



Assessing the Impacts of In-Pit Crushing and Conveying Technology on Optimum Transition Depth from Open-Pit to Underground Mining

Naser Badakhshan^{1*} , Kourosh Shahriar² , Sajjad Afraei² 

¹ PhD student, Department of Mining Engineering, Amirkabir University of Technology, Iran,

² Professor, Department of Mining Engineering, Amirkabir University of Technology, Iran.

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ABSTRACT

The issue of determining the time or depth of the transition from open-pit and underground (OPUG) mining is raised when the deposit can be extracted using a combination of open-pit and underground methods. Technological progress and alterations in geological conditions, exploration information, recovery rate, production capacity, and especially economic parameters such as price and costs can change the time and depth of transition. In deep mines with combined mining potential, optimizing hauling systems as the technological phase with the largest share in the total operating costs is considered essential from the aspect of achieving the profitability of the mining project. Using traditional haulage systems with trucks, which do not necessarily reduce costs, is constantly increasing. In such cases, it is necessary to find appropriate alternatives, among which continuous mining systems, such as in-pit crushing and conveying (IPCC) stand out. The impacts of applying IPCC in large-scale and deep open-pit (OP) mines with combined extraction potential were evaluated on optimum transition depth (OTD) utilizing a hybrid semi-quantitative approach. The results indicated that employing IPCC technology in deep OP mines with the possibility of combined mining leads to an increase in the OTD and more ore extraction using the OP mining.

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* Corresponding author: **Naser Badakhshan**
E-mail address: Naserbadakhshan@aut.ac.ir

1. Introduction

Today, continuing mining with the open-pit (OP) method or altering the method to one of the underground (UG) ones, known as the transition operation, is regarded as the main issue for deep OP mines. Determining the optimum transition depth (OTD), which is affected by significant factors such as the development of mining technologies, as well as economic, social, environmental, and technical factors, is considered the most critical challenge in transition operation. The promotion of technology, especially the advancement of new equipment, which impacts other critical factors such as economic, social, environmental, and technical, is among the most critical approaches in this field. Critical factors affecting the transition depth should be considered to obtain OTD in the transition operation from OP to UG mines. The depth close to the OTD can be determined by careful evaluation [1].

Mining operations are conducted to select the appropriate mining method that matches the unique characteristics of mineral deposits in order to achieve the lowest possible cost and maximum profit. Minerals are mainly extracted by surface and UG mining methods. Mining engineers tend to apply the first method whenever possible, although a large number of factors, such as depth, size, and shape of the deposit body, influence the selection of the mining method. Today, more than 90% of minerals are extracted by surface methods such as OP and strip mining because the first method is usually more appropriate and dominant than the UG one, especially in terms of recovery, production capacity, mechanization, control and cut-off grade, ore loss, as well as dilution, economy, and safety. Loading and hauling with a share of 65-70 % has always been a significant part of capital and operational costs in surface mines. Thus, optimizing such a system affects the mining economy substantially [2]. A combination of trucks and shovels is most commonly employed for loading and hauling materials in most surface mines. The flexibility and controllability have made such a system more practical. The unloading destinations (ore and waste) become more and more distant, and the transition length, as well as the height difference between the loading and unloading points, increase when the mines get deeper, resulting in a reduction of the economic benefits of shovel-truck (ST) systems [3]. To overcome such costs and make mining operations profitable in this situation, two general solutions are used, including altering the mining method from OP to UG and delaying the operation by making some changes. The first solution includes altering the mining strategy and moving from the surface to the UG mining method. Usually, such a process means a significant technology change, which affects the production and economics of a mining project. Most mining companies seek to delay such vital change using alternative solutions due to the risk of not achieving the business objectives (default or business commitment of the company) during and after the transition. To this aim, equipment such as STs with high loading and hauling capacity is purchased, along with utilizing continuous production systems containing in-pit crushing and conveying (IPCC) [4].

A large number of studies have been conducted in the field of IPCC and OTD. The studies related to IPCC are not comprehensive and ignore the combined extraction mode in evaluating the application of IPCC to OTD, while those related to OTD disregard the impact of IPCC during determining the optimal time and place to transition from OP to UG mining.

According to the review of previous studies, most of the researches are focused on reducing haulage costs and extractable tonnage with the open-pit method. In these studies, types of IPCC (fixed, semi-mobile, and mobile) and their impact on reducing haulage costs and tonnage that can be extracted by the open-pit method have been. [Table 1](#) summarizes the studies conducted in the field of IPCC and OTD.

2. Methodology

2.1. Overview IPCC system

In the future, mining for resources will be more complicated, take place deeper underground, and deal with lower-quality materials than those usually mined today. This is because the higher-quality resources near the surface are being used up. Truck fleets need to grow a lot because truck routes are getting longer, and the time it takes to complete them is increasing. This means we need more workers and more fuel to

keep everything running. These factors lead to higher operating costs for mines that use trucks for transporting materials. IPCC systems provide many ways to greatly lessen the effects of larger truck fleets.

Table 1. Summary of studies conducted in the field of IPCC and OTD.

| Reference | Country (Case Study) | Year | Comprehensive* | OP | OPUG | IPCC | OTD | Research focus | Commodity |
|------------|----------------------|------|----------------|----|------|------|-----|---|-----------|
| This study | Overall | 2023 | ✓ | | ✓ | ✓ | ✓ | Evaluating the impacts of IPCC technology on OTD from OP to UG mining | Metals |
| [5] | Canada | 2023 | | ✓ | | ✓ | | Short-term planning of OP mines with semi-mobile in-pit crushing and conveying (SMIPCC) | Copper |
| [6] | Australia | 2022 | ✓ | ✓ | | | ✓ | Timing of transition from OP to UG mining: A simultaneous optimization model for OP and UG mine production schedules | Gold |
| [7] | Canada | 2021 | ✓ | ✓ | | ✓ | | A framework for OP mine production scheduling under SMIPCC systems with the high-angle conveyor | Copper |
| [8] | China | 2020 | | ✓ | | ✓ | | Comparing fixed and mobile IPCC and ST systems applied in mineral industries through discrete-event simulation | Copper |
| [9] | Iran | 2019 | | ✓ | | ✓ | | IPCC technology in OP mining operations: A literature review and research agenda | Copper |
| [10] | Australia | 2018 | ✓ | ✓ | | ✓ | | Comparing strategic mine planning approaches for IPCCST systems | Copper |
| [11] | Africa | 2017 | | ✓ | | | ✓ | Optimizing the OP-to-UG mining transition | Copper |
| [12] | Germany | 2016 | | ✓ | | ✓ | | Contribution to the capacity determination of SMIPCC systems | Metals |
| [13] | China | 2015 | | ✓ | | ✓ | | Selecting and planning for fully-mobile in-pit crushing and conveying systems (FMIPCC) for deep OP metalliferous applications | Metals |
| [14] | Iran | 2011 | ✓ | ✓ | | ✓ | | Reviewing the IPCC system and its case study in the copper industry | Copper |
| [15] | Snowden | 2008 | | ✓ | | ✓ | | Key production drivers in IPCC studies | Iron |

Some important design factors need to be looked at for IPCC systems to be a suitable option for transportation. These factors include basic needs and practical choices. For example, to make the starting investment worthwhile, it is good to move more than 4 million tons per year, but moving over 10 million tons is even better. The mine should also last more than ten years to keep operating costs low and recover the initial investment. Additionally, electricity costs should be less than 25% of the cost of diesel [10].

2.1.1. Classifying IPCC system

The IPCC system includes different ways to bring in, break down, move, and release materials. The usual way to categorize IPCC systems is by the type of crusher they use. This leads to three main types: FIPCC, SMIPCC/SFIPCC, and FMIPCC.

Each concept benefits from its corresponding material flow compared to the traditional ST system (Fig.1) [3].

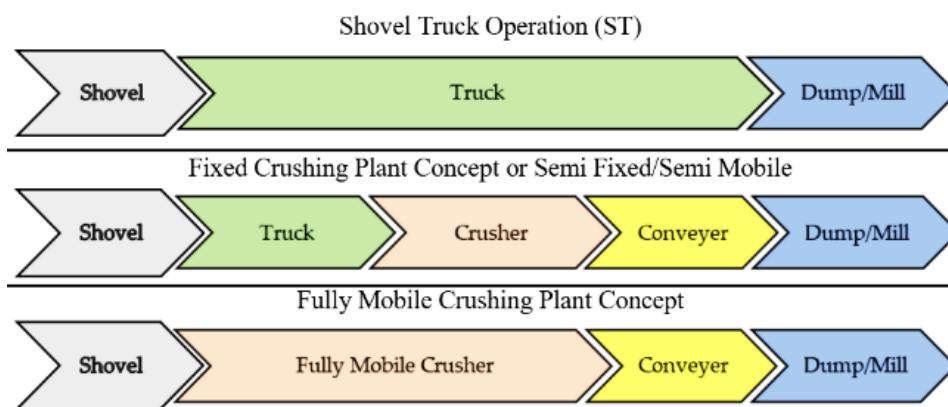


Fig. 1. Operating parts of IPCC systems [3].

2.1.2. Selecting and designing IPCC

Fig. 2 shows a diagram for designing an appropriate IPCC configuration and selecting proper equipment. The design process starts at step one by gaining knowledge of the ore body and host rock, which includes the characterization of rock mass and material types, models of ore body geometry, as well as grade and contaminant distributions. Step two analyzes appropriate crushing systems for the ore body and/or waste host rock. An IPCC selection framework under development at the University of

Queensland can be used to examine the appropriateness of the deposit for exploitation via an FMIPCC system. Such a framework utilizes material characteristics, ore body geometry, and geology as inputs. Step three analyzes different system configuration possibilities, as well as investigating various hopper loading alternatives, bench conveyor configurations, ramp conveyor alternatives, and dumps [16]. Once the system configuration is established, steps 4a to 4d involve monitoring the effective utilization of the system, dimensioning the workforce required to operate and maintain the system, calculating energy consumption in comparison to ST alternatives, and estimating material consumption for the system. Step five concerns the development of a mine life plan to extract the deposit.

Step seven involves elaborating a cost model employing the principal cost components established previously, including materials, energy, and general, as well as engineering overheads, which are used in the production model to estimate project cash flow and NPV [12].

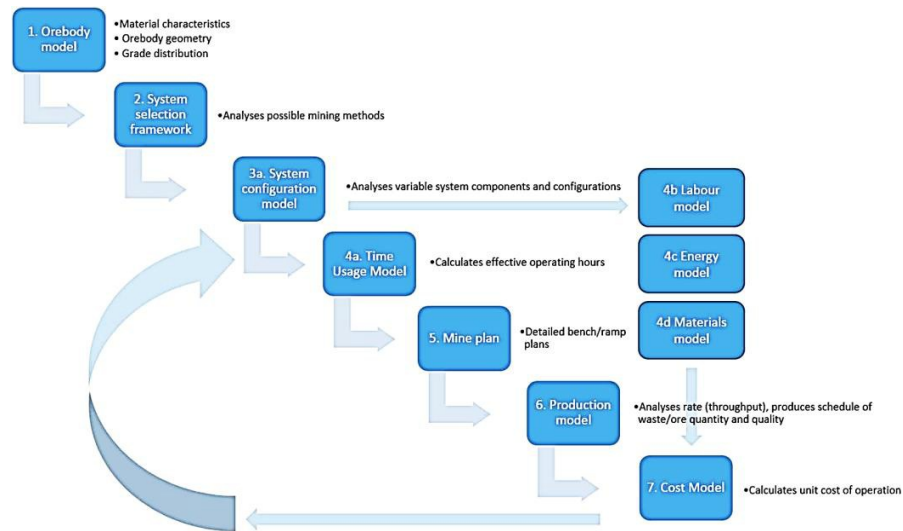


Fig. 2. A framework for designing and selecting the IPCC system [12].

2.2. Steps to study the impacts of IPCC on OTD

As indicated, utilizing qualitative methods only for reviewing different projects is not considered accurate. Therefore, mathematical techniques should be created and applied to assess other projects. Accordingly, the semi-quantitative-qualitative method was employed to assess the impacts of IPCC technology on OTD from OP to UG mining based on quantitative and mathematical methods. The present study aims to evaluate the impacts of IPCC technology on OTD from OP to UG mining using field surveys and the opinions of mining experts, especially those who are involved in transition issues from OP to UG mining and benefit from sufficient technical knowledge and experience in this field. To this aim, mines with the potential of combined OP-UG mining are examined. The deposit is mined with surface mining methods, especially OP, in metal deposits with a significant slope and depth expansion. As the mine deepens, the stripping ratio in the tonnage of wastes harvested per one ton of ore reaches a size at which mining by other surface methods has no economic, social, or environmental justification. Mining continues utilizing UG methods after the aforementioned depth when the reserve is appropriate for volume and grade. Determining the "OTD from OP to UG mining" is regarded as the most critical issue in this case. Companies usually believe that the OP mining method continues until it is economically viable, and then start UG mining. Such an approach stems from the idea that the economic pit of the mine, along with the OP mining equipment and experienced human resources, should not be challenged. Applying IPCC technology, which was investigated by several large-scale deep OP mines worldwide, is among the most critical positive factors affecting the above-mentioned approach.

The opinions of 46 experts with sufficient technical knowledge in the fields of extraction (N=29), environment (N=2), processing (N=7), exploration (N=3), and economics (N=5) were employed to make an accurate assessment. Totally, 20 positive and negative factors affecting the use of IPCC on the transition depth in large-scale deep OP mines with mining potential. A combination were selected with field surveys in deep OP mines and the information obtained in the fields of transition from OP to UG mining and the utilization of IPCC technology was selected. Then, five criteria (modes) related to the mining options were determined and considered based on the OTD, including independent OP mining, independent UG mining with and/or without crown pillar, simultaneous OPUG mining with and/or without a crown pillar, sequential OPUG mining without a crown pillar, and combinations of simultaneous and sequential OPUG mining without a crown pillar. In the next step, ten main factors with high significance were selected applying the technique for order preference by similarity to ideal solution (TOPSIS) method (Questionnaire No. 1 sent to experts), considering the scoring of each of the 30 primary factors based on

the opinions of specialists and experts. In the next procedure, the scoring scenarios were defined for each of the ten factors with high significance (Questionnaire No. 2 sent to experts). Then, pairwise comparison, weighting the criteria, and their analysis were conducted employing the analytic hierarchy process (AHP) method (Questionnaire No. 3 sent to experts). In the next step, the correlation and impact matrix between the factors and criteria, as well as the range of changes, was determined for each of the elements. Finally, the score for the effect of using IPCC technology on OTD in large-scale and deep OP mines, which benefit from the potential of combined mining, was determined. Fig. 3 illustrates the IPCC technology impact evaluation steps on OTD from OP to UG mining.

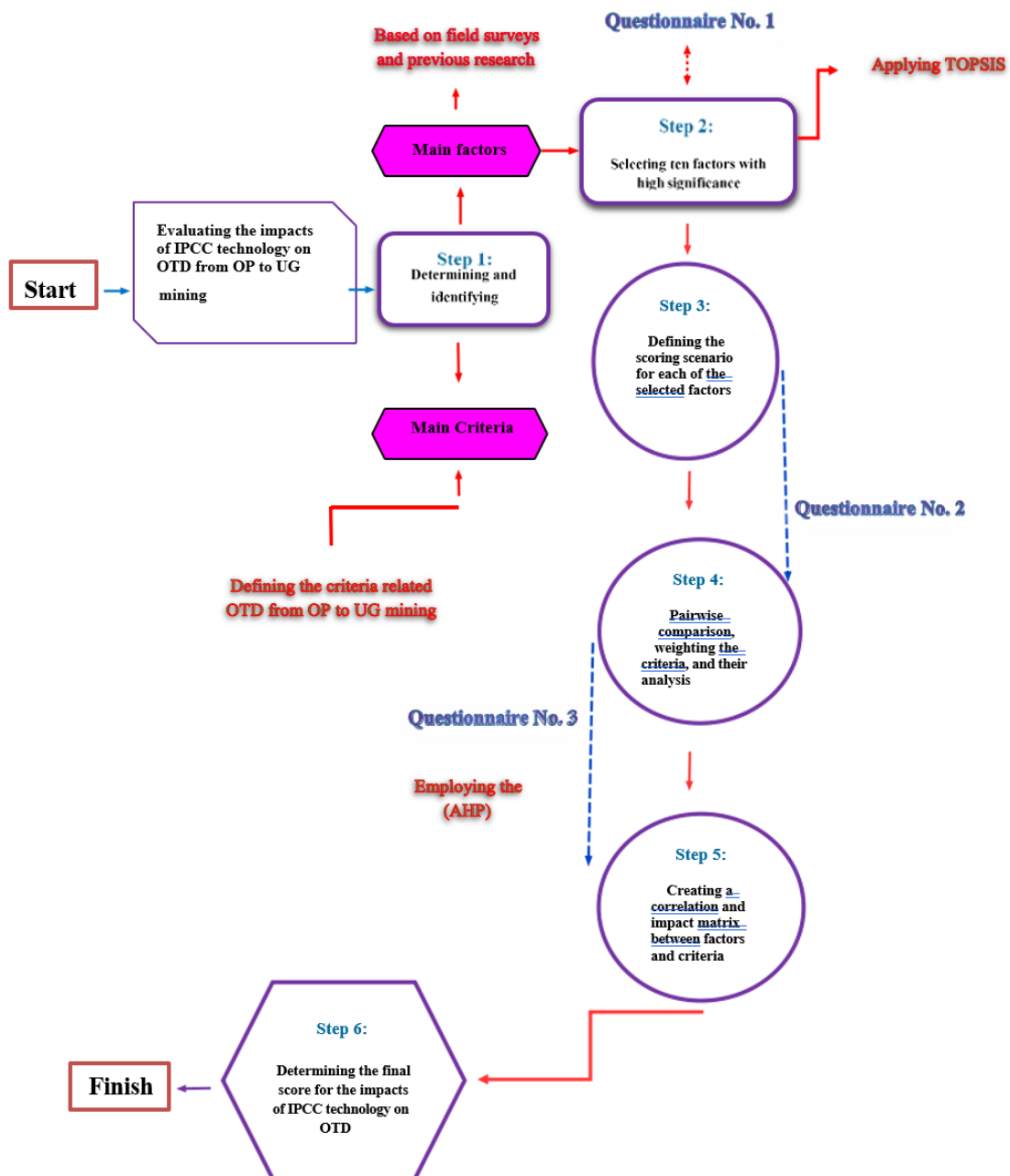


Fig. 3. Evaluating the impacts of IPCC technology on OTD from OP to UG mining.

3. Results

3.1. Determining and identifying the primary factors and criteria

Table 2 shows 20 significant positive and negative influences on the use of IPCC regarding the transition depth in large-scale deep open-pit mines with mining potential. These factors were chosen based on the expertise and experiences of mine personnel, along with field visits and surveys conducted at various mines with potential for combined extraction, including Angoran lead and zinc mine, Sarcheshmeh, and Songun copper mines. Table 3 outlines ten criteria connected to the OTD sectors, which are influenced by the primary factors [16 -17].

3.2. Selecting ten factors with high significance applying the TOPSIS method

Table 4 indicates the scoring method for each of the 20 initial factors to select ten critical factors in employing IPCC in mines with combined OP and UG mining potential and continuing to work with those ten factors (Questionnaire No. 1 sent to experts).

Table 5 presents the mean scores from experts on Questionnaire 1, which is designed to identify the ten most important and impactful factors.

Table 6 displays the application of the TOPSIS method to assess and rank the factors, identifying ten essential elements according to expert insights. The ongoing work and assessments are focused on the ten factors corresponding to ranks one through ten.

Table 2. Factors considered here [1-9].

| Parameters | symbol |
|--|--------|
| Capital and operating costs | F1 |
| Labor costs | F2 |
| Operational risks | F3 |
| Dependence on rubber | F4 |
| Fuel cost | F5 |
| CO ₂ gas emission | F6 |
| Ore body shape | F7 |
| Dependence on weather conditions | F8 |
| Hauling rate | F9 |
| Hauling time | F10 |
| Hauling distance | F11 |
| Existence of technical and operational knowledge | F12 |
| Slope | F13 |
| Government laws and related restrictions | F14 |
| Energy consumption | F15 |
| Reclamation of mine road | F16 |
| Continuity of sending feed | F17 |
| Dust emission | F18 |
| Safety | F19 |
| Flexibility | F20 |

Table 3. Criteria considered here [1-6].

| Criteria | Sub-criteria | Symbol |
|--|---|---------------|
| Independent OP mining | Ultimate pit limit (UPL) and optimum pit limit (OPL) | C1 |
| | Production rate and productivity (OP) | C2 |
| | Cutt-off grade (OP) | C3 |
| | Mine life (OP) | C4 |
| | Maximum use of OP mining facilities and equipment | C5 |
| | Mineable ore tonnage (OP) | C6 |
| Independent UG mining | Maximum mining depth (UG) | C7 |
| | Mining area border (UG) | C8 |
| | Mine life (OP) | C9 |
| | Production rate and productivity (UG) | C10 |
| | Mineable ore tonnage (UG) | C11 |
| | <i>Cutt-off grade (UG)</i> | C12 |
| Simultaneous OPUG | OTD (simultaneous OPUG) | C13 |
| | Maximum mining depth (simultaneous OPUG) | C14 |
| Mining with and/or without crown pillar | Mining area border (simultaneous OPUG) | C15 |
| | Mine life (simultaneous OPUG) | C16 |
| Sequential OPUG mining | Mineable ore tonnage (simultaneous OPUG) | C17 |
| | Production rate and productivity (simultaneous OPUG) | C18 |
| | OTD (sequential OPUG) | C19 |
| | Maximum mining depth (sequential OPUG) | C20 |
| | Mining area border (sequential OPUG) | C21 |
| without crown pillar | Mine life (sequential OPUG) | C22 |
| | Mineable ore tonnage (sequential OPUG) | C23 |
| | Production rate and productivity (sequential OPUG) | C24 |
| | OTD (simultaneous and sequential) | C25 |
| Combinations of simultaneous and sequential OPUG mining without crown pillar | Maximum mining depth (simultaneous and sequential OPUG) | C26 |
| | Mining area border (simultaneous and sequential OPUG) | C27 |
| | Mine life (simultaneous and sequential OPUG) | C28 |
| | Mineable ore tonnage (simultaneous and sequential OPUG) | C29 |
| | Production rate and productivity (simultaneous and sequential OPUG) | C30 |

Table 4. Scoring the factors to determine the most critical ones.

| | Score assigned |
|------------------|-----------------------|
| Nonsignificant | 1 |
| Very low (VL) | 2 |
| Low (L) | 3 |
| Medium (M) | 4 |
| High (H) | 5 |
| Very high (VH) | 6 |
| Very significant | 7 |

Table 5. Average scores of experts on questionnaire 1 to determine 10 significant and influential factors.

| Parameters | Score assigned | Symbol |
|--|----------------|----------|
| Capital costs | 5.44 | F_1 |
| Labor costs | 2.51 | F_2 |
| Operational risks | 6.13 | F_3 |
| Dependence on rubber | 5.65 | F_4 |
| Fuel cost | 5.33 | F_5 |
| CO ₂ gas emission | 4.71 | F_6 |
| Ore body shape | 5.11 | F_7 |
| Dependence on weather conditions | 6.54 | F_8 |
| Hauling rate | 4.22 | F_9 |
| Hauling time | 4.87 | F_{10} |
| Hauling distance | 6.24 | F_{11} |
| Existence of technical and operational knowledge | 3.12 | F_{12} |
| Slope | 3.03 | F_{13} |
| Government laws and related restrictions | 2.16 | F_{14} |
| Energy consumption | 3.21 | F_{15} |
| Reclamation of mine road | 2.93 | F_{16} |
| Continuity of sending feed | 2.26 | F_{17} |
| Dust emission | 3.34 | F_{18} |
| Safety | 4.65 | F_{19} |
| Flexibility | 5.72 | F_{20} |

Table 6. Results ranking of key influences.

| Parameters | Symbol | Rank |
|---|----------|------|
| Dependence on weather conditions Hauling distance | F_8 | 1 |
| Operational risks | F_{11} | 2 |
| Flexibility | F_3 | 3 |
| Dependence on rubber | F_{20} | 4 |
| Capital costs | F_4 | 5 |
| Fuel cost | F_1 | 6 |
| Ore body shape | F_5 | 7 |
| Hauling time | F_7 | 8 |
| CO ₂ gas emission | F_{10} | 9 |
| Dependence on weather conditions Hauling distance | F_6 | 10 |

3.3. Defining the scoring scenario for each of the selected factors

Table 8 outlines the scoring criteria for each of the ten main factors related to various conditions and their effects (referencing Questionnaire No. 2 distributed to experts), as well as the mean scores (based on the data presented in Table 7).

Table 7. Scoring the factors based on their impact.

| Extent of the impact | Score assigned |
|----------------------|----------------|
| Affectless (Z) | 1 |
| VL | 2-3 |
| L | 4-5 |
| M | 6-7 |
| H | 8-9 |
| VH | 9-10 |

Table 8. Size values or significance of influential factors for an ideal mine with standard conditions and case study (Songun copper mine).

| Factors | Possible options | Score range | Average score | symbol |
|---|--|--------------------|---------------|----------|
| Dependence on weather conditions (IPCC advantage: Considerably little dependence on weather conditions) | Favorable weather conditions (sunny) | $10 \leq S \leq 9$ | 9.02 | F_8 |
| | Normal conditions sometimes with wind and rain | $8 \leq S < 9$ | | |
| | Unfavorable conditions and snow, rain, and thick fog | $7 \leq S < 8$ | | |
| Hauling distance | $D > 2$ km | $10 \leq S \leq 8$ | 8.83 | F_{11} |
| | $D = 1-2$ km | $4 \leq S < 8$ | | |
| | $D < 1$ km | $1 \leq S < 4$ | | |
| Operational risks | VL | $10 \leq S \leq 6$ | 7.12 | F_3 |
| | M | $4 \leq S < 6$ | | |
| | VH | $1 \leq S < 4$ | | |
| CO ₂ gas emission | VL | $10 \leq S \leq 6$ | 4.74 | F_{20} |
| | M | $4 \leq S < 6$ | | |
| | VH | $1 \leq S < 4$ | | |
| Dependence on rubber (High dependence on rubber provides the conditions for IPCC presence) | VH | $10 \leq S \leq 8$ | 6.31 | F_4 |
| | M | $4 \leq S < 8$ | | |
| | VL | $1 \leq S < 4$ | | |
| Capital costs (in relation to the IPCC) | VH | $1 \leq S < 4$ | 8.33 | F_1 |
| | M | $4 \leq S < 8$ | | |
| | VL | $10 \leq S \leq 8$ | | |
| Fuel cost | Fuel price increase (severe changes) | $1 \leq S < 3$ | 4.84 | F_5 |
| | Fuel price increase (slight changes) | $3 \leq S < 5$ | | |
| | Fuel price unchanged | $5 \leq S < 8$ | | |
| | Lower fuel prices | $8 \leq S \leq 10$ | | |
| Ore body shape | Deep expansion with a low slope | $1 \leq S < 5$ | 8.02 | F_7 |
| | Deep expansion with a steep slope | $5 \leq S \leq 10$ | | |
| Hauling time (Truck: Long loading time with the track improves the conditions for utilizing IPCC) | L | $1 \leq S < 5$ | 7.95 | F_{10} |
| | H | $5 \leq S \leq 10$ | | |
| CO ₂ gas emission | Low emission of CO ₂ gas | $1 \leq S < 5$ | 6.45 | F_6 |
| | High emission of CO ₂ gas | $5 \leq S \leq 10$ | | |

3.4. Pairwise comparison, weighting the criteria, and their analysis with AHP

Pairs are compared, and then the criteria are weighted and analyzed using the AHP method (Questionnaire No. 3 was sent to mining specialists. This questionnaire shows how important each part is compared to the others. For this purpose, we choose the numbers 1, 3, 5, 7, and 9. The last number shows that the factor is more important than the one it's compared to, while the first number means both factors are equally important. The importance of indicators after performing calculations was obtained as F_{10} , F_3 , F_7 , F_1 , F_{11} , F_6 , F_4 , F_5 , F_8 , and F_8 , respectively.

Each row is split by adding up the values in the columns after making a comparison chart between the criteria. Finally, we find the importance of each criterion by adding up the values in each row (using the AHP method). Table 9 indicates the weight for each of the standards.

Table 9. Relative weight of criteria employing the AHP method.

| Factors | Relative weight of criteria | Rank |
|----------------|------------------------------------|-------------|
| F_8 | 0.342 | 1 |
| F_{11} | 0.212 | 2 |
| F_3 | 0.106 | 3 |
| F_{20} | 0.066 | 4 |
| F_4 | 0.061 | 5 |
| F_1 | 0.057 | 6 |
| F_5 | 0.052 | 7 |
| F_7 | 0.048 | 8 |
| F_{10} | 0.043 | 9 |
| F_6 | 0.013 | 10 |

3.5. Creating a correlation and impact matrix between factors and criteria

The effects on sustainable development parts are shown as very high (VH), high (H), medium (M), low (L), very low (VL), and none (Z). To score the questionnaires, we use the number 0 for an influential factor and the numbers 2, 4, 5, 7, and 9 for very low (VL), low (L), medium (M), high (H), and very high (VH) impacts, respectively. Next, the average scores given by the experts for the ten chosen factors, based on the specific situations for each factor (which form a 10x1 matrix), are multiplied by the weighted values of the factors affecting sustainable development (which form a 1x10 matrix). This results in a matrix that helps evaluate sustainable development. In the next step, the resulting sustainable development evaluation matrix is normalized. Finally, the weights obtained in the form of a diagonal matrix are multiplied by the normalized matrix, resulting in the weighted normalized correlation matrix.

3.6. Score of mining options criteria (worst case)

The scoring details for each of the ten main factors are combined with a special correlation matrix. This assumes that the highest score (which is 10) turns into a 1-in-10 matrix. [Table 10](#) indicates the maximum scores for each mining option criterion (worst-case).

The highest score for each mining option can change based on how important the different factors are in the evaluation. So, the scores for the mining options can't really be compared. So, to find the real impact, we calculate how each bar scores compared to the highest score. You can compare the estimated effect of each mining option to the highest possible effect measured in the evaluation matrix. [Table 11](#) shows the impact of utilizing IPCC on each criterion of mining options. As observed, the values close to 100% with a direct relationship indicate appropriate conditions for the sub-criteria of mining options when IPCC is used. However, the closeness of the number to 100% improves the conditions for the mining option and its sub-criteria.

Table 10. Maximum score per mining options criterion (worst case scenario).

| Criteria | Sub-criteria | Score |
|--|---|--------------------------|
| Independent OP mining | UPL and OPL | 56.74 (direct relation) |
| | Production rate and productivity (OP) | 24.24 (direct relation) |
| | Cutt-off grade (OP) | 71.23 (inverse relation) |
| | Mine life (OP) | 54.34 (direct relation) |
| | Maximum use of OP mining facilities and equipment | 44.12 (direct relation) |
| Independent UG mining | Mineable ore tonnage (OP) | 56.89 (direct relation) |
| | Maximum mining depth (UG) | 17.34 (direct relation) |
| | Mining area border (UG) | 66.76 (inverse relation) |
| | Mine life (OP) | 56.34 (inverse relation) |
| | Production rate and productivity (UG) | 11.23 (inverse relation) |
| Simultaneous OPUG mining with and/or without crown pillar | Mineable ore tonnage (UG) | 61.23 (inverse relation) |
| | Cutt-off grade (UG) | 66.34 (direct relation) |
| | OTD (simultaneous OPUG) | 78.45 (direct relation) |
| | Maximum mining depth (simultaneous OPUG) | 23.14 (direct relation) |
| | Mining area border (simultaneous OPUG) | 21.08 (direct relation) |
| Sequential OPUG mining without crown pillar | Mine life (simultaneous OPUG) | 17.87 (direct relation) |
| | Mineable ore tonnage (simultaneous OPUG) | 17.32 (direct relation) |
| | Production rate and productivity (simultaneous OPUG) | 11.23 (direct relation) |
| | OTD (sequential OPUG) | 76.35 (direct relation) |
| | Maximum mining depth (sequential OPUG) | 18.43 (direct relation) |
| Combinations of simultaneous and sequential OPUG mining without crown pillar | Mining area border (sequential OPUG) | 20.78 (direct relation) |
| | Mine life (sequential OPUG) | 34.47 (direct relation) |
| | Mineable ore tonnage (sequential OPUG) | 16.77 (direct relation) |
| | Production rate and productivity (sequential OPUG) | 13.23 (direct relation) |
| | OTD (simultaneous and sequential) | 71.44 (direct relation) |
| | Maximum mining depth (simultaneous and sequential OPUG) | 27.14 (direct relation) |
| | Mining area border (simultaneous and sequential OPUG) | 18.23 (direct relation) |
| | Mine life (simultaneous and sequential OPUG) | 35.87 (direct relation) |
| | Mineable ore tonnage (simultaneous and sequential OPUG) | 17.02 (direct relation) |
| | Production rate and productivity (simultaneous and sequential OPUG) | 13.63 (direct relation) |

Based on the results, the relative score of each mining option index which shows the overall impact of employing IPCC on that index is as follows.

$$\text{Independent OP mining} = \frac{160.1}{6} = 26.68 \quad (1)$$

$$\text{Independent UG mining} = \frac{-111.88}{6} = -18.65 \quad (2)$$

$$\text{Simultaneous OPUG mining with and, or without crown pillar} = \frac{12.19}{6} = 2.03 \quad (3)$$

$$\text{Sequential OPUG mining without crown pillar} = \frac{27.33}{6} = 4.56 \quad (4)$$

$$\text{Combinations of simultaneous and sequential OPUG mining without crown pilla} = \frac{40.45}{6} = 6.74 \quad (5)$$

To determine the overall effect of using IPCC technology on the transition depth (extraction option) and compare the results, the final relative score or "relative overall impact score" is calculated as follows.

$$\text{relative impacts of the score} = \frac{26.68 - 18.65 + 2.03 + 4.56 + 6.74}{5} = 4.272 \quad (6)$$

Table 11. Impact of applying IPCC on mining option and its sub-criteria.

| Criteria | Sub-criteria | Score | Intensity of impact |
|---|--|--------------------------|---------------------|
| Independent OP mining | UPL and OPL | 56.74 (direct relation) | H |
| | Production rate and productivity (OP) | 24.24 (direct relation) | L |
| | Cutt-off grade (OP) | 76.23 (inverse relation) | VH |
| | Mine life (OP) | 54.34 (direct relation) | H |
| | Maximum use of OP mining facilities and equipment | 44.12 (direct relation) | M |
| | Mineable ore tonnage (OP) | 56.89 (direct relation) | H |
| Independent UG mining | Maximum mining depth (UG) | 17.34 (direct relation) | L |
| | Mining area border (UG) | 66.76 (inverse relation) | H |
| | Mine life (OP) | 56.34 (inverse relation) | H |
| | Production rate and productivity (UG) | 11.23 (inverse relation) | L |
| | Mineable ore tonnage (UG) | 61.23 (inverse relation) | H |
| Simultaneous OPUG mining with and/or without crown pillar | Cutt-off grade (UG) | 66.34 (direct relation) | H |
| | OTD (simultaneous OPUG) | 78.45 (inverse relation) | VH |
| | Maximum mining depth (simultaneous OPUG) | 23.14 (direct relation) | L |
| | Mining area border (simultaneous OPUG) | 21.08 (direct relation) | L |
| | Mine life (simultaneous OPUG) | 17.87 (direct relation) | L |
| | Mineable ore tonnage (simultaneous OPUG) | 17.32 (direct relation) | L |
| Sequential OPUG mining without crown pillar | Production rate and productivity (simultaneous OPUG) | 11.23 (direct relation) | L |
| | OTD (sequential OPUG) | 76.35 (inverse relation) | VH |
| | Maximum mining depth (sequential OPUG) | 18.43 (direct relation) | L |
| | Mining area border (Sequential OPUG) | 20.78 (direct relation) | L |
| | Mine life (sequential OPUG) | 34.47 (direct relation) | M |
| | Mineable ore tonnage (sequential OPUG) | 16.77 (direct relation) | L |
| Sequential OPUG mining without crown pillar | Production rate and productivity (sequential OPUG) | 13.23 (direct relation) | L |
| | OTD (sequential OPUG) | 76.35 (inverse relation) | VH |
| | Maximum mining depth (sequential OPUG) | 18.43 (direct relation) | L |
| | Mining area border (Sequential OPUG) | 20.78 (direct relation) | L |
| | Mine life (sequential OPUG) | 34.47 (direct relation) | M |
| | Mineable ore tonnage (sequential OPUG) | 16.77 (direct relation) | L |
| | Production rate and productivity (sequential OPUG) | 13.23 (direct relation) | L |

Fig. 4 demonstrates the effects of the IPCC technology on OTD from OP to UG mining or mining option. As observed, utilizing IPCC decreases the costs in the field of OP operations, followed by a reduction in the cutt-off grade. More reserves can be extracted by the OP method following the decline of the cutt-off grade, and OP mining can be continued with high stripping ratios. Thus, the ultimate pit limit is regarded as large, resulting in transferring the transition depth to the bottom with a delay. Here, the life of the mine and cutt-off grade for competition increase in the OP and UG sections, respectively. Therefore, the boundary of the UG mining area and extractable tonnage should be reduced. Unlike the OP section, the life of the mine decreases, as well, due to the reduction of extractable reserves.

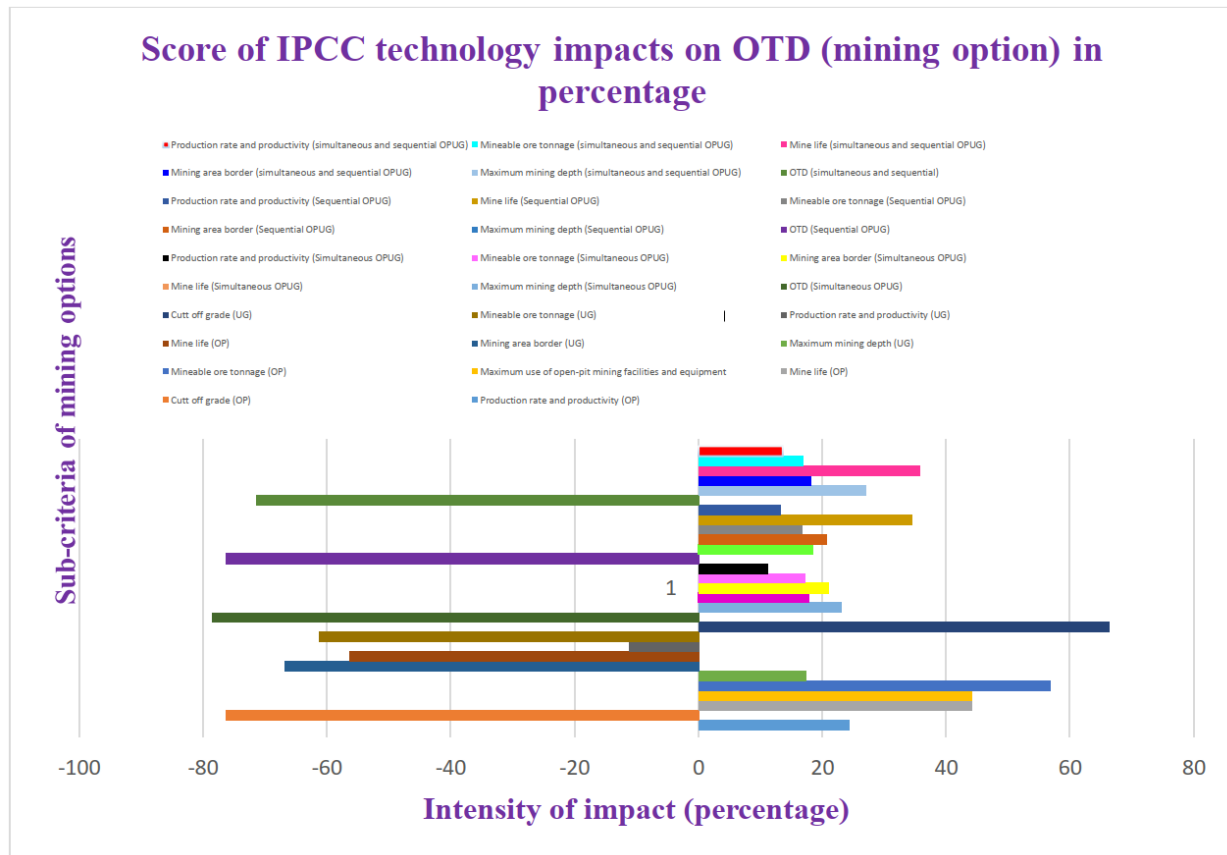


Fig. 4. Effects of IPCC on OTD.

4. Conclusion

Mining for metal deposits that are steep and deep begins with surface mining techniques, especially open-pit mining (OP). As the mine gets deeper, the amount of waste removed for each ton of mineral becomes so high that using other surface mining methods no longer makes sense economically, socially, or environmentally. Extraction will continue to use underground methods below this depth when the amount and quality of the resources are deemed suitable. Determining the "OTD from OP mining to UG" is regarded as the most critical issue in the aforementioned case.

As indicated, loading and hauling operations contribute the most significant percentage to the cost structure of the mining project. Such an operation is mainly executed by the ST system during the early stages of mining project development. The advantages of the ST system are significantly undermined when the depth and width of the ultimate pit limits increase in large-scale mining projects with combined extraction capability whose lifetimes are measured in decades.

Many studies have looked at the different impacts of mining using a mixed method that combines numbers and various decision-making techniques. However, the methods mentioned above are not complete and overlook the way of combining extractions. Most studies look at the effects of open-pit mining, and only a few consider both open-pit and underground sections.

The effects of employing IPCC in large-scale and deep OP mines with combined extraction possibilities were studied on OTD using a mixed semi-quantitative approach. Based on the results, utilizing IPCC technology leads mining operations in the direction of continuing OP ones, indicating that the potential transition to the UG mining method can be delayed by adopting the IPCC systems. In addition, operational and labor costs, safety risk, fuel and tire consumption, reduction of cut-off grade, growth of extractable reserves, increase in production, and low emission of CO₂ in the OP section. Due to the growth in the depth of the transition from OP to UG mining, and to continue the operation with the OP method. Applying IPCC decreases the costs, resulting in reducing the ultimate pit limit of the OP section, meaning an increase in the reserves which can be mined by the OP method, and the enlargement of the ultimate pit limit and continuation of the project by the OP method. Unlike the OP section, the limit increases and competition with the OP method becomes complicated in the UG section. The boundary of the UG area decreases following the increase of the cut-off grade, resulting in a reduction of the reserves that can be mined by the UG mining method.

Ethical Considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

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Conflict of Interest

The authors declare no conflict of interest.

References

- [1] Chung, J. S. Y. (2020). A Mixed Integer Programming Approach for Transitioning from open pit to underground mining. This thesis is presented for the Degree of Doctor of Philosophy Curtin University, Western Australian School of Mines.
- [2] Ma, K., Yang, T., Zhao, Y., Gao, Y., He, R., Liu, Y., ... & Li, J. (2023). Mechanical Model for Calculating Surface Movement Related to OP and UG Caving Combined Mining. *Minerals*, 13(4), 520. <https://doi.org/10.3390/min13040520>
- [3] Purhamadani, E., Bagherpour, R., & Tudeshki, H. (2021). Energy consumption in open pit mining operations relying on reduced energy consumption for haulage using in-pit crusher systems. *Journal of Cleaner Production*, 291, 125228. <https://doi.org/10.1016/j.jclepro.2020.125228>
- [4] Wachira, D., Githiria, J., Onifade, M., & Mauti, D. (2021). Determination of semi-mobile in-pit crushing and conveying (SMIPCC) system performance. *Arabian Journal of Geosciences*, 14(4), 297. <https://doi.org/10.1007/s12517-021-06550-4>
- [5] Nunes, R. A., Delboni, H., Tomi, G. D., Infante, C. B., & Allan, B. (2019). A decision-making method to assess the benefits of a semi-mobile in-pit crushing and conveying alternative during the early stages of a mining project. *REM-International Engineering Journal*, 72, 285-291. <https://doi.org/10.1590/0370-44672018720109>

- [6] Chung, J., Asad, M. W. A., and Topal, E. (2022). Timing of transition from open pit to underground mining: A simultaneous optimisation model for open pit to underground mine production schedules. *Resources Policy*, 77, 102632. <https://doi.org/10.1016/j.resourpol.2022.102632>
- [7] Liu, D., and Pourrahimian, Y. (2021). A framework for open pit mine production scheduling under semi-mobile in-pit crushing and conveying systems with the high-angle conveyor. *Mining*, 1(1), 59-79. <https://doi.org/10.3390/mining1010005>
- [8] Bernardi, L., Kumral, M., and Renaud, M. (2020). Comparison of fixed and mobile in-pit crushing and conveying and truck-shovel systems used in mineral industries through discrete-event simulation. *Simulation Modelling Practice and Theory*, 103, 102100. <https://doi.org/10.1016/j.simpat.2020.102100>
- [9] Osanloo, M., and Paricheh, M. (2020). In-pit crushing and conveying technology in open pit mining operations: a literature review and research agenda. *International Journal of Mining, Reclamation and Environment*, 34(6), 430-457. <https://doi.org/10.1080/17480930.2019.1565054>
- [10] Nehring, M., Knights, P. F., Kizil, M. S., and Hay, E. (2018). A comparison of strategic mine planning approaches for in-pit crushing and conveying, and truck/shovel systems. *International journal of mining science and technology*, 28(2), 205-214. <https://doi.org/10.1016/j.ijmst.2017.12.026>
- [11] King, B., Goycoolea, M., and Newman, A. (2017). Optimizing the open pit to underground mining transition. *European journal of operational research*, 257(1), 297-309. <https://doi.org/10.1016/j.ejor.2016.07.021>
- [12] Hay, E., Nehring, M., Knights, P., & Kizil, M. S. (2020). Ultimate pit limit determination for semi mobile in-pit crushing and conveying system: a case study. *International Journal of Mining, Reclamation and Environment*, 34(7), 498-518. <https://doi.org/10.1080/17480930.2019.1639006>
- [13] Paricheh, M., & Osanloo, M. (2020). Concurrent open pit mine production and in-pit crushing conveying system planning. *Engineering optimization*, 52(10), 1780-1795. <https://doi.org/10.1080/0305215X.2019.1678150>
- [14] Liu, S. Q., Lin, Z., Li, D., Li, X., Kozan, E., & Masoud, M. (2022). Recent research agendas in mining equipment management: A review. *Mining*, 2(4), 769-790. <https://doi.org/10.3390/mining2040043>
- [15] Shapka-Fels, T., & Elmo, D. (2022). Numerical modelling challenges in rock engineering with special consideration of open pit to underground mine interaction. *Geosciences*, 12(5), 199. <https://doi.org/10.3390/geosciences12050199>
- [16] Tegachouang, N. C., Bowa, V. M., Li, X., Luo, Y., & Gong, W. (2022). Study of the influence of block caving UG mining on the stability of the overlying open pit mine. *Geotechnical and Geological Engineering*, 40(1), 165-173. <https://doi.org/10.1007/s10706-021-01890-0>