified and can be implemented by any user given that the background information presented in this research is understood.

6. Recommendations

The user must understand the discussed MCDMs and must acknowledge that the model developed is a simplified approach and can only be useful if there is an understanding of the theoretical background behind the MCDMs. Fit-for-purpose criteria and alternatives may be added in the database for the specific problem being investigated, should the factors and methods in the results section be insufficient. For effective and reliable results, at least 2 of the MCDMs can be used in the MMSM to observe and record any variations in the final ranks. In MMSM, A problem or an objective must be defined appropriately before the MMSM is used to avoid inconsistency in the final rankings.

7. Suggestions for further work

A limitation in the study is that only AHP was used to elicit weights. This means that a room for other methods with capabilities to elicit and calculate weights is left. Therefore, a future study could be to investigate other weight elicitation methods and their influence on the final ranks.

One of the limitations in the study was that some of the articles, and journals reviewed were a translation from other languages to English. Therefore, in future, more articles from other languages can also be reviewed for more information on MCDMs. In future studies, algorithms for selection of a suitable MCDM in the MMSM can be developed so that once the problem has been defined and structured, the user may not struggle with knowing which method to use amongst the suggested. Since all the MCDMs have their unique strengths ad shortcomings, it is suggested that a group-decision making approach be further refined. A sensitivity analysis approach may need to be refined or specifically developed for the MMSM. To develop an application-based procedure so that the functionality of each MCDM may be built in and the user will just insert the evaluation performance of alternatives against criteria to obtain the final rankings.

Declaration of competing interest

My own work.

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