Simultaneous determination of the location and time of IPCC system installation and relocation in open pit mines considering the time value of money

Fardin Shirmohammadi, Sajjad Afraei*, Majid Ataee Pour

Department of Mining Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT

Transportation costs in open-pit mines account for 50–60% of total operating costs. To meet high-tonnage production requirements, open-pit mining is widely employed. As the mine depth increases, the truck loading rate per unit time decreases, and to maintain production, the fleet size usually needs to be increased, resulting in a significant rise in operating costs. In contrast, continuous transportation systems, such as conveyors, can handle larger volumes of ore and waste due to their higher capacity and capability to operate on steep slopes. Therefore, the use of in-pit crushing and conveying (IPCC) systems and the determination of their optimal placement have attracted significant research attention.

In this study, considering the high capital cost of the IPCC system, the optimal location and timing for the in-pit crusher station were determined to minimize the net present value (NPV) of the combined capital and operating costs of both truck and conveyor systems. For this purpose, a modified objective function was developed that incorporates the time value of money and simultaneously considers the capital and operating costs of both systems over the life of mine.

The results indicate that the transition from the truck–shovel system to the IPCC system in the year that minimizes NPV of costs represents the economically optimal decision. In a case study conducted on a hypothetical mine, the fifth bench in the fifth year was identified as the optimal location and timing for the in-pit crusher station, resulting in a 5.16% reduction in costs compared to implementing the system in the first year of the life of mine. All analyses and optimizations were carried out using GAMS software.

KEYWORDS

Open pit mines, Shovel-truck system, In-pit crushing and conveying system, Crusher location

* Corresponding Author: Email: sajjad.afraei@aut.ac.ir

1. Introduction

In open-pit mining operations, the shovel–truck system remains the predominant loading and haulage method, with transportation accounting for approximately 50% of total operating costs[1]. As mining depth increases, haulage distances become longer and fleet productivity declines, leading to substantial increases in both capital and operating expenditures. Consequently, the economic viability of portions of the mineral reserve may be adversely affected.

In-Pit Crushing and Conveying (IPCC) systems have been widely recognized as an effective alternative for reducing haulage-related costs. However, the optimal siting of the in-pit crusher is of critical importance, as improper placement can significantly increase overall transportation costs. The crusher location problem is classified as NP-hard, and its solution at large scales involves considerable computational complexity[2].

This study aims to optimize the crusher location over different periods of the life of mine for a hypothetical open-pit mine with a depth of 225 m. The deposit comprises 153 Mt of ore and 285 Mt of waste, with an overall stripping ratio of 1.86.

2. Methodology

This study focuses on optimizing the location of the in-pit crusher and determining the optimal year to implement the IPCC system, minimizing the net present value (NPV) of combined capital and operating costs. Although the high capital cost of the IPCC system makes early implementation economically unattractive, some studies have assumed its use from the start and focused on crusher location[2]. While Paricheh emphasized the importance of determining the optimal year to switch haulage methods, crusher location is closely linked to production scheduling, which is treated as an input parameter in this research[3]. The conveyor system is assumed to remain fixed along one wall of the final pit, with ore initially transported by trucks to the crusher station and then conveyed out of the mine.

Extraction begins on the side of the pit where the conveyor is located and proceeds sequentially to the opposite side. This ensures that blocks closer to the conveyor are extracted first, reflecting spatial and operational constraints. Geometric and production data—including the block model, extraction sequence, waste volumes, and potential conveyor positions—were derived from the production plan.

A multi-stage procedure was designed to evaluate candidate crusher locations over the life of mine. For each candidate, capital and operational costs, as well as their impact on the NPV, were calculated annually. The optimal start year for IPCC implementation was identified as the year when the total costs of truck and conveyor systems were minimized. Subsequently, the optimal crusher location was determined considering topography, conveyor route, and truck accessibility.

Scenario analyses and repeated calculations for different years were performed to assess the stability of results and sensitivity to discount rate variations. This integrated approach allows simultaneous evaluation of extraction sequence, crusher location, and timing of IPCC deployment, ensuring realistic and economically optimized decisions over the life of mine.

2.1. Minimization of Total Haulage Costs

The study formulates an objective function to minimize the total discounted cost of haulage, including both truck and IPCC conveyor systems. An additional constraint is introduced to prevent crusher installation in unextracted areas. The modified objective function incorporates_C_d, representing the sum of initial truck capital costs and the IPCC system capital cost in the deployment year. Before IPCC implementation, truck operational costs accumulate in C_d. The total discounted cost of material transport to each crusher (fc_{jt}) is calculated for all periods. The model is implemented in GAMS for optimization over the life of mine. This objective function is presented in Equation (1) and represents a modified version of Liu's original objective function[4]. In this equation, y_{jt} and z_{jt} represent, the use of the conveyor at bench j in year t and the movement of the crusher, respectively. C_t denotes the cost associated with relocating the crusher.

$$\min C_d + \sum_{j}^{J}\sum_{t}^{T} fc_{jt} \times y_{jt} + \sum_{j}^{J} c_t \times z_{jt} \tag{1}$$

2.2. Haulage Distance Calculation

According to Paricheh and Liu, haulage distances were calculated using the centroid of the bench and horizontal and vertical components, respectively[3, 4]. However, both methods may deviate from the actual optimal distance. Naturally, open-pit mining constraints prevent trucks from transporting material directly to the crusher or conveyors from moving material along a straight path. Truck routes are typically curved, while conveyor paths follow variable slopes. In Liu's study, two simplified straight-line routes were considered, consisting of one vertical and one horizontal segment for the truck path, as illustrated in Figure 1.

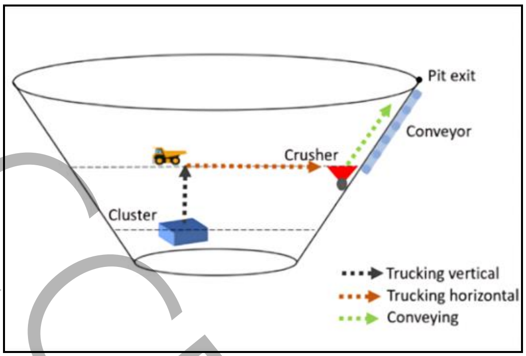

Figure 1. Method for calculating the haulage distance by truck and conveyor [4]

3. Results and Discussion

Haulage distances were calculated using both original centroid and horizontal-vertical component methods and a modified formula accounting for a 10% ramp slope for trucks. Operating costs of $0.5 per ton-km, including fixed return trips, were applied over 15 years. The results showed that the original methods can significantly underestimate costs, potentially leading to errors in identifying the year when IPCC implementation minimizes total discounted costs. Therefore, the modified distance calculation was adopted in this study.

In the previous section, the transition year from truck haulage to conveyor haulage was not considered, and conveyor operating costs were assumed for all blocks. Here, conveyor costs are calculated only from the transition year onward, while truck operating costs are applied to earlier years.

Although the lower operating cost of conveyors justifies the shift from trucks, the high capital cost of the IPCC system discourages its implementation in the early life of mine. Likewise, late implementation is not economically reasonable. Therefore, using a 15% discount rate, the combined impact of capital and operating costs on the NPV was evaluated to determine the optimal transition year through the second objective function.

After identifying the optimal transition year, crusher location optimization was performed for the remaining blocks. The results indicate three crusher relocations in years 5, 6, and 11, at levels 5, 7, and 10, respectively.

4. Conclusions

This study presented an integrated model for determining the optimal location and timing of in-pit crusher deployment within an IPCC system, considering both capital and operating costs of truck and conveyor haulage while incorporating the time value of money over the life of mine. The results demonstrate that the transition year to IPCC and the crusher location must be determined simultaneously, as separate optimization may lead to inconsistencies and higher overall costs.

The case study indicated that selecting level 5 in year 5 as the optimal location and transition time reduces total costs by approximately 5.16% compared to implementing the system at the beginning of the life of mine. This highlights the importance of coordinating production scheduling with equipment location decisions and emphasizes that simultaneous economic and operational analysis improves cost efficiency and decision-making.

The proposed model considers operational constraints such as conveyor routing, pit slope, and extraction sequence, making it a practical tool for mine planners. Compared to previous studies that determined location and transition timing separately or relied solely on truck haulage distance, this approach provides higher accuracy and applicability by incorporating all relevant costs in a unified framework.

In summary, the integrated analytical approach presented in this research enhances the economic performance of IPCC implementation, reduces capital and operating costs, and improves overall haulage system efficiency. The model also provides a foundation for future research on optimization of haulage systems in open-pit mines.

5. References

[1] A. Bozorgebrahimi, R.A. Hall, M.A. Morin, Equipment size effects on open pit mining performance, International Journal of Surface Mining, Reclamation and Environment, 19(1) (2005) 41-56.
[2] Q. Gu, X. Li, L. Chen, C. Lu, Layout optimization of crushing station in open-pit mine based on two-stage fusion particle swarm algorithm, Engineering Optimization, 53(10) (2021) 1671-1694.
[3] M. Osanloo, M. Paricheh, 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) (2020) 430-457.
[4] D. Liu, Y. Pourrahimian, 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) (2021) 59-79.