Decision Making and Analysis
https://ojs.luminescience.cn/DMA

LUMINESCIENCE
https://luminescience.cn

Original Research

A comprehensive approach to selecting mine transportation system using AHP and FUZZY-TOPSIS

Farhad Samimi Namin*[1], Hasan Ghasemzadeh[2], Ali Moghaddam Aghajari[3]

[1] Associate professor of mining engineering, University of Zanjan, Zanjan, Iran
[2] PhD Candidate of mining engineering, Amirkabir University of Technology, Tehran, Iran
[3] MSc in mining engineering, University of Zanjan, Zanjan, Iran

*Correspondence to: f.samiminamin@znu.ac.ir

Abstract: Mine transportation approximately accounts for more than half of operating costs. Therefore selection of the appropriate mine transportation system by considering the effective criteria has become an important issue in mining engineering. A hybrid decision support system based on Analytical Hierarchy Process (AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) was proposed to assess criteria and alternatives for balancing haulage distance, continuity, flexibility and reliability, which could provide the suitable balance between different goals, such as costs and safety. An application of this approach is carried out through the Sungun copper mine as case study. For this purpose, the production capacity, medium and short-term production plan, conditions of mining benches and ramps and future development plans collected from chosen mine located at the East Azerbaijan Province, Iran. This research has been studied comprehensively in terms of technical, economic, environmental, society, site information, geological and geo-mechanically criteria. More than 170 criteria were identified and classified under six main categories. To select the mine transportation system, the importance of each criteria is first measured relative to each other, then the importance of each option is evaluated for each criteria and were filtered to 55 items. The proposed model is based on the combination of the AHP and fuzzy TOPSIS. The hybrid model has advantages such as the possibility of using paired comparison and considering uncertainty. Finally, the in-pit crushing and conveying is selected as the best alternative, the truck-front shovel and truck-backhoe system are in the next priorities, respectively 45.2, 28.4 and 26.4%. In summary, from the results of the research, it can be mentioned to present the effective criteria in the selection of the transport system of open pit mines, to calculate their weight, to provide a framework for the selection of the transport system of open pit mines by considering the uncertainties.

Keywords: Decision support system, Multi criteria decision making, Mine transportation system, Sungun copper mine

Introduction

Surface mining operations include extraction of the minerals located at the surface or near-surface. These activities usually take place using mechanical and non-mechanical mining operations such as open pit, strip, quarry, auger, dredging or dredge mining, hydraulic, borehole and In-situ leaching. Nowadays, more than 90% of the minerals are extracted by these methods [1]. Strip mining and open pit mining methods are more significant

Received: Apr.18, 2023; Revised: Jun.25, 2023; Accepted: Jul.05, 2023; Published: Jul.21, 2023

DOI: https://doi.org/10.55976/dma.12023117323-39

than other methods, since they are large scale methods [2]. The main production operations involve drilling, blasting, loading and hauling. One of the most cost cases in mining cycle is depend on ore and waste transportations' cost. These costs may be approximately 50–60% of the total operating costs of open-pit mine. The combination of truck and shovel is used in more than 80% of this surface mining as the major system [2]. The number, capacity and type of equipment have a great impact on transportation efficiency. Choosing the number, capacity and type of machines is one of the main decisions in open pit mines that affect the economics of mining operations. A wrong choice, in addition to make mining operations uneconomical and reduce efficiency, can cause problems with fleet management. The process of selecting and determining mining machinery is not a simple process and many criteria affect this choice, which makes this decision a complex multi-criteria decision. The process of selecting and determining mining machinery is done based on operation research methods, simulation and scenario analysis [3,4]. Furthermore various models and methods have been used to select the transportation system, including the use of fuzzy logic, fuzzy multi-criteria decision-making methods, genetic algorithm, hierarchical analysis method, fuzzy TOPSIS method and VIKOR method [5-10]. In the past, surface mines were almost less deep than 400 m; nowadays, these mines may be more than 1000 m deep such as Chuquicamata mine in Chile has a depth of approximately 1100 m [11]. Hence, increasing depth is made haulage distances increase and the number of loads per truck decreases. Consequently, tire, fuel, and depreciation costs per ton increase. Due to these factors, open pit mining at great high depth using truck-front shovel (TS) and backhoe (TB) systems faces some problems. In-Pit Crushing and Conveying (IPCC) systems have been identified in the mining industry for many decades [12]. The first idea of IPCC was presented in 1956 in Germany. Today, the high reliability and cost efficiency of IPCC make it more interesting than conventional truck-shovel operation, especially in longer life projects with high production rates and lengthy transportation distances [13].

So far, many studies have been conducted with sometimes contradictory answers on the selection of the transport fleet, which are also given in the following sections. In this study, it has been tried to consider the important criteria influencing the choice of transportation system based on literature. The purpose of this study is to compare the transportation systems and select the appropriate transportation system in Sungun copper open pit mine. Improper choice of transport system can jeopardize the economical aspect of a mine, or at least cause part of the mine's extractable reserves to convert to non-extractable storage. Having a proper transportation system in the mine to reduce both costs and detrimental environmental impact is of particular importance. In this study, the main purpose is to reduce transportation costs and to consider technical, economical, social, environmental, site and geological issues by selecting the appropriate transportation option. To do this paper indicators, such as technical and engineering, economic, environmental, social, mining site characteristics, geology and geo-mechanics were considered. The transportation system alternatives under consideration are truck - hydraulic shovel, truck - mechanical shovel and In-pit crushing and conveying, which in the following sections, the advantages and disadvantages of each options are classified and using the opinion of mining engineers according to different scoring indicators, and finally the appropriate transportation system will be introduced.

To investigate *the technical and engineering* criteria of index such as remaining life of the mine, haulage distance, balancing haulage distance, transport continuity, flexibility of equipment, reliability, transportation capacity and production rate, *the economic* criteria such as capital and operation cost, payback period, rate of investment return and price uncertainty, *the environmental* criteria for example gas, dust, noise, safety, energy, fuel consumption and possible future uses, *the society* for instance maintaining the job, skill level and experience of engineers and access to skilled labor, the site situation for case mining policy and management, mine closure and reclamation plans, mining site location and flexibility and operational capacity and in the *geological and geo-mechanically* is mineral reserves, depth, grade distribution and final pit slope.

The aim of this paper is to present a model for selection of open pit mines transportation system. Some of novelty of proposed model include: flexibility, robustness, transparency, sensitivity analysis and applicability. Model can handle both quantitative and qualitative criteria. It is robust to change in input data and can handle uncertain and fuzzy information. It can be applied to various open pit mine. In addition, a comprehensive study has been done on the parameters affecting the open pit mines transport system selection, which supports the proposed model. In this research, in addition to economical and technical criteria, other parameters have been discussed.

Comparison of transportation fleets

Considering the economic and technical aspects, trucks are very flexible and manageable means at the beginning of the mine's projects. The economical flexibility of the trucks is due to the fact that at the start of the project's lifetime. When haulage distance is low, the process of extraction can happen with a low number of trucks. The primary destinations of the extracted minerals from the work faces (for example, primary crushers, stock piles, waste dumps) are very close to the center of the pit. Consequently, the project can set out with minimum capacity. Likewise, by regulating the number of the working trucks, the rate of the production can easily be changed.

The use of trucks is perfect in the following circumstances:
1. when the production rate is more than the capacity of

the excavator or 2. When the ore should be blended from multiple work faces for mill feeder. 3. When the ideal is to increase the flexibility of haulage from continually advancing work faces. 4. When scheduled production requires the sufficient maintenance of the ore faces while stripping. 5. Trucks can also accept coarse-grained material directly from the shovels. These reasons make the use of trucks at the beginning of the project broader and more appropriate than IPCC [14]. The distance of material transportation increases as the mine extends and develops. Increasing the carrying distance reduces truck productivity severely [14]. So, the number of trucks used to achieve a normal extraction rate in the mine must increase. Increasing the number of trucks not only increases the need for tires and fuel, but also requires more people, haul road size, maintenance, and more service stations [1]. All of this exponentially increases transportation costs by more than fifty percent of operating costs, which makes truck use less cost-effective [15]. These issues usually occur at the same time with the strip ratio increase, the start of a new phase or the expansion of the phase in the current project, and also reduce the useful life of the primary fleet of trucks. Answering the transportation problem has become a controversial affair, especially with regard to the future open pit deep mines. Accessing the reserves that are far into the ground and out of the reach requires the removal of large amounts of overburden and their grade is less than that of the existing reserves. Therefore, the total cost of mining will be increased [14]. Overall, these factors exert a great deal of pressure on costs, which result in lower profits and consequently lower proportions of mineral resources with extractable reserves.

Solutions proposed to overcome this problem include the addition of advanced haul trucks, the use of automatic trucks, transferring to underground mining, and the installation of an IPCC system [14].

To investigate the importance of indicators in the selection of the type of transport fleet, the expert group was asked with a variety of work records in this research. According to the engineer's answers, the main indicators were ranked. In the following, a study has been made on the advantages and disadvantages of the IPCC compared to the conventional (Truck-Front shovel) TS or (Truck-Backhoe shovel) TB system. The IPCC, Truck-front shovel and Truck-backhoe as an alternatives were defined based on the conditions of Sungun mine and available technologies based on the opinion of open pit mining experts and copper mining companies.

Technical/geological/geo-mechanically comparison

Mine life, production rate and transportation distance, deposit shape, existing geological status as well as system design can greatly affect the efficiency of a transportation system. Other influential factors in choosing the type of transport fleet are operational flexibility and stripping ratio. In general, in the IPCC system, the overall operational flexibility of mining activities is reduced. Transport trucks, on the other hand, are easily scaled to increase or decrease production, while IPCC system have large changes in production rate. The performance of the IPCC depends significantly on work skills, especially in the case of a fully mobile system in which the truck system may be completely eliminated. Workers often refuse to accept new and unfamiliar equipment. Not only workers but also field engineers may have a difficulty coping with the new system [14]. If the changes happen slowly, the severity of these problems will be less. If so, semi-moving types would offer a more sensible option. Semi-mobile systems can be easily integrated with the existing truck transport system. In fact, the introduction of a new transportation system should not disrupt the existing procedure and change should be smooth. Conveyors are less labor intensive both in terms of operation and serviceability [16]. The volume of repair operations as well as the consumption of spare and worn parts is much less than what happens in the truck system. Therefore, conveyors need smaller store inventory. The operation of the conveyor does not depend on the condition of the transport route or does not require very extensive and costly road construction and maintenance operations. Conveyors usually offer longer service life and power. They are almost insensitive to local weather conditions such as fog, rain and snow [17].

Another key problem with IPCC is system availability. In an IPCC system, the subsystems are connected in sequence, which means that shutting down every piece of equipment in the system shuts down the entire system. In fact, any planned or unplanned breakdown can have a negative impact on availability. Truck-Front shovel systems (TS), on the other hand, provide more flexibility because they are composed of discrete elements.

Economic comparison

According to the expert group opinion, the first and most important economic indicator is Net Present Value (NPV) of the two systems over the mine life is shown in Figure 1.

The equation defines NPV (Equation 1) as a function of the annual cash flow (CF), mine life (n) and discount rate (d).

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+d)^t} \quad (1)$$

As shown in Equation 2, CF is also a function of revenue (I), operation cost (OC), depreciation cost (DC) and tax rate (TR) as well as annual capital cost (CC). In this equation, the t index is year counter.

$$CF_t = (I_t - OC_t)(1-TR) + TR \times DC_t - CC_t \quad (2)$$

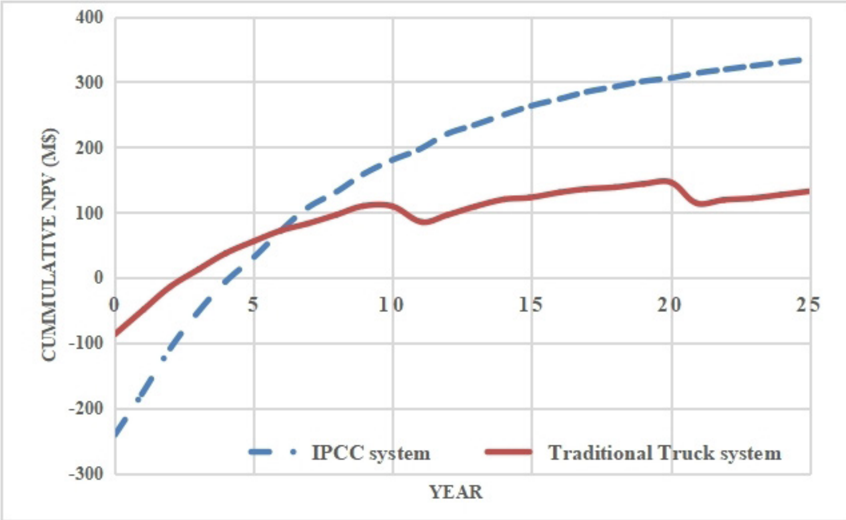


Figure 1. Typical economic comparison of IPCC and Truck-shovel systems [18]

The IPCC system requires more initial capital than the truck system, but the cost depends on the size of the mining operation. Digging dipper and larger pits using an ordinary TS system. Since such a pit requires more trucks. It will be more expensive than the IPCC installation. For a pit with a depth of 200 m, the cost may be approximately the same for both systems.

It is not correct to pay attention only to the investment cost of IPC in comparison with TS, and other economic criteria should also be considered. The accessories of the IPCC are usually replaced by 20 to 25 years (150,000 hours), while the economic exchange age for the trucks is about 45,000 to 60,000 hours of operation, equivalent to nearly 7 to 10 years [18]. The ordinary capital cost for the IPCC is in the range of 180 to 250 million US dollars. For a 360-ton truck, the cost is about 5 million dollars [1]. This means that for a 25-year project, two truck fleets must be replaced. If the trucks replacement is considered to be worn out because of wear, it should be noted that the conveyor system needs less capital cost during the mine lifetime. The useful life of equipment also affects the cost of depreciation and cash flow (see Equation 2) [14]. Other parameters also affect the NPV, for example, the revenue of each systems can be mentioned.

Another effective parameter in the net present value is the operating cost. As operations in the open pit progress, the length and transportation cost of conveyors and trucks will increase. But the rate of cost increase is not the same in both fleets (Figure 1). As shown in Figure 1, for a period of 20 years, the NPV of the IPCC system is twice that of the NPV of a typical TS system. On the other hand, as the distance increases, more trucks and more technical support are needed for the transportation of tailings and ore, thus increasing the cost of road maintenance, fuel, tires and depreciation per ton. However, increasing the distance will increase the maintenance of the conveyor, increase electricity costs and discount rates in the conveyor system. Overall, the conveyor system is economically better for long life, high production speed and high transport distance operation [19].

Social, safety and environmental comparison

Each truck needs five to seven people to work and maintain [1]. If the conveyor system is used, the number of trucks will be reduced. As a result, more than 100 jobs will be lost. On the negative side, job losses may lead to the migration of indigenous peoples and an increase in crime. On the plus side, reducing the number of trucks in open pit mines can also reduce the number of accidents. For example, data from the Sishan iron ore mine in South Africa show that more than 90% of fatal accidents occur due to trucks. Reducing the number of trucks reduces the volume of traffic and consequently reduces losses. In other words, less traffic not only saves fuel, but can also save lives. Trucks consume only 40% of their energy during each waste and ore handling cycle during the truck cycle. The remaining 60% is needed to move the weight of the truck. In the case of conveyor transport, in other words, more than 70% of the energy is spent on tailings and less than 30% is wasted [20]. Life cycle analysis of the IPCC and TS systems shows that if all the energy used by the truck is based on fossil fuels and all the energy used on the conveyor is based on natural gas. In this case, the energy consumption and greenhouse gases for the conveyor system are less than TS [21, 22].

In choosing a transportation system, there is a close relationship between various influential aspects, including technical, economic, and environmental. However, each has its advantages and disadvantages.

In selecting the transport fleet in open pit mining, there is a close relationship between various influential aspects, including technical, economic, environmental, and social and characteristics of the mining site, geology and geotechnics. However, each has advantages for mining engineers. Therefore, 178 criteria were considered for the selection of the shipping fleet. Among the important factors seen in this research, we can mention the life of the mine, the final slope of the mine and so on.

Methodology

Fuzzy method

In many cases, decision making is associated with uncertainty and precise values cannot be used. One suitable answer is the fuzzy ideal similarity method. Problem solving steps by similarity to the fuzzy ideal option in a multi-criteria decision problem with n criteria and m options include 1- forming a decision matrix, 2- determining the criteria weight matrix, 3- scaling the fuzzy decision matrix, 4- Determining weighted fuzzy decision matrices is 5- Finding fuzzy ideal solution and fuzzy counter-ideal solution and 6- Calculating the distance from fuzzy ideal and counter-ideal solution [23, 24].

Fuzzy logic was first introduced in 1965. This method can take into account uncertainties and solve problems where there are no definite boundaries and exact values. A language variable is a variable whose values are not numbers, but words or sentences in a natural language such as very strong, strong, medium, weak, and very weak. The concept of linguistic variables provides a tool for the approximate description of phenomena that are too complex or poorly defined and indescribable [25, 26].

A fuzzy set is a group of objects with a continuum of membership degrees. This set is marked with a membership function and each object is assigned a membership rank in the range of zero to one. That is, a fuzzy number belongs to the closed range 0 and 1, in which the number 1 indicates full membership and the number 0 indicates non-membership. In contrast, explicit sets allow only 0 or 1. Thus fuzzy sets are the general form of explicit sets. There are several types of fuzzy numbers that can be used depending on the situation. In practice, Triangular Fuzzy Number (TFN) is the most interesting because of its computational and visual simplicity.

As shown in Figure 2, a TFN can be distinct as a triplet $\widetilde{M}$ = (l, m, u) or $\widetilde{M} = (\frac{1}{m}, \frac{m}{u})$, where l, m, and u respectively indicate the lowest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

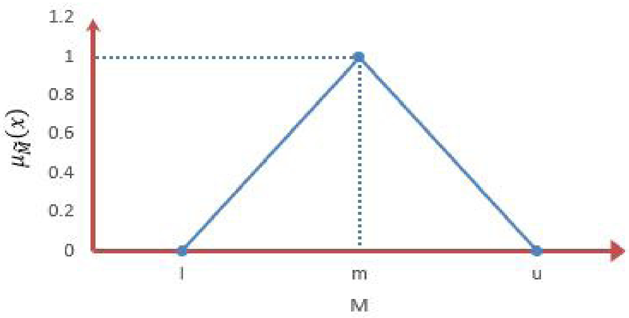


Figure 2. Schematic view of a triangular fuzzy number.

Each TFN, $\widetilde{M}$ has linear representations on its left and right sides such that its membership function, $\mu_{\widetilde{M}}(x)$ can be defined as:

$$u_{\tilde{M}}(x) = \begin{cases} (x-l)/(m-l) & if\ x \le m \\ (u-x)/(u-m) & if\ m \le x \le u \\ 0 & otherwise \end{cases} \quad (3)$$

Where, l, m, and u mean the lowest possible value, the most promising value, and the largest possible value, respectively as shown in Figure 2. A fuzzy number $\widetilde{M}$ is a curved normalized fuzzy set of the real line R → [0, 1] such that some researches [27, 28].

TOPSIS method

TOPSIS as an applicable Multi-Criteria Decision-Making (MCDM) approach was first suggested by Hwang and Yoon [29] and then extended by Chen et. al [23]. It is an applied and suitable technique for ranking and selection of a number of externally determined alternatives through distance measures [30].

The basic theory of this method is that the selected alternative should have the shortest distance from the positive ideal solution (the best possible status) and the farthest distance from the negative ideal solution (the worst possible status) [31].

The TOPSIS method is created on six computation steps. The first step is the gathering of the performances of the alternatives on the different criteria. In the second step, these performances need to be normalized. The normalized scores are then weighted and after determination of the positive and negative ideal solutions, the distances to the ideal and anti-ideal points are calculated. Finally, the closeness is given by the ratio of these relative distances [29-31].

The classical TOPSIS method operates in a deterministic context and evaluation process which involves judgments exactly defined and crisp values. However, under some conditions crisp values are insufficient to model real world decision problems, because actual problems usually contain uncertain, indefinite and subjective data, which make the decision-making process more complex and challenging. On the other hand, human choice and preferences are often unclear and cannot be estimated with strict numerical values. Therefore, the fuzzy TOPSIS method is proposed where the consequence and likelihood are evaluated by linguistic variables characterized by fuzzy numbers to address such uncertainty and ambiguity in the traditional TOPSIS [32].

Fuzzy TOPSIS method

One of the powerful mathematical tools for the management of the existing uncertainty in decision making is fuzzy logic. Conquering the uncertainty of qualitative data, the fuzzy TOPSIS method may accomplish the ranking process. The mathematical concept of fuzzy TOPSIS recommended by Chen can be abridged as follows [24].

The fuzzy numbers should be calculated corresponding to each linguistic variable subsequent to the identification of the consequence and likelihood. Before analyzing and modeling, the data must be normalized to be reserved in the set range of 0 and +1. The normalization of fuzzy numbers is accomplished by the use of linear scale transformation for the conversion of the different units into a similar unit [32].

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right) \qquad \forall j^+$$
$$u_j^+ = \max_i u_{ij} \tag{4}$$

$$\tilde{r}_{ij} = \left(\frac{u_j^-}{l_{ij}}, \frac{u_j^-}{m_{ij}}, \frac{u_j^-}{u_{ij}}\right) \qquad \forall j^-$$
$$l_j^- = \min_i l_{ij} \tag{5}$$

For benefit criteria the larger $\tilde{r}_{ij}$ has the better preference; however, for the cost criteria the smaller $\tilde{r}_{ij}$ has the better preference. Therefore, the normalized fuzzy decision matrix can be gained as:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{n\times m} \tag{6}$$

$\tilde{V}_{ij}$ is the weighted normalized value calculated by the normalized fuzzy decision matrix $\tilde{r}_{ij}$ with multiplying the weights ($\tilde{w}_j$) of criteria.

The weighted normalized decision matrix $\tilde{V}$ for each criterion is calculated through the next relation:

$$\tilde{V} = [\tilde{w}_j\tilde{r}_{ij}] = [\tilde{v}_{ij}]_{n\times j}$$
$$i = 1,2, \dots, m, j = 1,2, \dots, n \tag{7}$$

In this matrix, each element $\tilde{V}_{ij}$ is a fuzzy normalized number which ranges within the closed interval [0,1]. Then fuzzy negative ideal solution (A^-) and the fuzzy positive ideal solution (A^+) are obtained as:

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \dots, \tilde{v}_n^-)$$
$$= \left\{\min_i v_{ij} \middle| (i = 1,2, \dots, m;\ j = 1,2, \dots, n)\right\} \tag{8}$$

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \tilde{v}_3^+, \cdots, \tilde{v}_n^+)$$
$$= \left\{\max_i v_{ij} \middle| (i = 1,2, \dots, m;\ j = 1,2, \dots, n)\right\} \tag{9}$$

The distance of each alternative from A^- and A^+ are calculated as:

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \tag{10}$$

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+) \tag{11}$$

Where, d_i^+ and d_i^- are the primary and secondary distant measures, respectively. The distance measurement between two TFNs of (I_1, m_1,u_1) and (I_2, m_2, u_2), can be calculated by the vertex method as follows:

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \tag{12}$$

Finally, ranking of the alternatives can be achieved using nearness coefficient (C_i) index in decreasing order. The better performance of the alternatives has a direct relation with the size of the index value. The C_i considers the d_i^+ and d_i^- at the same time. The relative C_i index of each alternative with respect to the fuzzy positive ideal solution is obtained as:

$$C_i = \frac{d_i^-}{(d_i^+ + d_i^-)}$$
$$C_i = 1 \ if\ A_i = A^+, C_i = 0 \ if\ A_i = A^- \tag{13}$$

As $d_i^- \geq 0$ and $d_i^+ \geq 0$, then clearly $C_i \in [0,1]$.

AHP method

Established by Saaty (1980), The AHP method was and probably is the most recognized and widely used MADM technique. AHP is a striking decision-making methodology for the determination of the priorities amongst diverse attributes [33, 34].

Weights of the attributes were calculated by means of AHP method. The process of AHP weighting can be summarized as follows; according to decision goal, pairs of elements of the n-attribute framework are compared within pair-wise comparison matrixes A. (Equation 14):

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix}$$

$$a_{iz} = \frac{1}{a_{zi}}, \; a_{ii} = 1 \;\; , \; i \, , z = 1,2, \ldots, n \quad (14)$$

Where, the element a_{iz} can be engaged as the degree of preference of i_{th} attribute over z_{th} attribute; and vice versa. Next, each column of the pair-wise comparison matrix is distributed by the sum of entries of the corresponding column to achieve the normalized comparison matrix. The eigenvalues λ_i of this matrix would provide one with the relative weights of attributes i. Then the obtained relative weight vector is multiplied with the weight coefficients of the elements at the advanced levels, until the top of the hierarchy is achieved. The outcome is the global weight vector W of the attributes and can be shown as (Equation 15):

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \end{bmatrix} \quad (15)$$

AHP also computes an inconsistency index CI to replicate the consistency of decision maker's assessments during the evaluation phase. The inconsistency index in pair-wise comparison matrixes could be calculated with the (Equation 16):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (16)$$

Where, λ_{max} is highest eigenvalue of the pair-wise comparison matrix. The closer the consistency index is to zero, the greater the consistency, so the relevant index should be lower than 0.1 to accept the AHP results as consistent.

The normalized decision matrix

Normalized rating for each element in the decision matrix was determined. The normalized value can be determined as:

$$r_{ji} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{j} f_{ij}^2}} \, , \qquad \text{For benefit attributes}$$

$$i = 1, \ldots, n \, ; \quad j = 1, \ldots, J$$

$$r_{ji} = \frac{1/f_{ij}}{\sqrt{\sum_{j=1}^{j} 1/f_{ij}^2}} \, , \qquad \text{For cost attributes}$$

$$i = 1, \ldots, n \, ; \quad j = 1, \ldots, J \quad (17)$$

Weighted normalized decision matrix, the positive and negative ideal solutions The weighted normalized ratings (value v_{ji}) calculate by (Equation 18):

$$v_{ji} = r_{ji} \times w_i = \begin{pmatrix} r_{11}w_1 & \cdots & r_{1n}w_n \\ \vdots & \ddots & \vdots \\ r_{J1}w_1 & \cdots & r_{Jn}w_n \end{pmatrix} ,$$

$$i = 1, \ldots, n \, ; \quad j = 1, \ldots, J \quad (18)$$

Then the positive ideal (A^+) and negative ideal (A^-) solutions are identified. The A^+ and A^- are described in terms of the weighted normalized values, as shown in (19) and (20), respectively:

$$A^+ = (v_1^+, v_2^+, v_3^+, \ldots, v_n^+) = \left\{ \left(\max_j v_{ji} \middle| i \in I' \right), \left(\min_j v_{ji} \middle| i \in I'' \right) \right\} \quad (19)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \ldots, \tilde{v}_n^-) = \left\{ \left(\min_j v_{ji} \middle| i \in I' \right), \left(\max_j v_{ji} \middle| i \in I'' \right) \right\} \quad (20)$$

Where, I' is correlated with benefit attributes, and I" is linked with cost attributes.

The separation measures and relative closeness.

The departure among the alternatives measure using the n-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution, D_j^+, is given by (Equation 21):

$$D_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2} \quad j = 1, \ldots, J \quad (21)$$

Similarly, the separation from the negative ideal solution, D_j^-, is given by (Equation 22):

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \quad j = 1, \ldots, J \quad (22)$$

Then the relative closeness C_j of each alternative is calculated. The relative closeness of the alternative j with regard to A^+ is defined as:

$$Cj = \frac{D_j^-}{(D_j^+ - D_j^-)} \qquad j = 1, \ldots, J \quad (23)$$

Application of the methodology: case study

In the first step, which is the implementation of the transportation system selection, it is necessary to determine the structure of the decision-making process. Noting that several factors must be considered to select the appropriate transportation option, the study on the choice of transportation option is very important and many factors are effective in making a choice between all of the transportation options. In order to choose a transportation system, it is necessary to recognize the effective criteria in this field so that a suitable transportation option can be introduced according to the effective transportation criteria in the mine. In countries with limited resources and facilities, setting and recognizing criteria becomes even more important.

In this research, the possible transportation options in Sungun copper mine are first investigated. Then, using the opinion of mining experts, the criteria affecting the introduction of a suitable transportation system with observance of economic, technical, social, site, environmental and geological issues are introduced from the selected alternative options in the mine. Due to the large number of trucking machines in the Sungun copper mine and their incompatibility and compatibility with loading machines, as well as increasing the life of the mine and lengthening the load-bearing routes and ramps, the time of material transportation increases and in this case the freight system may not work with trucks alone, consequently, given the mining conditions and competition in the global market, new transportation systems should be considered, including the use of an in-pit crusher and a conveyor system with a truck-carrying system.

Sungun copper mine

The Sungun copper mine is an open pit mine located in northwestern Iran, East Azarbaijan province, 130 km north of Tabriz. This mine is one of the largest copper mines in Iran and is operated by the National Iranian Copper Industries Company (NICICO).

According to exploratory studies and estimates made by Itok Iran Company, the definite reserve is 796 million tons, overburden is equal to 105 million tons, total tailings are 767 million tons, oxide reserves are 6.7 million tons and the amount of ore can be extracted is 388 million tons.

Copper mining operations involve the extraction of copper ore from underground or open-pit mines. The process typically involves several stage, including exploration, development, extraction, processing and refining. The exploration stage involves identifying potential copper deposits through geological surveys, drilling and sampling. Geological analyze the data to determine the quality and quantity of the copper ore. Once a viable deposit is identified, the mining company will begin developing the mine site. This includes constructing access roads, building infrastructure such as power and water supply system and establishing a processing plant. The extraction stage involves extracting the copper ore from the mine. This can be done through mining activities such as drilling, charging and blasting, loading and haulage. The copper ore is extracted, it is crushed into a fine powder in processing stage. The powder is then mixed with water and chemicals to separate the copper from other minerals. This process is called flotation. The final stage involves refining the copper concentrate to produce pure copper. This is done through a process called smelting, which involves heating the concentrate in furnace with oxygen and fluxes to remove impurities. The resulting molten copper is then cast into ingots or other shapes for further processing.

The mining operation of Sungun copper mine involves extracting copper ore from the ground using heavy equipment such as dump trucks, shovels and drills in extraction stage. The Sungun Mine employs over 1500 people and produces approximately 75000 tons of copper concentrate per year. The main focus of this research is on the extraction stage and selection of transportation machinery. Due to the characteristics of the deposit and due to high production and the need to use very large mining machines, open pit mining has been designed. This method has some advantages over other extraction methods; such as high production, high safety, possibility of extracting minerals with low grade and low mineral waste. The transport fleet of Sungun copper mine generally includes machines such as shovels, loaders, bulldozers, graders and dump trucks. After the extraction operation at the Sungun copper mine, the ore is transported by truck to the crusher building on the 1987 horizon. The fragmentation varies depending on the drilling pattern and the quality of blast. A plan view of Sungun mining site shown in Figure 3.

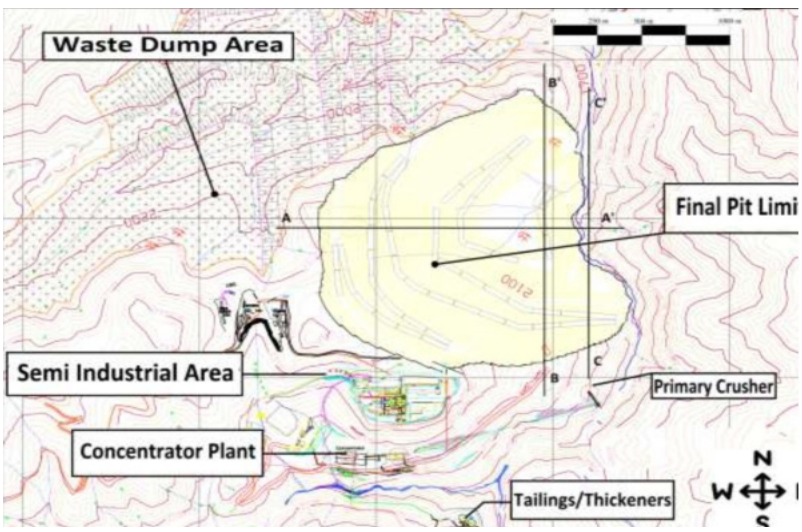


Figure 3. Plan view of Sungun mining site (2021/extraction stage)

Classifying input data

In any research, data collection is one of the most important and fundamental parts. In this study, based on the monitoring of historical information and opinions of mining engineers, a decision matrix was created to determine the influential criteria. These criteria were 178 in the Sungun copper mine. These criteria were collected from previously published researches. According to the conditions of Sungun mine, some criteria are less effective and some are more effective. Furthermore some criteria are the same in concept such as access to maintenance or warranty. Therefore, it was decided to calibrate the number of influencing factors at this stage using the Fuzzy TOPSIS method and then reduce their number. In relation to the decision to select the transport fleet at the Sungun copper mine in six main groups, a total of 178 criteria were identified based on experience and various reports. Details of the selected criteria are summarized in Table 1.

Table 1. Main groups and criteria in the Sungun copper mine to select the transport fleet

	Main criteria
Technical	1-Remain life (Te1), 2-Ore transportation distance (Te2), 3-Waste transportation distance (Te3), 4- Safe distance for blasting (Te4), 5-Production rate (Te5), 6-Strategy of recovery (Te6), 7-Infrastructure (Te7) , 8-Future technology (Te8), 9-Access after-sales service (Te9), 10-Transportation continuity (Te10), 11-Flexibility (Te11), 12-Power outage (Te12), 13-Dilution (Te13), 14-Exploitation efficiency (Te14), 15-Carrying capacity (Te15), 16-Height of extraction (Te16), 17-Block size (Te17), 18-Ramp width (Te18), 19-Ramp slope (Te19), 20-System resilience (Te20), 21-Explotion works (Te21), 22-Cut-off grade (Te22), 23-Waste dump management (Te23), 24- Break-even Cut-off Grade (Te24), 25-Efficiency of existing transport system (Te25), 26-Coordination between machine operators (Te26), 27-Transport system used (Te27), 28-Future production rate (Te28), 29-Existing mining method (Te29), 30-Mining design reliability (Te30), 31-Reliability of long-term mine planning (Te31), 32-Reliability of mid-term mine planning (Te32), 33-Reliability of short-term mine planning (Te33), 34-Stockpile management (Te34), 35-Equipment life (Te35), 36-Continuity of operation (Te36), 37-Transportation traffic (Te37), 38-Blasting efficiency (Te38), 39-System reliability (Te39), 40-Capacity and number of fleets (Te40), 41-Loading system used (Te41) and 42-Safety (Te42)
Economic	43-GDP (Ec1), 44-Company goal (Ec2), 45-Period payback (Ec3), 46-IRR (Ec4), 47-Profitability (Ec5), 48-During-mining income (Ec6), 49-Post-mining income (Ec7), 50-Capital cost (Ec8), 51-Cost of drilling operations (Ec9), 52-Cost of blasting operations (Ec10), 53-Cost of loading operations (Ec11), 54-Cost of hauling operations (Ec12), 55-Operation cost of maintenance (Ec13), 56-Operation cost of installation and relocation (Ec14), 57-Energy operating cost (Ec15), 58-Labor wages cost (Ec16), 59-Depreciation cost (Ec17), 60-Cost of fuel (Ec18), 61-Cost of access to the equipment purchase market (Ec19), 62-Cost of access to the product sales market (Ec20), 63-Monitoring cost (Ec21), 64-environment cost (Ec22), 65-Reclamation cost (Ec23), 66-Society cost (Ec24), 67-Capital potentials (Ec25), 68-Financial credits (Ec26), 69-Value of land post-mining (Ec27), 70-Investment protection (Ec28), 71-Taxes and government rights (Ec29), 72-Inflation rate (Ec30) and 73-Price uncertainly (Ec31)
Environmental	74-Improving the reuse of mined lands (En1), 75-Improve mine closure (En2), 76-Impact of mine reclamation (En3), 77-Flexibility to separate sulfide and non-sulfide wastes (En4), 78-Polluion caused by crushing (En5), 79-Rate of increase of pollutants compared to the permissible environmental indicators (En6), 80-Contaminants available (En7), 81-Possibility of pollution in future (En8), 82-prevent pollution (En9), 83-Reduce greenhouse gas emissions (En10), 84-Reduce soil contamination (En11), 85-Reduce water contamination (En12), 86-Reduce air contamination (En13), 87-Preserve local animals (En14), 88-Preserve local plants (En15), 89-Reduction of gases produced by machinery and facilities (En16), 90-Energy consumption (En17), 91-Fuel consumption (En18), 92-Reduce land occupation (En19), 93-Reduce dust spread (En20), 94-Wrist with the environment (En21), 95-Reduce noise pollution (En22), 96-Noise reduction (En23) , 97-Dust reduction (En24) , 98-Environmental conditions before mining (En25) and 99-Ecosystem improvement (En26),
Social	100-Improving the situation of local people (So1), 101-Reduce social problems (So2), 102-Wage and economic conditions of worker's lives (So3), 103-Job security (So4), 104-Number of mining jobs (So5), 105-Level of training programs (So6), 106-Existing skill and experience level of workers (So7), 107-Existing skill and experience level of mining engineers (So8), 108-Difficult working conditions (So9), 109-Access to skilled labor (So10), 110-Occupational health and safety (So11), 111-Occupational accidents (So12), 112-Decreased immigration (So13), 113-Increase migration (So14), 114-Working conditions (So15), 115-Mine view (So16), 116-Sustainable development stability (So17), 117-Reception of local people in the area (So18), 118-Aesthetics (So19), 119-Land ownership (So20), 120-Exposed areas (So21), 121-Survival of the mined city (So22) and 122-Cost of each job (So23)
Site situation	123-Company policies on the flexibility of changing transportation methods (SS1), 124-Company policies in mine closure and reclamation (SS2), 125-Manager type (SS3), 126-Mine size (SS4), 127-Site location (SS5), 128-Ways to access the city (SS6), 129-Previous use of mining lands (SS7), 130-Extent of mined lands (SS8), 131-Topography of mined lands (SS9), 132-Above sea level (SS10), 133-Type of reclamation method (SS11), 134-Automation in mining (SS12), 135-Detailed exploration programs (SS13), 136-Loading and hauling capacity flexibility (SS14), 137-Flexibility in case of change of face (SS15), 138-Flexibility against the number of face (SS16), 139-Flexibility against changing production rates (SS17), 140-Flexibility in the cost of future opportunities (SS18), 141-Need auxiliary machines (SS19), 142-Exploitation capacity (SS20), 143-Factory capacity (SS21), 144-Smelting and refining capacity of the factory (SS22), 145-Climatic conditions (SS23), 146-Mining site research and development (SS24), 147-Access to explosives (SS25), 148-Other exploitation method (SS26), 149-Access to water resources (SS27), 150-Repair shop area (SS28) and 151-Seasonal winds (SS29)
Geology/ Geo-mechanics	152-Type of ore reserve (GG1), 153-Remain reserve (GG2), 154-Reserve depth (GG3), 155-Physical properties of mined lands (GG4), 156-Chemical properties of mined lands (GG5), 157-Reserve shape (GG6), 158-Reserve slope (GG7), 159-Grade distribution (GG8), 160-Grade uncertainly (GG9), 161-Pit geometry (GG10), 162-Pit final slope (GG11), 163-Break-even stripping ratio (GG12), 164-Periodic stripping ratio (GG13), 165-Compressive and shear strength (GG14), 166-Ore and waste wear (GG15), 167-Ore and waste density (GG16), 168-Ore and waste inflation factor (GG17), 169-Discontinuity (GG18), 170-Water zones (GG19), 171-Circular failure (GG20), 172-Filling rate (GG21), 173-Access to the reserve (GG22), 174-Geomorphology of the region (GG23), 175-Groundwater level (GG24), 176-Earthquake (GG25), 177-Flood (GG26) and 178-Fire (GG27)

To select the most important criteria for this decision, in the first stage, a questionnaire was prepared and distributed among mining experts (Table 2).

In this questionnaire, the importance of different criteria was questioned. The purpose of this section was to filter the most important criteria based on the opinions of experts using the TOPSIS fuzzy method. To calculate the weight of the importance of each expert, the accuracy of the individual's response was considered by first weighing the main groups of criteria, including economical, technical, social, site situation, environmental and geological criteria, and then all the criteria of the main subgroups. 178 criteria were scored by experts. By comparing the primary and secondary answers of the experts in both sections, the weight of each expert's score was determined (Table 2).

Table 2. Expert group information and results based on expert group

Number	Code	Experience (Years)	Education	Error (%)	Accuracy (%)	Weight (%)
1	Expert 01	29	PhD of Mining Engineer	17	83	16
2	Expert 02	23	Bachelor of Mining Engineer	56	0	0
3	Expert 03	22	Master of Mining Engineer	41	59	11
4	Expert 04	18	Master of Mining Engineer	60	0	0
5	Expert 05	12	PhD of Mining Engineer	13	87	17
6	Expert 06	10	Master of Mining Engineer	26	74	14
7	Expert 07	10	Master of Mining Engineer	30	70	14
8	Expert 08	9	PhD of Mining Engineer	15	85	16
9	Expert 09	6	Master of Mining Engineer	40	60	12
10	Expert 10	5	Master of Mining Engineer	60	0	0

Results and discussion

Due to the fact that a ranking system was necessary to select the most important criteria, the TOPSIS method was chosen, but since the conditions in the mine are probable and do not have complete certainty, the FUZZY-TOPSIS system, considering the degree of uncertainty, the title of the method used in this step was selected.

In the next step, by eliminating the less important criteria, a two-way comparison based on the AHP method was used to select the transportation system.

FUZZY-TOPSIS modeling

In this research, the importance of each criterion is determined by the probability dimension. In this regard, the probabilities were qualitatively classified on a scale of 1 to 5. As shown in Table 2, probability is defined as a qualitative description of probability and frequency from L1 to L5.

After describing the probabilities, the most important task in examining the criteria is to calculate the rank of all the criteria and arrange them according to the calculated priority to understand the criteria of double importance (Table 3).

Ranking with TOPSIS is not an exact quantity for selecting the main criteria. In real-world situations, such as mining, accurate assessments of rankings are usually difficult due to uncertainty and ambiguity, but they can be appropriately described with linguistic terms that are FUZZY in nature and then transferred to FUZZY numbers. Therefore, due to the limitations of quantitative approaches, the FUZZY-TOPSIS method was used for evaluation and ranking. For this purpose, FUZZY-TOPSIS is used to calculate the ideal positions of positive FUZZY and negative FUZZY to find the C_i index. From now on, the criteria will be evaluated and ranked based on the C_i index.

According to (Equation 4), the normalized FUZZY decision matrix is denoted by $\tilde{R} = [\tilde{r}_{ij}]_{n \times m}$. Therefore, as the FUZZY linguistic ratings, presented in Table 3, preserve the property that the ranges of normalized TFNs belonging to the closed interval [0, 1], the normalization procedure is not necessary.

Based on the TFNs presented in Table 3, A^+ and A^- are determined as (0.75, 0.9, 1) and (0.00, 0.1, 0.25) using (Equation 7) and (Equation 8), which indicates the most and the least preferable alternatives, respectively.

For evaluating and ranking criteria on the basis of the C_i index, the results of calculation of the C_i index are shown in Table 4. According to (Equation 11), the C_i is calculated simultaneously based on the distance d^+ and d^- to both A^+ and A^- using (Equation 9) and (Equation 10). Finally, a preference order can be ranked according to the order of the C_i index.

According to the basic principle of FUZZY-TOPSIS method, the criterion of double importance is the criterion that has the shortest distance from the FUZZY positive ideal solution and the farthest distance from the fuzzy negative ideal solution. Therefore, based on the results, the ranking of the criteria is determined in such a way that the criteria that have the closest value of C_i to 1 have the highest rank and the criteria that have the value of C_i farther than 1 have the lowest rank.

Finally, Details of overall C_{is} for the ten experts are presented in Table 4. As can be seen in the box, blue boxes have higher values of C_i and will be used in the next step.

Table 3. Qualitative description of the likelihoods

Likelihood	Linguistic	Triangular fuzzy numbers
L1	Almost certain	(0.75,0.90,1.00)
L2	Likely (probable)	(0.55,0.70,0.85)
L3	Possible	(0.35,0.50,0.65)
L4	Unlikely	(0.15,0.30,0.45)
L5	Rare	(0.00,0.10,0.25)

Table 4. The overall C_{is} of each 178 criteria codes

code	C_i	code	C_i	code	C_i	code	C_i	code	C_i	code	C_i
Te1	0.89	Ec1	0.75	En1	0.33	So1	0.32	SS1	0.89	GG1	0.95
Te2	0.83	Ec2	0.95	En2	0.18	So2	0.38	SS2	0.70	GG2	1.00
Te3	0.78	Ec3	0.88	En3	0.21	So3	0.40	SS3	0.82	GG3	0.82
Te4	0.72	Ec4	0.90	En4	0.58	So4	0.83	SS4	0.76	GG4	0.47
Te5	0.77	Ec5	0.87	En5	0.53	So5	0.63	SS5	0.71	GG5	0.29
Te6	0.57	Ec6	0.82	En6	0.58	So6	0.59	SS6	0.71	GG6	0.67
Te7	0.52	Ec7	0.72	En7	0.50	So7	0.78	SS7	0.24	GG7	0.62
Te8	0.95	Ec8	0.94	En8	0.72	So8	0.83	SS8	0.17	GG8	0.75
Te9	0.63	Ec9	0.47	En9	0.62	So9	0.47	SS9	0.76	GG9	0.66
Te10	0.71	Ec10	0.36	En10	0.58	So10	0.88	SS10	0.61	GG10	0.65
Te11	0.42	Ec11	0.41	En11	0.43	So11	0.68	SS11	0.36	GG11	0.82
Te12	0.50	Ec12	0.47	En12	0.57	So12	0.48	SS12	0.55	GG12	0.49
Te13	0.31	Ec13	0.70	En13	0.50	So13	0.32	SS13	0.76	GG13	0.61
Te14	0.61	Ec14	0.53	En14	0.39	So14	0.43	SS14	0.78	GG14	0.29
Te15	0.93	Ec15	0.42	En15	0.34	So15	0.57	SS15	0.77	GG15	0.36
Te16	0.51	Ec16	0.62	En16	0.50	So16	0.34	SS16	0.77	GG16	0.41
Te17	0.51	Ec17	0.55	En17	0.76	So17	0.65	SS17	0.82	GG17	0.44
Te18	0.38	Ec18	0.52	En18	0.89	So18	0.70	SS18	0.59	GG18	0.36
Te19	0.25	Ec19	0.76	En19	0.42	So19	0.31	SS19	0.59	GG19	0.44
Te20	0.63	Ec20	0.69	En20	0.52	So20	0.37	SS20	0.93	GG20	0.63
Te21	0.68	Ec21	0.26	En21	0.46	So21	0.31	SS21	0.87	GG21	0.49
Te22	0.63	Ec22	0.21	En22	0.44	So22	0.34	SS22	0.75	GG22	0.61
Te23	0.54	Ec23	0.37	En23	0.36	So23	0.50	SS23	0.44	GG23	0.76
Te24	0.59	Ec24	0.29	En24	0.41			SS24	0.65	GG24	0.57
Te25	0.56	Ec25	0.36	En25	0.23			SS25	0.48	GG25	0.66
Te26	0.65	Ec26	0.68	En26	0.25			SS26	0.36	GG26	0.61
Te27	0.70	Ec27	0.18					SS27	0.57	GG27	0.60
Te28	0.76	Ec28	0.73					SS28	0.31		
Te29	0.74	Ec29	0.51					SS29	0.29		
Te30	0.70	Ec30	0.62								
Te31	0.62	Ec31	0.78								
Te32	0.64										
Te33	0.65										
Te34	0.53										
Te35	0.57										
Te36	0.68										
Te37	0.42										
Te38	0.58										
Te39	0.41										
Te40	0.60										
Te41	0.55										
Te42	0.50										

The results shown in Table 4 are listed in descending order in Figure 4. As can be seen from Figure 4, two groups with different ranks are obtained, which are shown A and B. Group A, which has the highest rank (red color), was selected for the next step calculations. In fact, after scoring all the criteria by the experts group, 30% of the criteria that had the highest score were classified as an effective criteria in group A.

The C_i is always between 0 and 1, if an action is closer to the ideal than the anti-ideal, then C_i approaches 1, whereas if an action is closer to the anti-ideal than to the ideal, C_i approaches 0.

Finally, according to the opinions of experts, out of 178 criteria in the six main groups, 55 criteria were selected as the most important. After a thorough examination, 55 of the most significant items were filtered. These influential factors were used to continue the research. To evaluate the 178 criteria, qualitative expressions were used, which are the linguistic variables defined in fuzzy logic. Therefore, the process of filtering criteria is done by converting language scales to triangular fuzzy numbers (TFNs) and C_{is}.

AHP approach

In this part of the research, the selected criteria were prepared using the method of hierarchical analysis to select the type of transport fleet. AHP approach is one of the most efficient and comprehensive multi criteria decision-making techniques. The approach in this method is to answer the ambiguities of complex problems such as fleet selection, which divides the problems into smaller components, from solving part of the problems to solve the whole problem. This method is based on the formation of hierarchical structure (Figure 5) and pairwise comparisons (Table 5) and allows the decision maker to consider different scenarios. In explaining pairwise comparisons, a pairwise comparison is between the desirability of the elements of each level by considering the elements of the higher level.

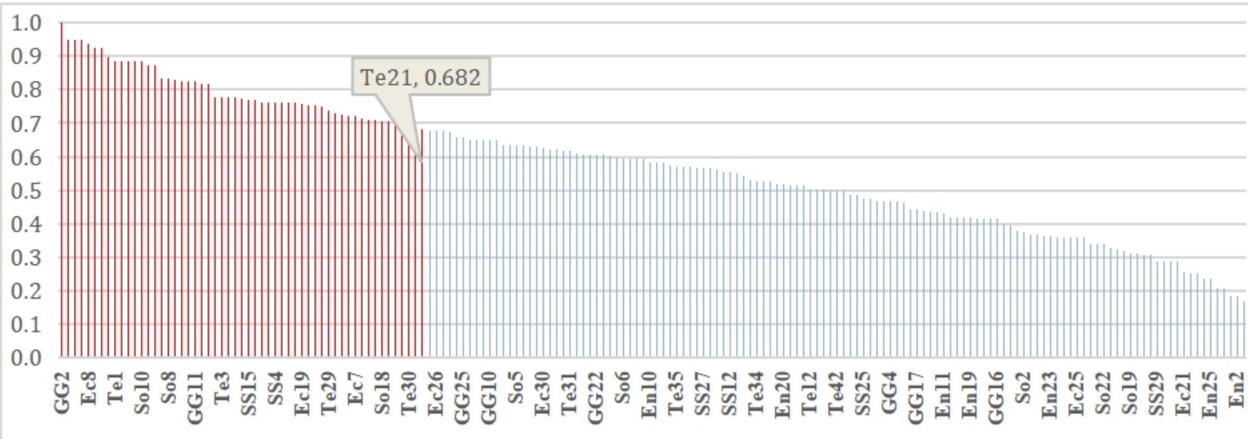


Figure 4. Criteria different ranks

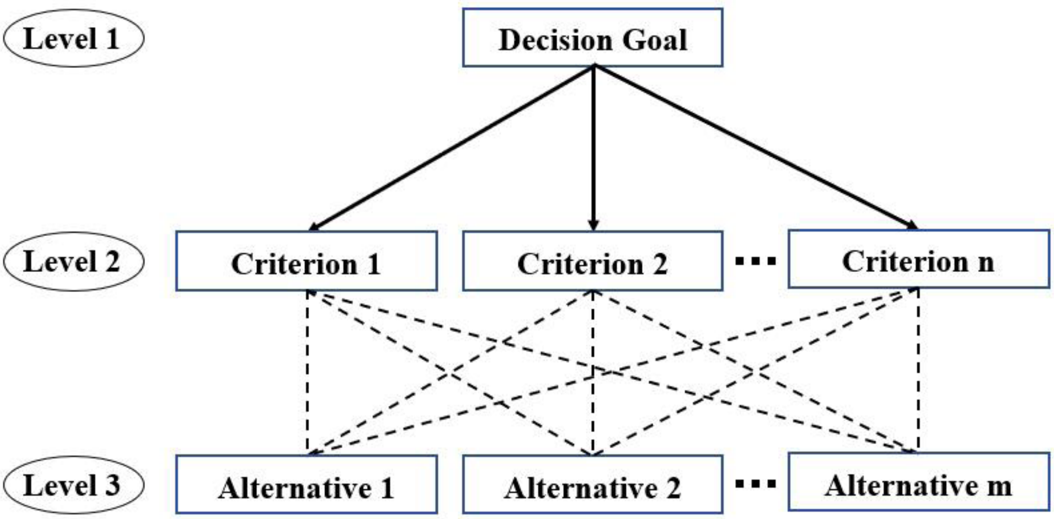


Figure 5. Formation of hierarchical structure

Table 5. Pairwise comparison of Saaty [33]

Scale	Type of preferred
9	Extremely preferred: First element is *extremely* more important than second one
7	Very strongly preferred: First element is *very strongly* more important than second one
5	Strongly preferred: First element is *strongly* more important than second one
3	Moderately preferred: First element is *moderately* more important than second one
1	Equally preferred: Importance of elements are equal or decision maker is indifferent between elements
2, 4, 6 and 8	Intermediate values
1, ½, … and 1/9	Use reciprocals for inverse comparisons

The reasons for using this method are:
1. The possibility of formulating the problem hierarchically,
2. The possibility of considering different quantitative and qualitative indicators in the problem,
3. The possibility of sensitivity analysis on indicators and sub-indicators,
4. The possibility of examining the degree of consistency and incompatibility of judgments,
5. Strong theoretical basis,
6. Analysis of complex problems into simple problems, and
7. Dividing the decision problem into levels of purpose, criterion, sub-criterion and option.

In the previous section IPCC, Truck-front shovel and Truck-backhoe as an alternatives were defined based on the conditions of Sungun mine and available technologies based on the opinion of open pit mining experts and copper mining companies. The results shown in Figure 6. As can be seen from this figure, three alternatives with different weights are obtained, which are shown IPCC, Truck-front shovel and Truck-backhoe. IPCC, which has blue color, Truck-front shovel, which has red color and Truck-backhoe, which has green color, were measured for the different criteria. Figure 6 helps with the better understanding of the sensitivity analysis of alternatives. Also, the weights of each criterion are shown separately.

Some normalized values of the attributes which were derived using (Equation 17), have been shown in Table 6 as a fragmented normalized decision matrix.

Such a procedure is common in mathematics; however, Expert Choice software was used here, which is a multi-objective decision support tool. A descending order of the calculated weights has been illustrated in Figure 7. According to (Equation 16), an overall inconsistency index of 0.02 motivated the decision-makers to accept final weighting results of the AHP method.

Then the relative closeness Cj of each post-mining land-use to the ideal solution (Figure 7) was calculated. The relative closeness of the alternative j with respect to A^+ is defined. A descending order of the ranked alternatives has also been illustrated in Figure 7. As it can be perceived, the industrial land-use has maximum value of relative closeness to ideal solution and is the most preferable alternative of this MLSA example. According to the opinions of experts, each main group of indicators is given a weight, which is given in Table 7.

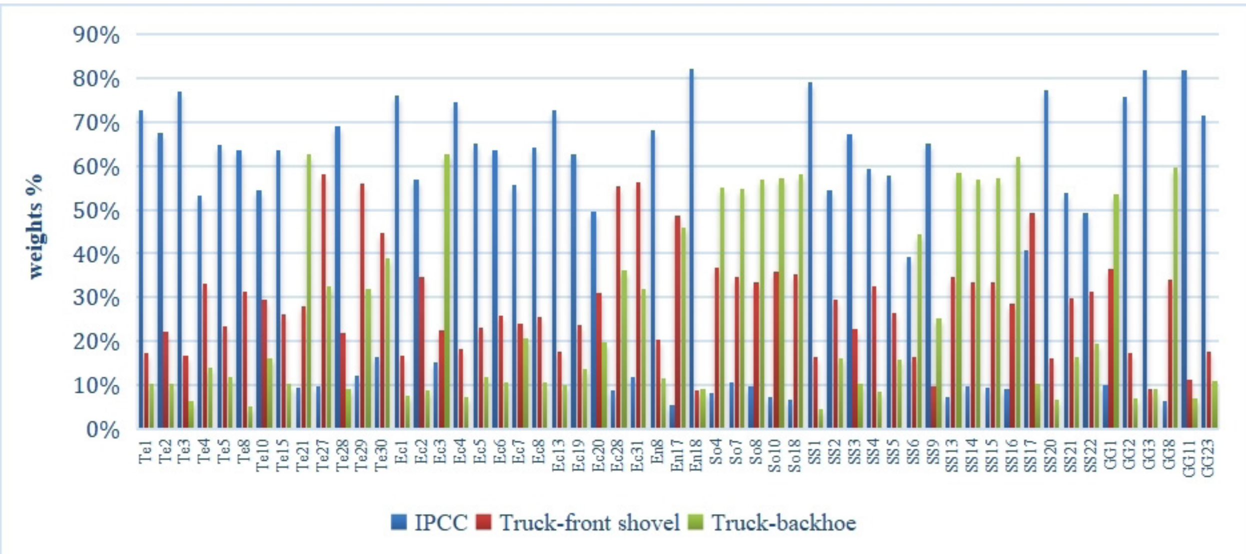


Figure 6. Three alternatives with different weights of criteria

Table 6. Normalized values of the attributes with different weights of criteria

code	IPCC	Truck-front shovel	Truck-backhoe	code	IPCC	Truck-front shovel	Truck-backhoe
Te1	73%	17%	10%	En18	82%	9%	9%
Te2	68%	22%	10%	So4	8%	37%	55%
Te3	77%	17%	6%	So7	10%	35%	55%
Te4	53%	33%	14%	So8	10%	33%	57%
Te5	65%	23%	12%	So10	7%	36%	57%
Te8	63%	31%	5%	So18	7%	35%	58%
Te10	54%	29%	16%	SS1	79%	16%	5%
Te15	64%	26%	10%	SS2	54%	29%	16%
Te21	9%	28%	63%	SS3	67%	23%	10%
Te27	10%	58%	32%	SS4	59%	32%	8%
Te28	69%	22%	9%	SS5	58%	26%	16%
Te29	12%	56%	32%	SS6	39%	16%	44%
Te30	17%	45%	39%	SS9	65%	10%	25%
Ec1	76%	17%	7%	SS13	7%	35%	58%
Ec2	57%	34%	9%	SS14	10%	33%	57%
Ec3	15%	22%	63%	SS15	9%	33%	57%
Ec4	75%	18%	7%	SS16	9%	29%	62%
Ec5	65%	23%	12%	SS17	41%	49%	10%
Ec6	64%	26%	11%	SS20	77%	16%	7%
Ec7	56%	24%	20%	SS21	54%	30%	16%
Ec8	64%	25%	11%	SS22	49%	31%	20%
Ec13	73%	17%	10%	GG1	10%	37%	54%
Ec19	63%	24%	14%	GG2	76%	17%	7%
Ec20	50%	31%	20%	GG3	82%	9%	9%
Ec28	9%	55%	36%	GG8	6%	34%	60%
Ec31	12%	56%	32%	GG11	82%	11%	7%
En8	68%	20%	11%	GG23	72%	17%	11%
En17	5%	49%	46%				

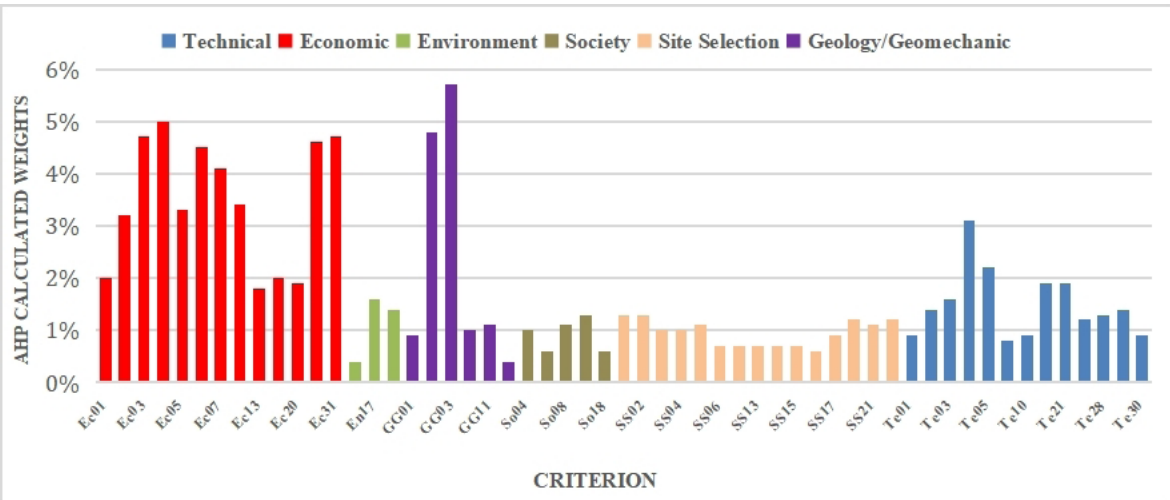
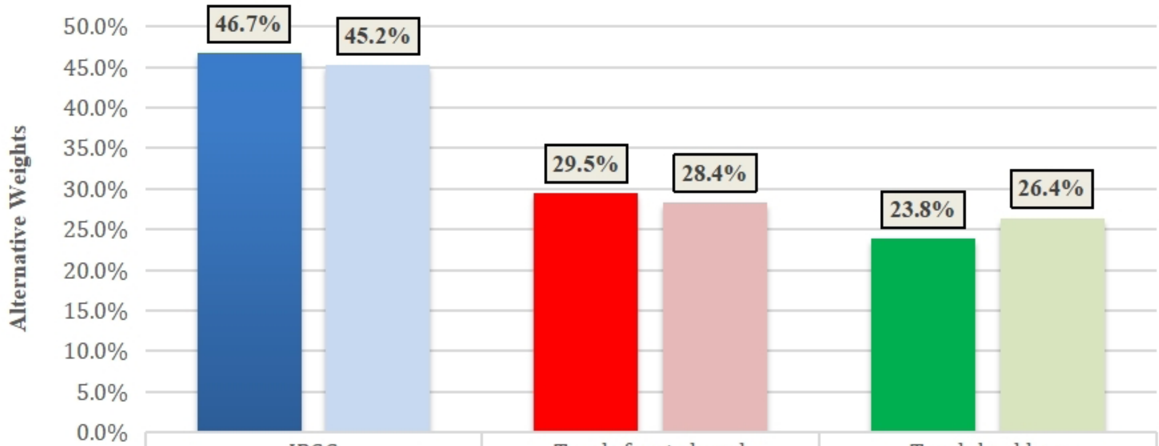


Figure 7. Global weights of evaluation attributes calculated using AHP method

Table 7. Normalized values of each main group of indicators

	Technical	Economic	Environment	Society	Site situation	Geology/Geomechanics
weights	25%	18%	12%	12%	17%	16%



	IPCC	Truck-front shovel	Truck-backhoe
Primary	46.7%	29.5%	23.8%
Final	45.2%	28.4%	26.4%

Figure 8. The weight of primary and final alternatives

In evaluating the superior transportation option by calculating the total weight of 55 criteria, first the weight of the options was calculated once and in the second step, considering the weight of the main groups, the final weight of the options were obtained as well (Figure 8).

In this research, at the highest level of the goal, i.e. selecting the type of transport fleet, at the middle levels of the index (six main groups of criteria) and sub-index (55 selected criteria) and at the lowest level of options IPCC, truck-front shovel and truck-backhoe were selected. Finally, the weight of each alternatives was 45.2, 28.4 and 26.4%, respectively.

Finally, the limitations and uncertainties of the proposed model should be mentioned. The process of pairwise comparison used in AHP can be time-consuming and complex, especially when dealing with a large number of criteria (55 criteria). The weights assigned to criteria in this model are based on relative comparisons, which may not accurately reflect their true importance or value. In proposed model assumes that all criteria independent each other, which may not always be true in real-world decision making scenarios. Furthermore the result can be sensitive to the choice of fuzzy membership function, which can affect the raking of alternatives.

Conclusion

Due to the importance of considering different decisions and criteria, along with the different opinions of experts in relation to the selection of the appropriate transportation system, this selection was done using the FUZZY-TOPSIS and AHP methods. Based on this study, six indicators were evaluated in which technical 25%, economic and site situation indicators accounted for about 18% of the weight; while the geology/geomechanics was ranked third in importance, respectively. Then, for all indicators, factors were considered that became the overall evaluation criteria and some criteria with less importance were eliminated. Effective criteria in selection and decision-making methods were introduced and then the main subject of the research was selected. The appropriate transportation system was selected based on pairwise comparison between criteria in Sungun copper mine using AHP decision-making method. In order to conduct the research, 55 criteria were selected by experts and were divided into six categories: technical, economical, social, site, environmental and geology/geo-mechanics. By preparing a questionnaire and presenting it to mining experts and specialists, their opinions were examined. In the first step of hierarchical analysis, pairwise comparison of selected criteria (55 criteria) was performed with the aim of the problem and the weight of each criterion was calculated. Using the second matrix, a 55 pairwise comparison between transportation options with economic, technical and environmental criteria and etc. was performed and the weight of alternatives was calculated. At the end of the present study, by examining all the scores and weights obtained from the opinions of experts using the AHP method, it was established that the conveyor system and crusher inside the pit had the highest score, followed by truck-front shovel and truck-backhoe, respectively. According to the research and the results that were obtained, with the opinion of the experts of Sungun copper mine, a transportation system with conveyor and crusher inside the pit was proposed for Sungun mine and large open pit mines with 45.2% of weight. Potential areas of research could include the development of decision making framework and model based on different fuzzy numbers, fuzzy distance or gray theory. Furthermore future researches could focus on the integrating of emerging technologies such as artificial intelligence, machine learning to decide open pit mine transportation system selection.

Authors' contributions

Farhad Samimi Namin: supervision and administration, conceptualization, investigation resources, final review & editing. Hasan Ghasemzadeh: conceptualization, formal analysis, data processing, excel software tool, writing – original draft. Ali Moghaddam Aghajari: investigation, data and results validation, writing – review & editing.

Funding

No external funding was received for this research.

Competing interests

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript. Furthermore this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Abbaspour, H., Drebenstedt, C., Paricheh, M., et al. Optimum location and relocation plan of semi-mobile in-pit crushing and conveying systems in open-pit mines by transportation problem. *International Journal of Mining, Reclamation and Environment*. 2019;33(5): 297-317. doi: https://doi.org/10.1080/17480930.2018.1435968

[2] Hartman, Howard L., Jan M. Mutmansky. Introductory mining engineering. John Wiley & Sons, 2002.

[3] Shamsi, M., Nehring, M. Determination of the optimal transition point between a truck and shovel system and a semi-mobile in-pit crushing and conveying system. *Journal of the Southern African Institute of Mining and Metallurgy.* 2021;121(9): 497-504. doi: http://dx.doi.org/10.17159/2411-9717/1564/2021

[4] Shamsi, M., Pourrahimian, Y., Rahmanpour, M. Optimisation of open-pit mine production scheduling considering optimum transportation system between truck haulage and semi-mobile in-pit crushing and conveying. *International Journal of Mining, Reclamation and Environment.* 2022;36(2): 142-158. doi: https://doi.org/10.1080/17480930.2021.1996983

[5] Paricheh M, Osanloo M. How to exit conveyor from an open-pit mine: A theoretical approach[C]// Proceedings of the 27th International Symposium on Mine Planning and Equipment Selection-MPES 2018. Springer International Publishing. 2019: 319-334. doi: https://doi.org/10.1007/978-3-319-99220-4_26

[6] Paricheh, M., Osanloo, M. Concurrent open-pit mine production and in-pit crushing–conveying system planning. *Engineering Optimization*. 2020;52(10):1780-1795. doi: https://doi.org/10.1080/0305215X.2019.1678150

[7] Chamzini-Y, A., Shariati, S. Selection of material handling equipment system for surface mines by using a combination of fuzzy MCDM models. *International Research Journal of Applied and Basic Sciences*. 2013;5(12):1501-1511.

[8] Valli, P., Jeyasehar, C. A. Genetic algorithm based equipment selection method for construction project using MATLAB tool. *Iran University of Science & Technology*. 2012;2(2):235-246.

[9] Öztaş, O., Başçetin, A., Kanli, A. EQS: a computer software using fuzzy logic for equipment selection in mining engineering. *Journal of the Southern African Institute of Mining and Metallurgy*. 2006;106(1): 63-70. available from: https://hdl.handle.net/10520/AJA0038223X_3172

[10] Erçelebi, S. G., Basçetin, A. Optimization of shovel-truck system for surface mining. *Journal of the Southern African Institute of Mining and Metallurgy*. 2009;109(7): 433-439.

[11] Olavarría, S., Adriasola, P., Karzulovic, A. Transition from open pit to underground mining at Chuquicamata, Antofagasta, Chile. Paper presented at the Proceedings of The SAIMM International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering. 2006

[12] Koehler, F. In-pit crushing system the future mining option. In Twelfth International Symposium on Mine Planning and Equipment Selection. 2003: 371-37.

[13] Ritter, R., Herzog, A., Drebenstedt, C. Automated dozer concept aims to cut IPCC downtime. *Engineering and Mining Journal*. 2014;215(11): 52.

[14] Osanloo, M., Paricheh, M. In-pit crushing and conveying technology in open-pit mining operations: a literature review and research agenda. *International Journal of Mining, Reclamation and Environment*. 2020;34(6): 430-457. doi: https://doi.org/10.1080/17480930.2019.1565054

[15] Tutton, D., Streck, W. The application of mobile in-pit crushing and conveying in large, hard rock open pit mines. Paper presented at the Mining Magazine Congress, Canada. 2009

[16] Darling, P. SME mining engineering handbook (Vol. 1): SME. 2011

[17] Terezopoulos, N. Continuous haulage and in-pit crushing in surface mining. *Mining Science and Technology*. 1988;7(3): 253-263. doi: https://doi.org/10.1016/S0167-9031(88)90777-3

[18] Dean, M., Knights, P., Kizil, M., et al. Selection and planning of fully mobile in-pit crusher and conveyor systems for deep open pit metalliferous applications. Paper presented at the AusIMM 2015 3rd International Future Mining Conference, Sydney, NSW, Australia. 2015: 4-6.

[19] Institution of Mining and Metallurgy, Lieberwirth H. Economic advantages of belt conveying in open-pit mining. Mining Latin America/Minería Latinoamericana: Challenges in the mining industry/Desafíos para la industria minera. 1994: 279-295. doi: https://doi.org/10.1007/978-94-011-1216-1_20

[20] Paricheh, M., Osanloo, M., Rahmanpour, M. In-pit crusher location as a dynamic location problem. *Journal of the Southern African Institute of Mining and Metallurgy*. 2017;117(6):599-607. doi: http://dx.doi.org/10.17159/2411-9717/2017/v117n6a11

[21] Liu, F., Cai, Q., Chen, S., et al. A comparison of the energy consumption and carbon emissions for different modes of transportation in open-cut coal mines. *International Journal of Mining Science and Technology*. 2015;25(2):261-266. doi: https://doi.org/10.1016/j.ijmst.2015.02.015

[22] Norgate, T., Haque, N. The greenhouse gas impact of IPCC and ore-sorting technologies. *Minerals Engineering*. 2013;42:13-21. doi: https://doi.org/10.1016/j.mineng.2012.11.012

[23] Chen S J, Hwang C L. Fuzzy multiple attribute decision making methods. Fuzzy multiple attribute decision making: Methods and applications. Berlin, Heidelberg: Springer Berlin Heidelberg, 1992: 289-486.

[24] Chen, C.T. Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems*. 2000;114(1):1-9. doi: https://doi.org/10.1016/S0165-0114(97)00377-1

[25] Zadeh, L. A. Information and control. *Fuzzy Sets*. 1965;8(3): 338-353.

[26] Zadeh, L. A. The concept of a linguistic variable and its application to approximate reasoning—I. Information sciences. 1975;8(3): 199-249. doi: https://doi.org/10.1016/0020-0255(75)90036-5

[27] Buckley, J. J. Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*. 1985;17(3):233-247. https://doi.org/10.1016/0165-0114(85)90090-9

[28] Burt, C. N., Caccetta, L. Equipment selection for surface mining: a review. *Interfaces*. 2014;44(2): 143-162. doi: https://doi.org/10.1287/inte.2013.0732

[29] Zimmermann, E., Kruse, W. Mobile crushing and conveying in quarries-a chance for better and cheaper production! Paper presented at RWTH Aachen-Institut für Bergbaukunde III, 8th International Symposium Continuous Surface Mining. 2006: 481-487.

[30] Hwang C L, Yoon K, Hwang C L, et al. Methods for multiple attribute decision making. Multiple attribute decision making: methods and applications a state-of-the-art survey. 1981: 58-191. doi: https://doi.org/10.1007/978-3-642-48318-9_3

[31] Zhou, X., Lu, M. Risk evaluation of dynamic alliance based on fuzzy analytic network process and fuzzy TOPSIS. 2012;5(3). doi: 10.4236/jssm.2012.53028

[32] Lai, Y.J., Liu, T.Y., Hwang, C.L. Topsis for MODM. *European Journal of Operational Research*. 1994;76(3): 486-500. doi: https://doi.org/10.1016/0377-2217(94)90282-8

[33] Mahdevari, S., Shahriar, K., Esfahanipour, A. Human health and safety risks management in underground coal mines using fuzzy TOPSIS. *Science of the Total Environment*. 2014;488:85-99. doi: https://doi.org/10.1016/j.scitotenv.2014.04.076

[34] Saaty, T. L. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*. 2008:1(1):83-98. doi: https://doi.org/10.1504/IJSSCI.2008.017590

[35] Soltanmohammadi, H., Osanloo, M., Aghajani, A. Developing a fifty-attribute framework for mined land suitability analysis using AHP-TOPSIS approach. Paper presented at the proceedings of post-mining symposium, Nancy, France. 2008: 1-12.